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Tracking Post-Harvest Soil Nitrate in Agricultural Fields in the Hullcar Valley in 2017-18

Final Report

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Tracking Post-Harvest Soil Nitrate in Agricultural Fields in the Hullcar Valley in 2017-18

Short title: 2017-18 Post-Harvest Nitrate Study: Hullcar Valley

Final Report

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Summary

To minimize the amount of nitrate that can leach down through the soil profile, it is important to understand the amount of excess soil nitrate relative to crop needs in agricultural fields. These excesses can be measured by the post-harvest nitrate test (PHNT). The year-to-year trends in a field's PHNT values are an indicator of the effectiveness of adjustments to nitrogen (N) management practices over time. In the fall of 2017, residual nitrate in 39 agricultural fields in the Hullcar Valley of the North Okanagan was measured in the 0-90 cm soil layer using the PHNT. Of the 39 fields, 34 (or 87%) had low or medium average PHNT values (less than 100 kg N ha^{-1}). Only 5 (or 13% of the fields, representing 64 ha of the 776-ha study area) had greater than 100 kg N ha^{-1}. In 2016, 54% of these 39 fields had low or medium PHNT values and 46% were in the high or very high range. Overall, crop N management was close to optimal in most fields in 2017 and there was less post-harvest (residual) soil nitrate in 2017 than in 2016.

In a separate analysis, weather conditions were assessed for their effects on soil nitrate movement during the non-growing season from October 2017 until May 2018. A site, 70 to 140 m^2 in area, was established in each of 6 of the 39 agricultural fields that were sampled for PHNT. At each site, soil was sampled for nitrate-nitrogen on six dates during the non-growing season, from the 0-30, 30-60, and 60-90 cm soil layers. Results suggest that nitrate leached from the top 30 cm of soil by early spring 2018, below the 90 cm depth at sites with coarse-textured soils, or to the 30-60 cm and 60-90 cm layers at sites with finer-textured soil. Nitrate leached deeper in the soil profile than previously observed in the North Okanagan, likely due to the large amount of precipitation, nearly 50% more from November 2017 to February 2018 than the long-term average or the previous year. In the Hullcar Valley, soil properties and weather conditions need to be factored into predictions of the amount of nitrate leached from the root zone in this region, rather than assuming that all or none of the nitrate will be leached over a non-growing season.

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1 Introduction

In recent years, the drinking water quality in Aquifer 103 in the Hullcar Valley in the North Okanagan of British Columbia (B.C.) has been compromised by elevated levels of nitrate[1]. Agricultural fields in the Hullcar Valley, dominated by forage crops grown for livestock feed, are possible sources of nitrate. For nitrate to leach from agricultural fields to an aquifer, nitrate must be present in the soil, and water must be moving down or percolating through the soil. The post-harvest nitrate test (PHNT) is a soil test that was developed to guide decisions about nitrogen (N) management. A PHNT is meant to measure the amount of excess soil nitrate not used by the recently harvested crop (i.e. post-harvest soil nitrate). Relative differences in PHNT values help guide decisions about N management, no matter what the crop-specific target values for PHNT are or should be. For a given field, monitoring PHNT, crop yield and crop quality year-to-year provides information to minimize excess nitrate over time without compromising crop production objectives (BC AGRI 2010). In the fall of 2016, baseline measurements of PHNT were taken in agricultural fields that represent most of the cropped area in the Hullcar Valley (Poon and Code 2017). The 2016 results suggested an opportunity to reduce excess N in roughly half of the fields sampled, after which efforts continued to improve N management practices[1]. Fall 2017 was the first opportunity to repeat the PHNT testing in the previously sampled fields and monitor year-to-year trends.

In regions with freezing temperatures and dry winters like the Okanagan, any soil nitrate remaining in the soil at the end of the growing season is most vulnerable to leaching during the fall and spring thaw periods when evapotranspiration and crop nutrient uptake rates are lowest (Drury et al. 2016). However, nitrate leaching during these periods is limited by freezing conditions and the amount of soil water. Thus, despite a wet and warm fall followed by an above-average snow accumulation during the winter of 2016/17, the leaching of soil nitrate in the Hullcar Valley was limited during the winter of 2016/17 and before crop growth in 2017: nitrate leached from the 0-30 cm soil layer to the 30-60 cm layer but not deeper, even in coarse-textured and well-drained soil (Poon and Code 2017). These results were consistent with those previously observed in the Okanagan Valley (Kowalenko et al. 2009).

While the results were insightful, the depth to which nitrate leaches between crop growing seasons depends on the amount of soil nitrate and the amount of water that percolates. Therefore, additional monitoring of the movement of soil nitrate was needed for the non-growing season in the North Okanagan.

This report addresses the need to better understand 1) the distribution of fields with different levels of PHNT, to help guide producers' decisions about crop N management in the Hullcar Valley and 2) the movement of soil nitrate through the top 90 cm of the agricultural soils during the non-growing season in the Hullcar Valley, to determine what, if any environmental interpretations, can be made of the PHNT soil test in the North Okanagan.

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[1] http://www2.gov.bc.ca/gov/content/environment/air-land-water/site-permitting-compliance/hullcar-aquifer

The study aimed to address the following questions and hypotheses:

1. Overlying Aquifer 103 and the nearby area, how many agricultural fields had elevated levels of residual soil nitrate in the 0-90 cm layer of soil in 2017?
    - Hypothesis: most agricultural fields in the Hullcar Valley had less than 100 kg N ha^{-1} of post-harvest soil nitrate (0-90 cm soil layer) in 2017. [Post-Harvest Soil Testing]
2. How did PHNT levels compare between 2016 and 2017 in these fields?
    - Hypothesis: PHNT levels were lower in 2017 than in 2016. [Post-Harvest Soil Testing]
3. Does nitrate leach through and below the 0-90 cm layer of soil during the non-growing season in the Hullcar Valley?
    - Hypothesis: soil nitrate concentrations leached within but not below the top 90 cm of soil during the non-growing season of 2017/18, as shown by a decrease in the nitrate concentrations in the 0-30 cm layer of soil and increases in the 30-60 cm and 60-90 cm layers during this period. [Benchmark Testing]

2 Materials and Methods

Study area

The study area was in the Hullcar Valley of the North Okanagan, overlying the mapped boundary of Aquifer 103 south of Grindrod, B.C. (Fig. 1). Over the years, agriculture has been an important part of the landscape in the study area. Currently, most of the land base is used for growing forage crops for intensive beef and dairy operations. Cereal grains, a plant nursery, poultry production, and small scale agriculture lots make up the remainder of the area. Soils in most of the study area are well to rapidly-drained soils, in the Chernozemic or Brunisolic soil orders, and there are small areas of poorly-drained Gