Tracking Post-Harvest Soil Nitrate in Agricultural Fields in the Hullcar Valley in 2019-20

Final Report

BRITISH COLUMBIA | Ministry of Agriculture

Tracking Post-Harvest Soil Nitrate in Agricultural Fields in the Hullcar Valley in 2019-20

Short title: 2019-20 Post-Harvest Nitrate Study: Hullcar Valley

Final Report

November 2020

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Acknowledgements

Thanks to the producers who volunteered their fields for soil sampling. Doug Macfarlane and Ruth McDougall helped with soliciting producer cooperation, sampling the fields, and arranging soil testing. Hayley Tumas and Benjamin Pearse assisted with several figures for the report. Jeff Nimmo provided editorial comments.

Disclaimer

Summary

The nitrate (NO_3-N) left in the soil profile after harvest is susceptible to leaching to groundwater during cooler months when precipitation exceeds plant evapotranspiration. Measuring the nitrate left in the soil after crop harvest is conducted through a post-harvest nitrate test (PHNT), a measure used for both environmental and agronomic objectives. In 2019, soil sampling was completed on 39 fields lying above Aquifer 103 in the Hullcar Valley of the North Okanagan to a 90-cm depth. Overall, the area-weighted average PHNT value in 2019 was similar to 2018 (78 and 75 kg NO_3-N ha^{-1}, respectively), and the median PHNT of the overall study area was also similar in 2019 when compared to 2018 (70 and 68 kg NO_3-N ha^{-1}, respectively). From 2018 to 2019, the area-weighted average PHNT and median PHNT increased for fields cropped with corn silage while these values decreased for fields cropped with alfalfa/grass.

Among the fields sampled, 51% of the nitrate in the sampled 90 cm of soil was found in the 0-30 cm layer on average, while 22% and 27% was found in the 30-60 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 2019 growing season.

A Benchmark study was also established at six sites to determine the potential for nitrate leaching over the non-growing season. From October 2019 through April 2020, NO_3-N was found to have moved from upper soil layers to lower soil layers in all six sites. However, NO_3-N concentration decreased in the 60-90 cm depth in only one of the six sites over the course of the study period, likely from leaching. The relative frequency of NO_3-N leaching in 2019/20 is consistent with results from earlier Benchmark studies conducted in 2016/17 and 2017/18.

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1 Introduction

In recent years, the water quality of Aquifer 103, located in the Hullcar Valley in the North Okanagan of British Columbia, has had elevated concentration of nitrate (NO_3-N). Some environmental impact studies have suggested that the elevated concentration of NO_3-N is due to over-application of nitrogen (N) on agricultural fields, as this region of British Columbia is dominated by forage crops grown for livestock feed (Associated Environmental 2016, Associated Environmental 2017a, Associated Environmental 2017b, Poon and Code 2017). However, it has not yet been established the rate at which NO_3-N moves from the crop rooting zone to the aquifer, which may range from a few years to several decades. Therefore, it is prudent for agricultural producers to minimize the amount of NO_3-N remaining in the soil after crop harvest, as this NO_3-N may contribute to contamination of the underlying aquifer. The amount of NO_3-N in the soil after crop harvest is typically measured using a post-harvest nitrate test (PHNT), and several studies have been conducted over the past few years to monitor post-harvest nitrate in the Hullcar Valley above Aquifer 103 (Andrews 2020, Poon and Code 2017, Poon and Code 2018).

Results of post-harvest nitrate testing 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 (Andrews 2020).

Post-harvest nitrate testing has previously been completed in the Hullcar Valley in 2016, 2017, and 2018 to establish trends in PHNT levels and evaluate medium-term N management practices (Poon and Code 2017, Poon and Code 2018). Results from 2017 and 2018 showed that most fields had a PHNT rating of 'Low' or 'Medium,' but that the area-weighted average PHNT value did increase over this time period. Evaluation of PHNT values from fall 2019 serve as an opportunity to continue evaluation of PHNT values in the study area.

Benchmark testing has also been completed during the 2016/17, 2017/18, and 2018/19 non-growing season to determine the movement of NO_3-N through the soil profile and below the monitored soil zone. Earlier studies indicate that NO_3-N movement within the 0-90 cm soil profile is limited (Kowalenko et al. 2009, Poon and Code 2017) while more recent studies indicate that NO_3-N movement both within and potentially below the 0-

90 cm soil zone (Andrews 2020, Poon and Code 2018). While precipitation and soil physical properties are the two main factors affecting NO_3-N leaching, it is important to monitor NO_3-N movement over several periods to determine the true potential for NO_3-N leaching.

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 2019?
2. How is nitrate distributed throughout the three soil sampling depths (0-30, 30-60, and 60-90 cm) in 2019?
3. How did PHNT levels compare between 2018 and 2019 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 ha^{-1} of post-harvest soil nitrate (0-90 cm soil layer) in 2019.
2. The majority (>50%) of nitrate was found in the 0-30 cm soil layer for each crop type in 2019.
3. The area-weighted average and median PHNT values of the entire study area did not increase from 2018.
4. Soil nitrate leached within but not below the 90-cm soil depth 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 mineralization 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 application and management as well as post-harvest sampling ranged from April through October 2019. During this time, the area received 297 mm of cumulative precipitation, similar to the long-term average (LTA; 1981-2010) of 292 mm during the same period. However, some fields in the study area did receive supplemental irrigation. Additionally, average air temperature exceeded that of the LTA for four of the seven selected months.

Table 1. Cumulative precipitation and average temperature for spring through fall of 2017 - 2019 and the long-term average (LTA; 1981-2010) values at the Sliver Creek station (approximately 7 km from the study area).

	Cumulative precipitation (mm)				Temperature (°C)			
Month	2017	2018	2019	LTA	2017	2018	2019	LTA
April	77.7	44.8	23.4	29.9	7.7	7.4	7.5	8.4
May	66.3	25.6	29.8	48.7	13.5	16.2	14.5	12.6
June	20.8	66.4	39.4	51.4	16.7	16.2	17.0	16.1
July	0.7	32.4	67.5	44.8	21.0	19.4	18.5	19.1
August	1.9	24.0	23.4	33.8	19.4	17.9	18.8	18.4
September	8.7	87.6	79.8	34.0	14.8	12.3	14.3	13.5
October	35.9	49.6	33.6	49.1	6.0	6.0	5.8	6.7
Total	212.0	330.4	296.9	291.7	-	-	-	-

Data: Environment Canada 2019.

2.1 Post-Harvest Soil Testing

Field selection and Sampling Methodology

All thirty-nine fields that were sampled in 2018 for post-harvest nitrate were sampled again in 2019 (Supplemental Figures 1 & 2). Field delineation was based on having consistent N management within the area. Additionally, all of the original nine fields that were split in 2017 and 2018 were also split in 2019. These fields were split either due to differences in soil types or to keep the total field size under 25 ha. In summary, there were 39 fields and 48 sampling areas in 2019. No changes to the field numbering system were made from 2018 to 2019.

As no field changes were made from 2018 to 2019, the total study area remained 791 hectares (Table 2). From 2018 to 2019, there were two fewer sampling areas with an alfalfa/grass crop which decreased the total cropped area for alfalfa/grass from 335 to 302 hectares. Silage corn was grown on four more sites in 2019 than in 2018 and increased in total cropped area from 369 hectares to 421 hectares. Unlike in 2018, no winter wheat was grown in the study area in 2019. The same sampling areas were grown with nursery trees in 2019 as in 2018, so there was no change in the number of sampling areas or the total cropped area.

The soil sampling methodology was consistent with those used previous from 2016 to 2018 (Andrews 2020, 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 2019, fields were sampled from 13 September through 18 October, and each field was sampled within 10 days of harvest.

Analyses

The laboratory and data analyses were the same as in previous years (Andrews 2020, 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 Laboratories (London, ON).

The concentrations 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 0-15 and 15-30 cm soil layers 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 was 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 (100-200 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 six rounds of soil sampling from mid-October 2019 through mid-April 2020 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. All six of the sites had previously been used for Benchmark Testing in the 2018 Post-Harvest Nitrate Study, referred to as 'Sites 6, 17, 26, 31, and 38' (Andrews 2020). A range of soil types were represented with the Benchmark study area (Table 2).

Each site was roughly 70 to 140 m^2 in size and even 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 2019, early November 2019, late November 2019, mid-March 2020, early April 2020, and mid-April 2020.

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 (corn silage)					
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 (alfalfa/grass)					
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

2019 Results

Overall, 27% of the total sampled land area had a 'Low' PHNT rating (8 fields), 44% had a 'Medium' rating (20 fields), 29% had a 'High' rating (10 fields), and <1% had a 'Very High' rating (1 field) (Figure 1, Supplemental Tables 2 - 4). Therefore, 71% of the total sampled land area, a total of 28 fields, had PHNT values less than 100 kg NO_3-N ha^{-1}. This supports the hypothesis (Hypothesis 1) that the majority of fields had PHNT values below 100 kg NO_3-N ha^{-1}.

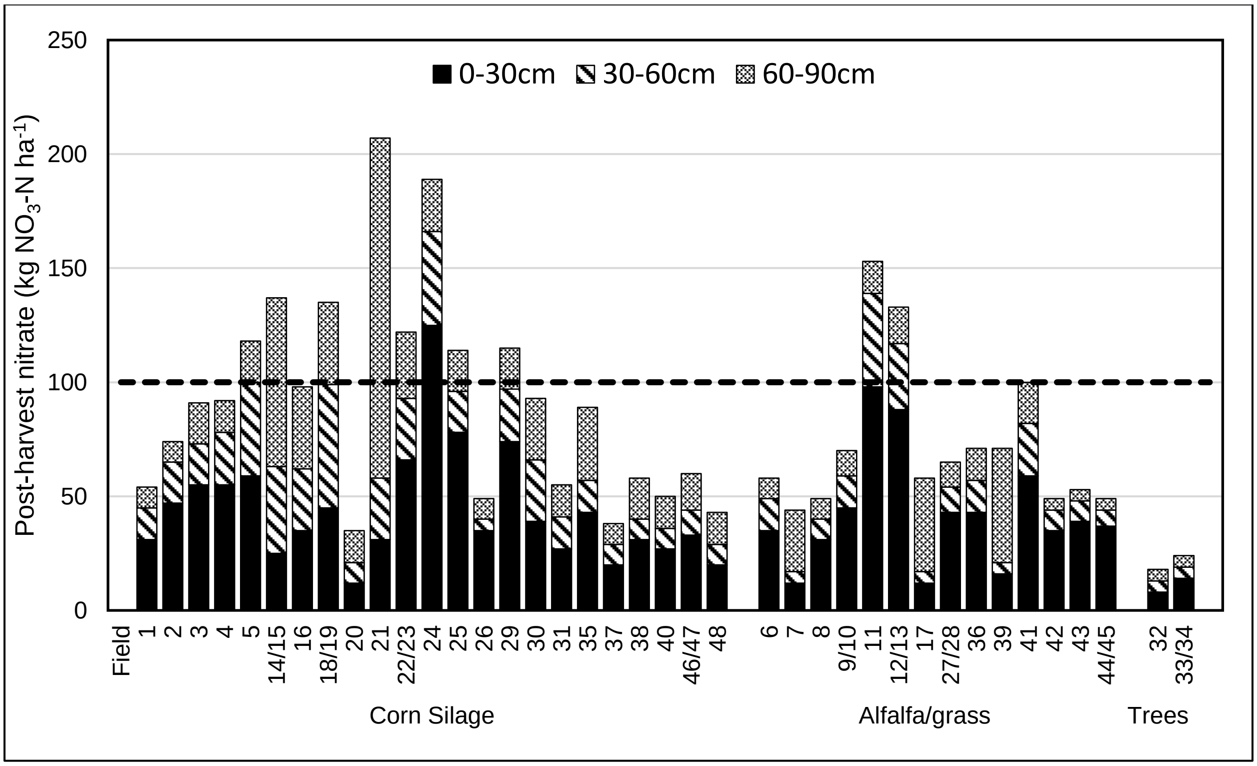

Figure 1. The PHNT value (0-90 cm) of each sampled field in the study area in 2019. The dotted line represents 100 kg NO_3-N ha^{-1}, the point at which the PHNT values is considered 'High' (Kowalenko et al. 2009).

There were differences in average post-harvest nitrate (0-90 cm) between crop types in 2019 (Table 3). Silage corn had the greatest area-weighted average PHNT value of 88 kg NO_3-N ha^{-1} and accounted for approximately 53% of the total sampled land area. Of the three crop types, alfalfa/grass had the median area-weighted average PHNT value of 77 kg NO_3-N ha^{-1} and accounted for roughly 38% of the total sampled land area. Nursery trees had an area-weighted average of 20 kg NO_3-N ha^{-1}, the lowest of the three crop types, but only accounting for 9% of the total sampled land area.

Table 3. Sampling area and post-harvest nitrate test statistics for the 2019 post-harvest 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	18	302	77	152	66	44
Silage corn	27	421	88	209	92	33
Nursery trees	3	68	20	23	21	17
All crops	48	791	78	209	70	17

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

Of the nine fields that were split into two samplings areas, eight of the fields had the same agronomic PHNT rating as their complementary sampling area (Table 4). The one field that did not have the same agronomic PHNT rating as their complementary sampling area, Field 44/45, had a 1 kg NO_3-N ha^{-1} difference from each complementary sampling area but was on the threshold between the 'Low' and 'Medium' rating. In fact, this difference was lower than many fields that had the same agronomic PHNT rating as their complementary sampling areas. Therefore, these results suggest that fields with similar management, small differences in soil characteristics, or are larger than 25 ha can be sampled for post-harvest nitrate as one unit instead of being split into two or more sampling areas. However, these nine fields will continue to be split into two sampling areas to monitor any potential future differences in PHNT levels for future reports.

While PHNT is typically used to monitor N use on a year-to-year basis for a particular field, some inferences on N application rates and use can be made (Sullivan and Cogger 2003). Based on the range of PHNT values for all three crop types and the minimal expected N movement though the soil profile during the growing season, it appears that the majority of fields either had a greater N uptake than the typical assumption of 50% of applied N (Hermanson et al. 2000) or did not receive significant amounts of supplemental N. This indicates for these fields that N was applied at an agronomic rate and managed for optimal crop uptake (Sullivan and Cogger 2003).

Table 4. 2019 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	69	Medium	71	Medium
	10	15	74	Medium		
Alfalfa/grass	12	20	146	High	134	High
	13	21	121	High		
Corn silage	14	20	161	High	138	High
	15	21	115	High		
Corn silage	18	14	157	High	137	High
	19	15	118	High		
Corn silage	22	15	141	High	123	High
	23	10	106	High		
Alfalfa/grass	27	15	67	Medium	66	Medium
	28	15	64	Medium		
Nursery trees	33	17	23	Low	22	Low
	34	24	21	Low		
Alfalfa/grass	44	14	50	Medium	49	Low
	45	16	48	Low		
Corn silage	46	17	69	Medium	63	Medium
	47	8	56	Medium		

[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 (100-200 kg NO_3-N ha^{-1}), and Very High (≥ 200 kg NO_3-N ha^{-1}).

In 2019, a significant portion (51%) of the total area-weighted average post-harvest nitrate for each field was found in the uppermost 0-30 cm sampling zone (Figure 2). This supports the hypothesis (Hypothesis 2) that the majority of nitrate would be found in this sampling zone. At lower depths, 22% and 27% of the total area-weighted average post-harvest nitrate was found at the 30-60 and 60-90 cm depths, respectively. As noted in the previous report (Andrews 2020), the additional value of the nitrate data from sampling to a lower depth (from 30 to 60 cm, or 60 to 90 cm) may not have warranted the extra effort required to sample lower depths for the purposes of determining agronomic N use of a recently harvested crop. Sampling deeper has the potential to describe excess nitrate that originated from previous cropping years. For example, the NO_3-N concentration at the 30-60 and 60-90 cm depths from April 2019 and October 2019 at all six Benchmark sites did not differ significantly (Supplemental Table 1). This potentially indicates that NO_3-N did not move below the 30-cm depth during the growing season of 2019, and that sampling below that depth would capture excess nitrate applied before the growing season. This fact, combined with the fact that many areas lose more soil moisture during the growing season as evapotranspiration than they gain in rainfall, contribute to many agricultural organizations recommending sampling for post-harvest nitrate at the 0-30 cm depth (British Columbia Ministry of Agriculture 2020; Sullivan and Cogger 2003).

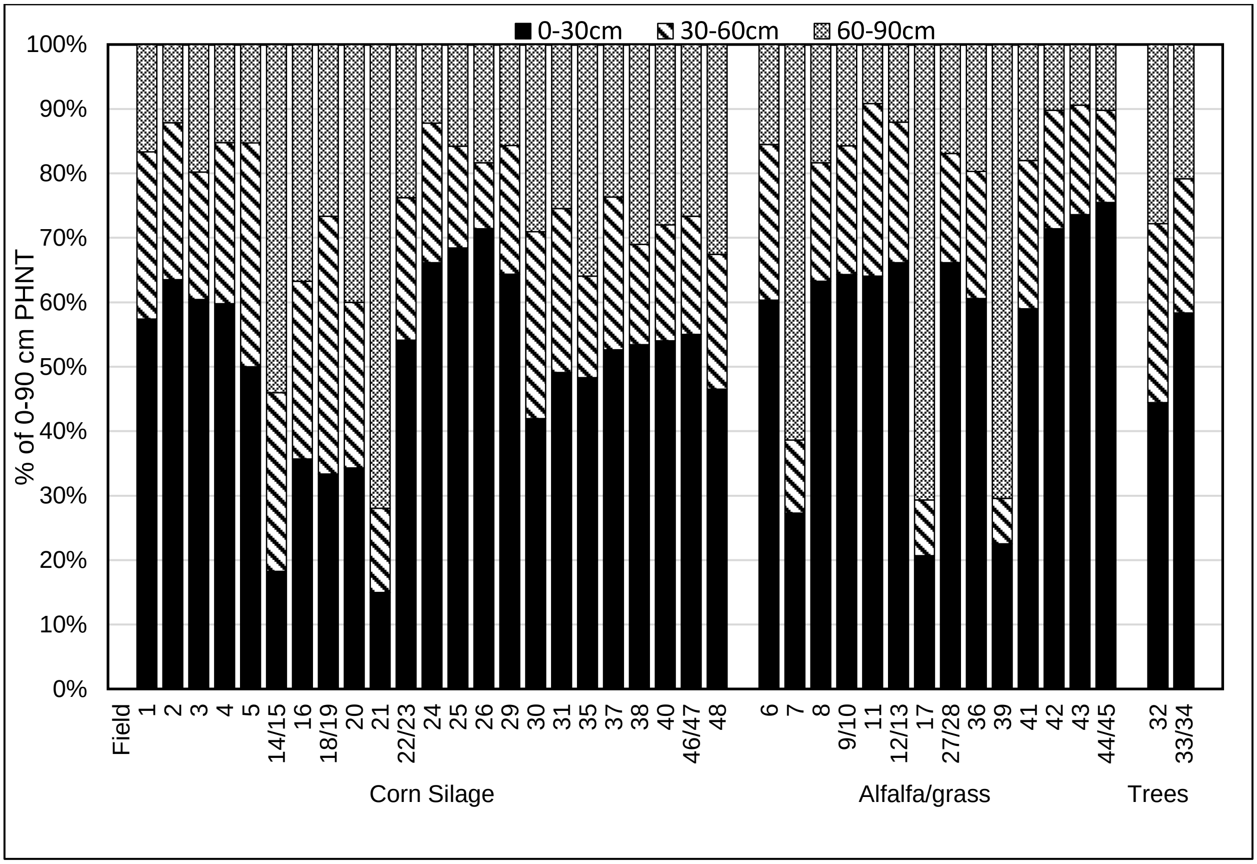

Figure 2. The percentage of total nitrate found in the 0-30, 30-60, and 60-90 cm soil layers for fields that were sampled in 2019.

Comparisons between years

The area-weighted average and median PHNT value for the study area was similar in 2019 in comparison to 2018 (Table 5). In 2018, the area-weighted average PHNT value and the median PHNT value was 75 and 68 kg NO_3-N ha^{-1}, respectively, while these values were 78 and 70 kg NO_3-N ha^{-1}, respectively, for 2019. As these two measures have little difference between the two years, it supports the hypothesis that they did not change from 2018 to 2019 (Hypothesis 3).

Table 5. Sampling area and post-harvest nitrate test statistics for the 2018 and 2019 post-harvest sampling periods.

	2018				2019			
Crop type	No. of sampling areas	Area sampled	Area-weighted average PHNT[a]	Median PHNT	No. of sampling areas	Area sampled	Area-weighted average PHNT[a]	Median PHNT
	-	(ha)	---kg NO_3-N ha^{-1}---		-	(ha)	---kg NO_3-N ha^{-1}---	
Alfalfa/grass	20	335	80	71	18	302	77	66
Silage corn	23	369	69	57	27	421	88	92
Nur. trees	3	68	40	42	3	68	20	21
All crops	48	791	75	68	48	791	78	70

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

While there were seemingly no differences in area-weighted average and median PHNT values for the entire study area, these measures decreased in fields cropped with alfalfa/grass and increased in fields crop with silage corn (Table 5). The increase in these measure for silage corn may be due to its growth in a greater number of fields, as silage corn is expected to have greater PHNT values than alfalfa/grass (Kowalenko et al. 2007, Kowalenko et al. 2009, Sullivan and Cogger 2003). Overall, this trend indicates an improvement in N management for alfalfa/grass while consistently increasing PHNT values for silage corn would indicate the need to re-evaluate N application practices.

Year-to-year trends in PHNT values for a given field can only be compared if the crop is the same between years. From 2018 to 2019 in such fields, 10 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 no fields had a decrease (Supplemental Table 2). For alfalfa/grass, 6 fields had no change in PHNT values, 3 increased, and 1 decreased (Supplemental Table 3). Of the two fields planted with trees, one had no change while the other had a decrease in PHNT values (Supplemental Table 4). For all fields that saw an increase in post-harvest nitrate, an evaluation of N application rates should be conducted to ensure that an agronomic N rate is being applied on these fields.

Overall, post-harvest nitrate was similar in 2019 in comparison to PHNT values from 2018. The area-weighted average PHNT value and median PHNT value for the overall study area only differed by 3 and 2 kg NO_3-N ha^{-1}, respectively, for 2018 and 2019. Silage corn had an increase in the two PHNT measures while alfalfa/grass had a decrease. Some fields did see an increase in PHNT values when compared to 2018 results. In these fields, N application rates should be reviewed to ensure that N is not being overapplied.

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 17, 31, and 38) while significant changes were observed at the remaining three sites (Sites 4, 6, and 26) (Figure 3, Table 6). Two of the sites, Site 4 and 26, saw decreases in NO_3-N concentration over the course of the monitoring period while Site 6 had an increase and then eventual decrease in NO_3-N. The trend observed at Site 6, similar to 2018, is 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 (Andrews 2020).

Only one site, Site 4, had a significant decrease in NO_3-N concentration over time at the 30-60 cm depth (Figure 3, Table 6). Three sites, Sites 6, 26, and 38, had significant increases but no decrease in NO_3-N concentration, indicating that NO_3-N was leaching into, but not out of, the 30-60 cm soil depth. The final two sites, Sites 17 and 31, had no significant change in NO_3-N concentration over the Benchmark period.

In the 60-90 cm layer, five of the six sites (Sites 6, 17, 26, 31, and 38) had a significant increase in NO_3-N concentration over the course of the Benchmark period (Figure 3, Table 6). These sites did not have a corresponding significant decrease, indicating that NO_3-N did not leach below the 90-cm depth. One site, Site 4, had a significant increase and eventual decrease in NO_3-N concentration. This shows that NO_3-N may have leached below the sampling zone in at least one site over the course of the non-growing season.

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, all six sites had significant changes in NO_3-N concentration among the three soil layers and one site had a significant decrease in NO_3-N concentration, indicating NO_3-N leaching below the 90-cm depth. While temperature and cumulative precipitation were similar to the long-term average during the Benchmark period (Table 7), soil moisture from mid-March 2020 through April 2020 at all measured depths was generally high (Supplemental Table 5). This suggests that there was a significant amount of available moisture in the soil profile, likely from infiltrated snowmelt, that was the cause of NO_3-N movement in the later periods of the Benchmark study.

Overall, changes in NO_3-N concentration among the sampled soil depths occurred frequently in the Benchmark sites during the 2019/20 study period, a similar result to the 2018/19 Benchmark study (Andrews 2020). However, leaching below the 90-cm depth likely occurred at one site during the study period, which is more in line with results from less recent studies (Poon and Code 2017, Poon and Code 2018). Similar to the 2018/19 study, the NO_3-N concentration at the 30-60 and 60-90 cm depths was generally low.

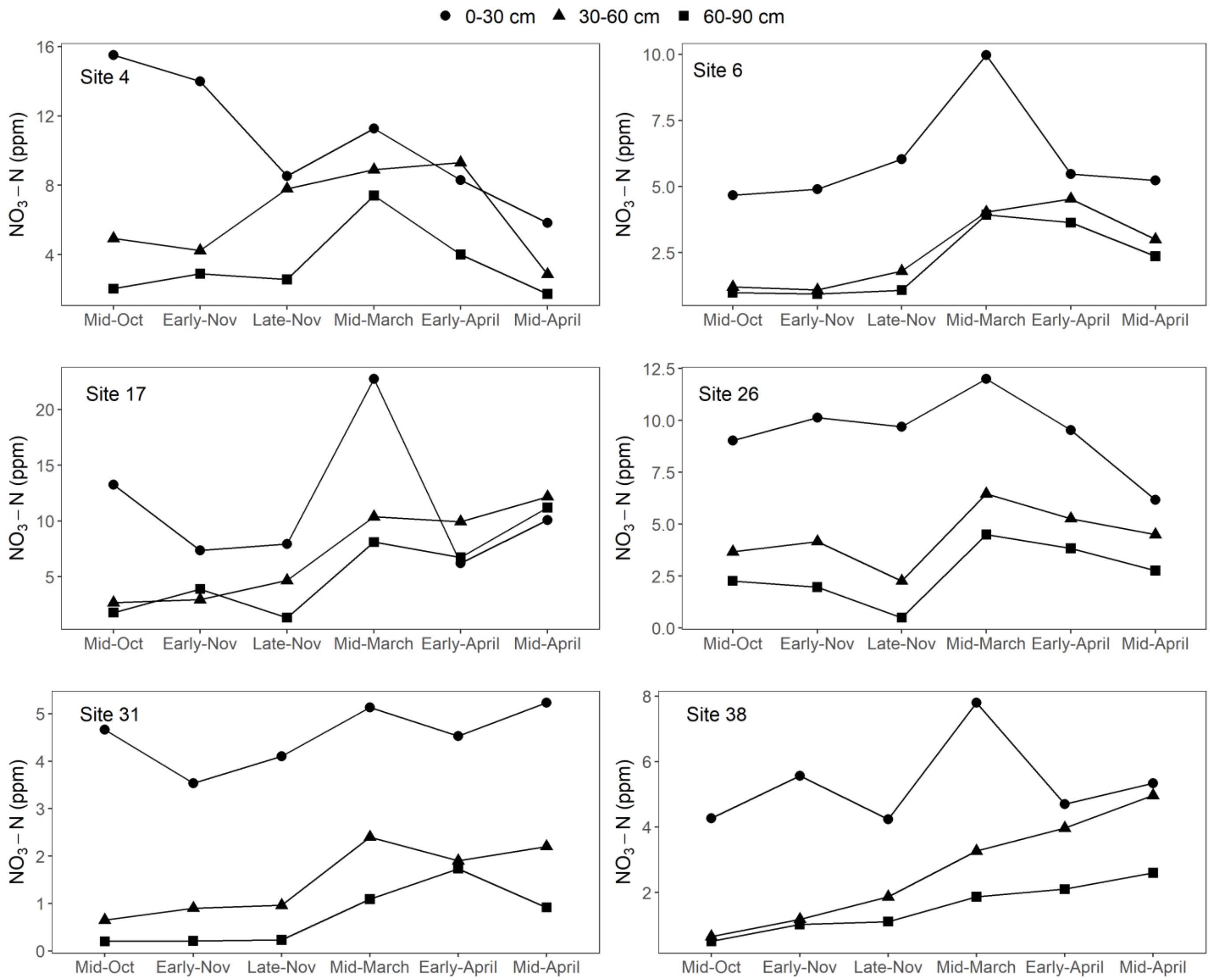

Figure 3. Changes in NO_3-N concentration at the six Benchmark sites from October 2019 through April 2020.

Table 6. NO_3-N concentrations (ppm) at the 0-30, 30-60, and 60-90 cm depths at the six Benchmark sites over the non-growing season in 2019/20. Concentrations followed by the same letter within each site and soil depth are not significantly different.

Date	0-30 cm	30-60 cm	60-90 cm
		Site 4	
21-Oct	15.5a	4.9abc	2.0b
05-Nov	14.0ab	4.2bc	2.9b
25-Nov	8.5ab	7.8ab	2.6b
17-Mar	11.3ab	8.9a	7.4a
01-Apr	8.3ab	9.3a	4.0b
20-Apr	5.8b	2.9c	1.7b
		Site 6	
21-Oct	4.7b	1.2bc	1.0b
05-Nov	4.9b	1.1c	0.9b
25-Nov	6.0ab	1.8bc	1.1b
17-Mar	10.0a	4.0a	3.9a
01-Apr	5.5b	4.5a	3.6a
20-Apr	5.2b	3.0ab	2.4ab
		Site 17	
21-Oct	13.3a	2.7a	1.8b
05-Nov	7.4a	2.9a	3.9ab
25-Nov	7.9a	4.7a	1.3b
17-Mar	22.7a	10.4a	8.1ab
01-Apr	6.2a	9.9a	6.7ab
20-Apr	10.1a	12.2a	11.2a
		Site 26	
21-Oct	9.0ab	3.7ab	2.3ab
05-Nov	10.1ab	4.2ab	2.0ab
25-Nov	9.7ab	2.3b	0.5b
17-Mar	12.0a	6.5a	4.5a
01-Apr	9.5ab	5.3a	3.8a
20-Apr	6.2b	4.5ab	2.8ab
		Site 31	
21-Oct	4.7a	0.7a	0.2b
05-Nov	3.5a	0.9a	0.2b
25-Nov	4.1a	1.0a	0.2b
17-Mar	5.1a	2.4a	1.1a
01-Apr	4.5a	1.9a	1.7a
20-Apr	5.2a	2.2a	0.9ab
		Site 38	
21-Oct	4.3a	0.7c	0.5b
05-Nov	5.6a	1.2c	1.0ab
25-Nov	4.2a	1.9bc	1.1ab
17-Mar	7.8a	3.3abc	1.9ab
01-Apr	4.7a	4.0ab	2.1ab
20-Apr	5.3a	5.0a	2.6a

Table 7. Cumulative precipitation and average temperature for October through April of the 2018/19 and 2019/20 Benchmark periods and the long-term average (LTA; 1981-2010) values during the same periods at the Silver Creek station.

	Cumulative precipitation (mm)			Temperature (°C)		
Month	2018/19	2019/20	LTA	2018/19	2019/20	LTA
October	49.6	33.6	49.1	6.0	5.8	6.7
November	85.1	51.1	72.2	2.5	1.1	1.5
December	50.4	86.0	68.2	-0.1	-0.9	-2.7
January	25.6	112.4	60.2	-1.2	-3.2	-3.4
February	46.2	29.0	31.1	-9.2	-0.8	-1.1
March	13.2	16.6	33.8	0.9	1.5	3.1
April	23.4	12.0	29.9	7.5	6.9	8.4
Total	293.5	340.7	344.5	-	-	-

4 Conclusions

The 2019 area-weighted average and median PHNT values of the study area were similar to 2018 values. Some fields had an increase in PHNT values from 2018 to 2019, indicating the need to evaluate N management on those fields. As a group, corn fields had higher PHNT in 2019 than in 2018. Post harvest nitrate is expected to be higher in corn in comparison to perennial forages, however producers should continue to monitor PHNT and N management to ensure the increasing trend does not continue.

Leaching of NO_3-N below the sampled soil profile likely occurred at one site where a significant decrease in NO_3-N concentration occurred in April at 60-90 cm. While indications of NO_3-N leaching below the 90-cm depth was similar to earlier studies in the area, it should be apparent that NO_3-N movement from one sampled soil depth to another in several Benchmark sites indicates that NO_3-N leaching in the North Okanagan occurs more frequently than initially assumed. Therefore, producers should continue to manage N to reduce the potential N loss to groundwater.

5 References

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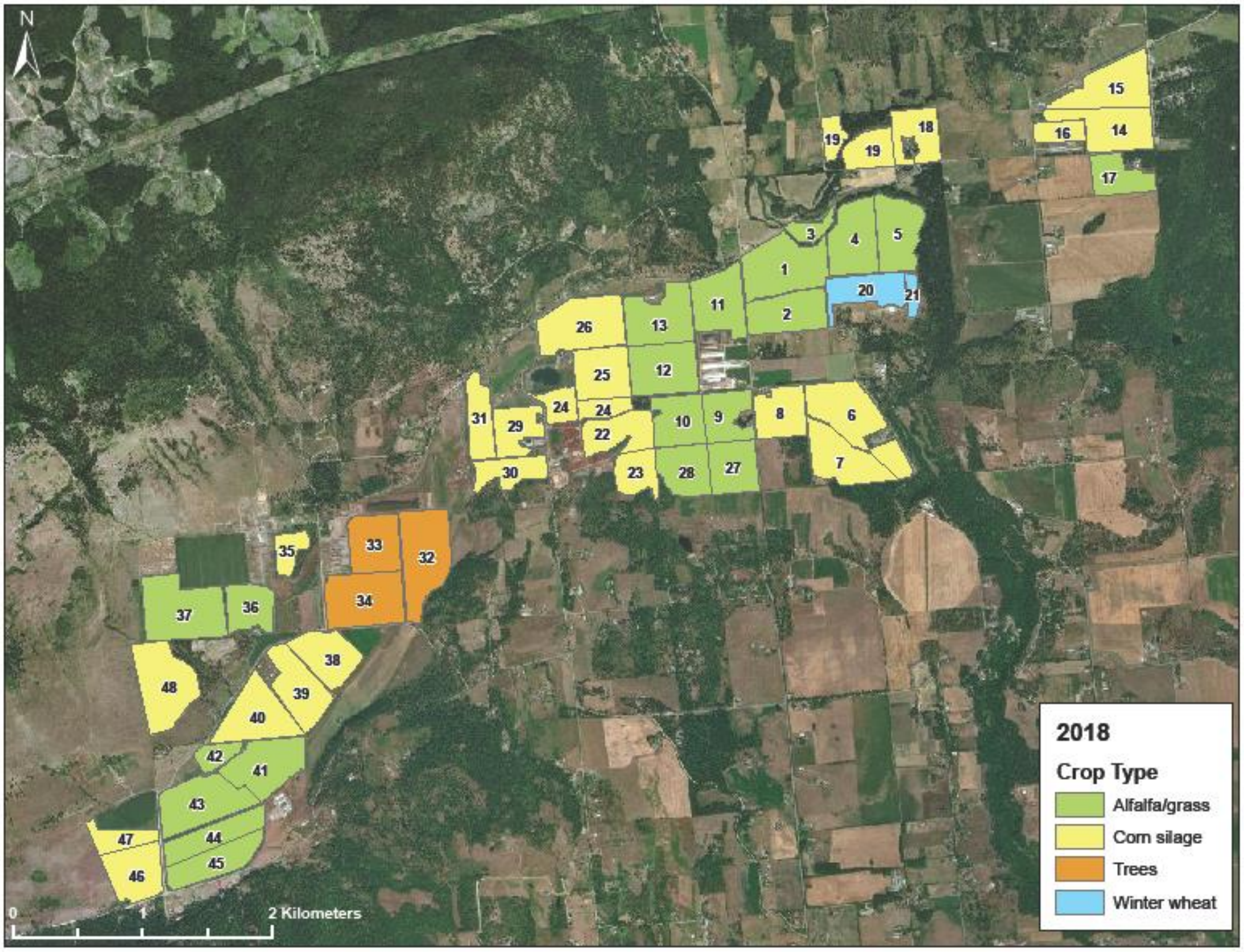
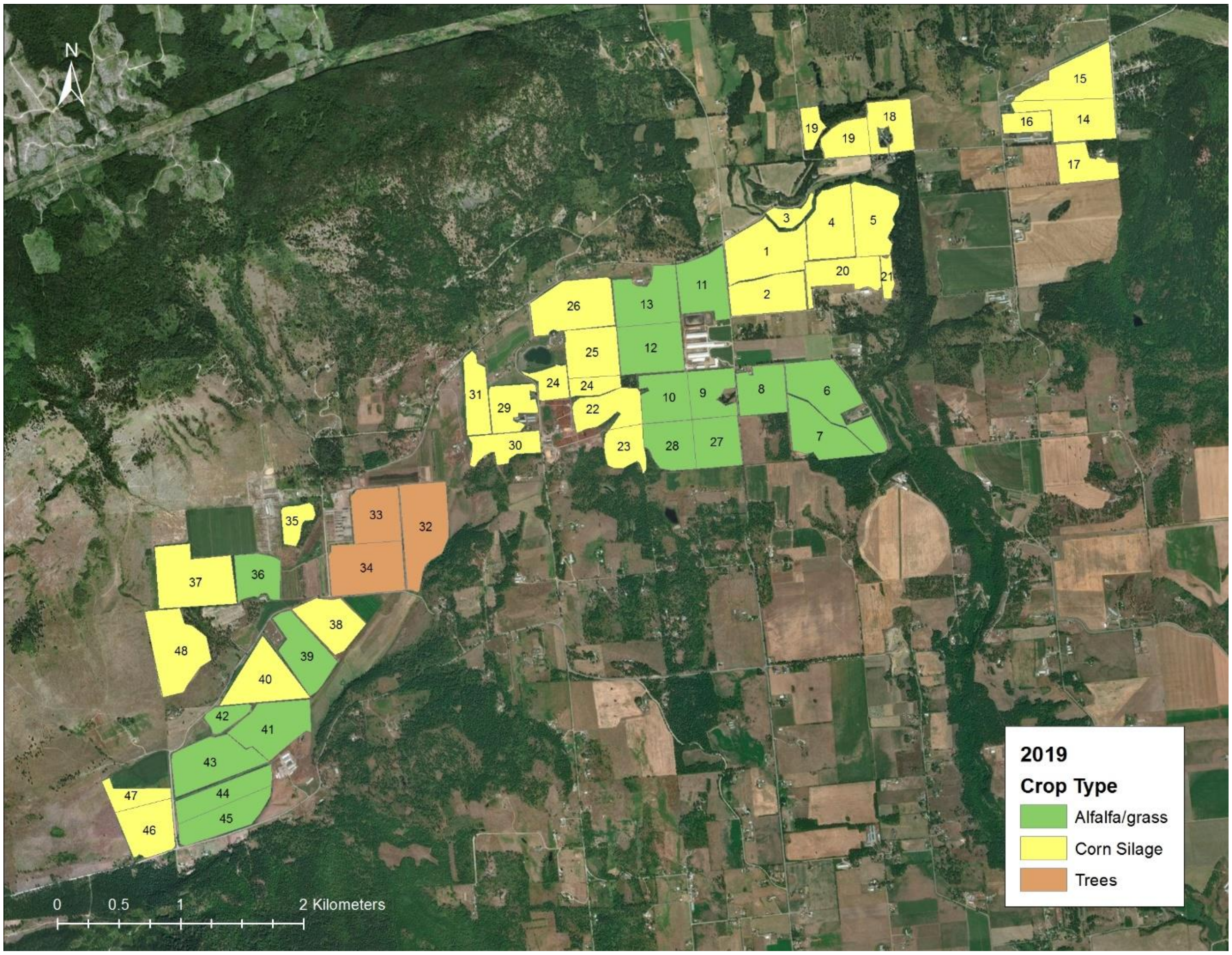
6 Supplemental Materials

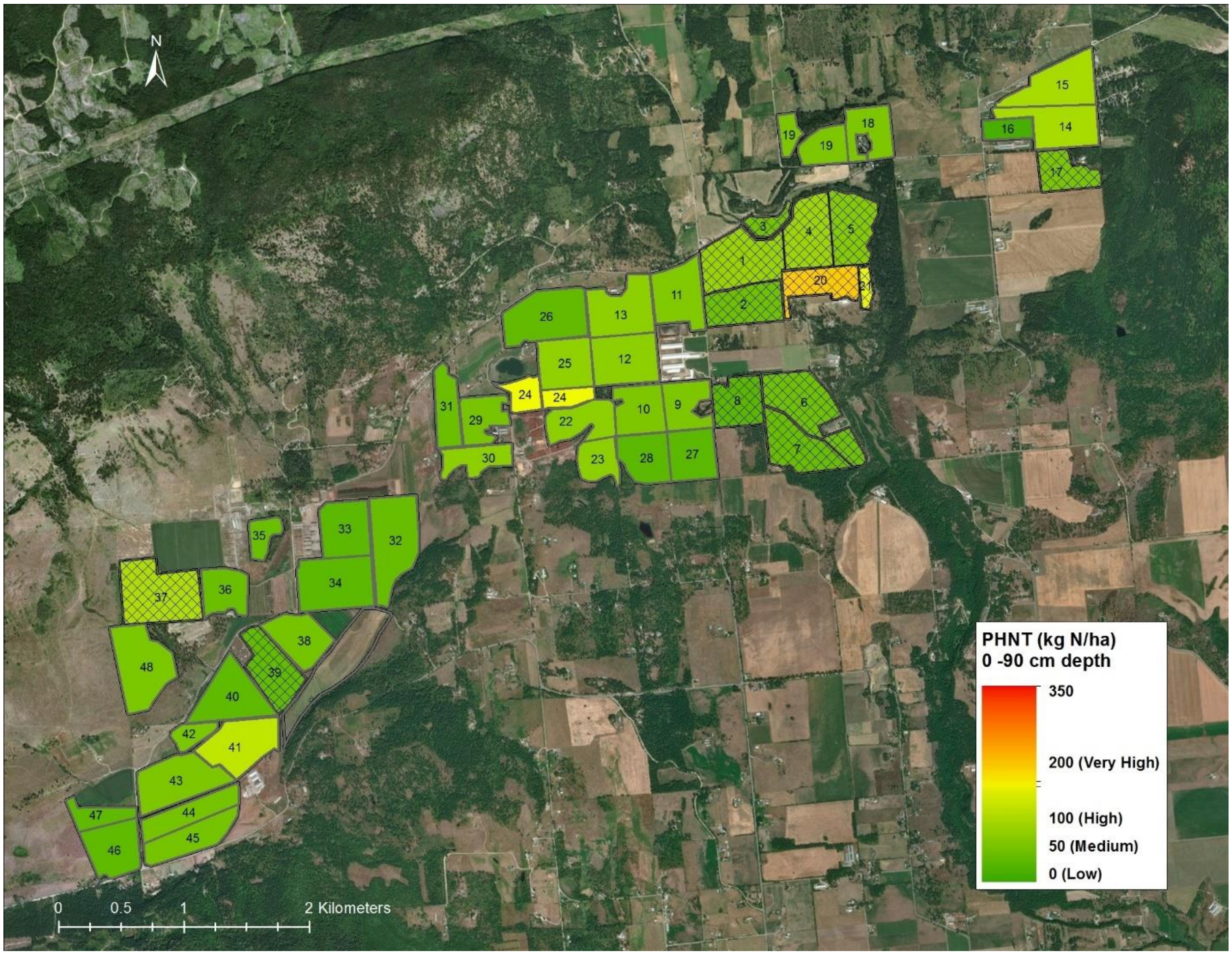
Figures



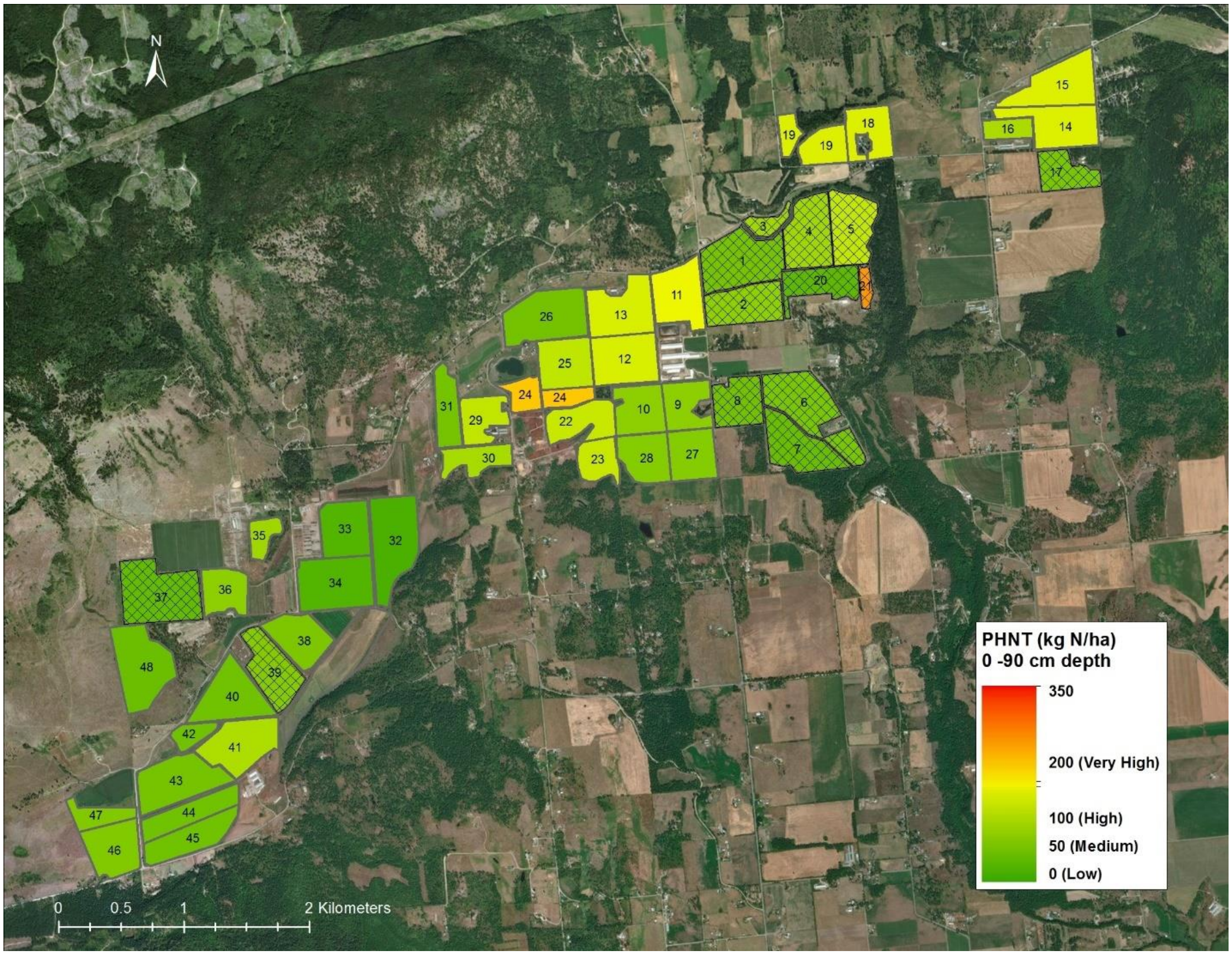
Supplemental Figure 1. Crop type in the study area during the 2018 growing season. The field ID numbers are based on sample area IDs used initially in 2018.



Supplemental Figure 2. Crop type in the study area during the 2019 growing season. The field ID numbers are based on sample area IDs used initially in 2018.



Supplemental Figure 3. Post-harvest nitrate test (PHNT) ratings in fall of 2018. Sampling areas with a cross-hatch pattern had a change in crop type from 2018 to 2019.



Supplemental Figure 4. Post-harvest nitrate test (PHNT) ratings in fall of 2019. Sampling areas with a cross-hatch pattern had a change in crop type from 2018 to 2019.

Tables

Supplemental Table 1. NO_3-N concentrations at the 30-60 and 60-90 cm depths for the six Benchmark sites in spring and fall of 2019 (the final sample from the 2018/19 Benchmark study and first sample from the 2019/20 Benchmark study). Concentrations followed by the same letter within the same site and depth are not significantly different.

	Spring	**Fall**
Site 4	----------ppm----------	
30-60 cm	3.9a	4.9a
60-90 cm	2.2a	2.0a
Site 6		
30-60 cm	2.0a	1.2a
60-90 cm	1.1a	1.0a
Site 17		
30-60 cm	5.1a	2.7a
60-90 cm	2.6a	1.8a
Site 26		
30-60 cm	4.3a	3.7a
60-90 cm	0.9a	2.3a
Site 31		
30-60 cm	1.0a	0.7a
60-90 cm	0.4a	0.2a
Site 38		
30-60 cm	2.3a	0.7a
60-90 cm	1.2a	0.5a

Supplemental Table 2. Post-harvest nitrate by soil layer (depth) in fields that were silage corn in 2018 and 2019.

		2018				2019			
Field	Sampling Depth	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop	kg NO_3-N ha^{-1}	kg NO3-N ha^{-1} (0-90cm)	PHNT Rating	Crop
14/15	0-30 cm	48	115	High	Corn silage	25	138	High	Corn silage
	30-60 cm	38				39			
	60-90 cm	29				73			
16	0-30 cm	8	18	Low	Corn silage	34	99	Medium	Corn silage
	30-60 cm	5				28			
	60-90 cm	5				37			
18/19	0-30 cm	34	72	Medium	Corn silage	45	137	High	Corn silage
	30-60 cm	17				54			
	60-90 cm	22				37			
22/23	0-30 cm	51	86	Medium	Corn silage	66	123	High	Corn silage
	30-60 cm	21				27			
	60-90 cm	14				230			
24	0-30 cm	87	185	High	Corn silage	124	188	High	Corn silage
	30-60 cm	43				41			
	60-90 cm	56				23			
25	0-30 cm	47	94	Medium	Corn silage	79	115	High	Corn silage
	30-60 cm	19				18			
	60-90 cm	28				18			
26	0-30 cm	34	43	Low	Corn silage	37	51	Medium	Corn silage
	30-60 cm	5				5			
	60-90 cm	5				9			
29	0-30 cm	39	67	Medium	Corn silage	76	118	High	Corn silage
	30-60 cm	14				23			
	60-90 cm	14				19			
30	0-30 cm	51	89	Medium	Corn silage	40	95	Medium	Corn silage
	30-60 cm	19				27			
	60-90 cm	19				27			
31	0-30 cm	38	52	Medium	Corn silage	26	54	Medium	Corn silage
	30-60 cm	5				14			
	60-90 cm	9				14			
35	0-30 cm	32	51	Medium	Corn silage	43	89	Medium	Corn silage
	30-60 cm	9				14			
	60-90 cm	9				32			
38	0-30 cm	39	62	Medium	Corn silage	32	60	Medium	Corn silage
	30-60 cm	14				9			
	60-90 cm	9				18			
40	0-30 cm	27	41	Low	Corn silage	26	48	Low	Corn silage
	30-60 cm	9				9			
	60-90 cm	5				14			
46/47	0-30 cm	25	40	Low	Corn silage	35	63	Medium	Corn silage
	30-60 cm	7				12			
	60-90 cm	7				16			
48	0-30 cm	31	68	Medium	Corn silage	20	43	Low	Corn silage
	30-60 cm	18				9			
	60-90 cm	19				14			

Supplemental Table 3. Post-harvest nitrate by soil layer (depth) in fields that were grass/alfalfa in 2018 and 2019.

		2018				2019			
Field	**Sampling Depth**	**kg NO_3-N ha^{-1}**	**kg NO_3-N ha^{-1} (0-90cm)**	**PHNT Rating**	**Crop**	**kg NO_3-N ha^{-1}**	**kg NO3-N ha^{-1} (0-90cm)**	**PHNT Rating**	**Crop**
9/10	0-30 cm 30-60 cm 60-90 cm	40 12 19	71	Medium	Alfalfa 1	46 14 11	71	Medium	Alfalfa 2
11	0-30 cm 30-60 cm 60-90 cm	47 14 14	75	Medium	Alfalfa 3	97 41 14	152	High	Alfalfa 4
12/13	0-30 cm 30-60 cm 60-90 cm	50 19 19	88	Medium	Alfalfa 2	87 30 16	134	High	Alfalfa 3
17	0-30 cm 30-60 cm 60-90 cm	53 14 5	72	Medium	Alfalfa 3	12 5 41	58	Medium	Alfalfa 4
27/28	0-30 cm 30-60 cm 60-90 cm	23 5 9	37	Low	Alfalfa 1	43 11 11	66	Medium	Alfalfa 2
36	0-30 cm 30-60 cm 60-90 cm	33 9 9	52	Medium	Alfalfa 1	44 14 14	71	Medium	Alfalfa 2
41	0-30 cm 30-60 cm 60-90 cm	113 14 9	137	High	Alfalfa /grass 2	59 23 18	100	High	Alfalfa /grass 3
42	0-30 cm 30-60 cm 60-90 cm	59 5 5	69	Medium	Alfalfa 1	37 9 5	50	Medium	Alfalfa 2
43	0-30 cm 30-60 cm 60-90 cm	53 14 5	71	Medium	Alfalfa /grass 2	41 9 5	54	Medium	Alfalfa /grass 3
44/45	0-30 cm 30-60 cm 60-90 cm	53 7 5	65	Medium	Alfalfa /grass 3	37 7 5	49	Low	Alfalfa /grass 4

Supplemental Table 4. Post-harvest nitrate by soil layer (depth) in fields that were trees or had a crop change in 2018 and 2019.

		2018				2019			
Field	Sampling Depth	kg NO_3-N ha^{-1}	kg NO_3-N ha^{-1} (0-90cm)	PHNT Rating	Crop	kg NO_3-N ha^{-1}	kg NO3-N ha^{-1} (0-90cm)	PHNT Rating	Crop
1	0-30 cm 30-60 cm 60-90 cm	68 19 14	101	High	Alfalfa 5	32 14 9	55	Medium	Corn silage
2	0-30 cm 30-60 cm 60-90 cm	41 9 9	59	Medium	Alfalfa 5	48 18 9	76	Medium	Corn silage
3	0-30 cm 30-60 cm 60-90 cm	37 14 14	65	Medium	Grass	54 19 19	92	Medium	Corn silage
4	0-30 cm 30-60 cm 60-90 cm	79 19 9	107	High	Alfalfa 5	54 23 14	91	Medium	Corn silage
5	0-30 cm 30-60 cm 60-90 cm	71 5 5	80	Medium	Alfalfa 5	60 41 18	119	High	Corn silage
20	0-30 cm 30-60 cm 60-90 cm	170 37 5	212	Very High	Winter wheat	10 9 14	33	Low	Corn silage
21	0-30 cm 30-60 cm 60-90 cm	126 14 38	179	High	Winter wheat	30 28 151	208	Very High	Corn silage
37	0-30 cm 30-60 cm 60-90 cm	99 9 14	123	High	Alfalfa /grass	28 9 9	37	Low	Corn silage
6	0-30 cm 30-60 cm 60-90 cm	33 14 9	57	Medium	Corn silage	34 14 9	57	Medium	Alfalfa 1
7	0-30 cm 30-60 cm 60-90 cm	28 9 14	52	Medium	Corn silage	12 5 28	44	Low	Alfalfa 1
8	0-30 cm 30-60 cm 60-90 cm	18 5 14	37	Low	Corn silage	32 9 9	51	Medium	Alfalfa 1
39	0-30 cm 30-60 cm 60-90 cm	27 14 5	45	Low	Corn silage	16 5 50	70	Medium	Alfalfa 1
32	0-30 cm 30-60 cm 60-90 cm	28 9 9	47	Low	Trees	8 5 5	17	Low	Trees
33/34	0-30 cm 30-60 cm 60-90 cm	25 7 5	36	Low	Trees	13 5 5	22	Low	Trees

Supplemental Table 5. Changes in volumetric soil moisture content (%) over the non-growing season at the six Benchmark sites in 2018/19 and 2019/20.

2018/19				2019/20			
Date	0-30 cm	30-60 cm	60-90 cm	Date	0-30 cm	30-60 cm	60-90 cm
Site 4	Sandy loam	Loamy sand	Loamy sand	**Site 4**	Sandy loam	Loamy sand	Loamy sand
21-Oct	21.6	16.7	12.0	21-Oct	16.7	12.2	6.7
07-Nov	21.2	15.4	10.6	05-Nov	18.5	11.6	9.3
25-Mar	30.6	21.3	11.1	25-Nov	23.4	17.2	7.2
01-Apr	21.6	16.5	11.9	17-Mar	36.5	28.4	26.0
				01-Apr	41.4	26.3	17.1
				20-Apr	28.8	23.3	12.7
Site 6	Sandy loam	Sandy loam	Sandy loam	**Site 6**	Sandy loam	Sandy loam	Sandy loam
21-Oct	28.4	23.5	22.4	21-Oct	26.0	21.9	16.3
07-Nov	25.5	20.9	18.9	05-Nov	27.9	23.5	18.9
25-Mar	36.8	27.5	25.5	25-Nov	27.9	25.0	18.4
01-Apr	28.9	25.0	24.5	17-Mar	40.7	37.7	37.7
				01-Apr	42.1	34.7	32.1
				20-Apr	36.8	31.6	38.3
Site 17	Silt loam	Silt loam	Sandy loam	**Site 17**	Silt loam	Silt loam	Sandy loam
21-Oct	28.4	33.8	37.2	21-Oct	28.4	32.8	38.7
07-Nov	28.9	32.2	34.5	05-Nov	29.8	34.8	40.3
25-Mar	44.0	33.8	39.3	25-Nov	30.3	35.4	38.7
01-Apr	31.2	38.5	39.3	17-Mar	45.4	53.0	56.0
				01-Apr	46.9	53.6	53.9
				20-Apr	38.8	50.4	53.9
Site 26	Sandy loam	Sandy loam	Sand	**Site 26**	Sandy loam	Sandy loam	Sand
21-Oct	20.4	15.2	9.1	21-Oct	19.2	13.5	8.5
07-Nov	20.8	14.3	8.3	05-Nov	21.7	15.9	8.8
25-Mar	32.5	19.9	9.4	25-Nov	24.6	12.9	9.0
01-Apr	22.1	16.3	10.0	17-Mar	21.7	43.9	22.2
				01-Apr	31.3	21.9	13.6
				20-Apr	30.8	19.4	11.0
Site 31	Sandy loam	Loamy sand	Sand	**Site 31**	Sandy loam	Loamy sand	Sand
21-Oct	21.3	12.1	10.3	21-Oct	21.7	11.9	7.3
07-Nov	20.4	13.3	6.9	05-Nov	22.2	14.5	7.9
25-Mar	29.7	18.6	7.6	25-Nov	25.3	12.5	8.3
01-Apr	20.8	13.2	9.1	17-Mar	37.7	31.2	17.9
				01-Apr	27.9	20.6	12.7
				20-Apr	25.7	14.3	10.7
Site 38	Loam	Loam	Clay loam	**Site 38**	Loam	Loam	Clay loam
21-Oct	21.5	21.9	24.1	21-Oct	23.3	23.8	26.0
07-Nov	20.4	21.9	23.7	05-Nov	22.2	24.3	26.0
25-Mar	28.9	23.4	23.7	25-Nov	21.8	26.8	26.5
01-Apr	21.5	24.8	26.5	17-Mar	34.0	31.6	36.0
				01-Apr	31.5	31.6	34.1
				20-Apr	26.3	30.7	32.7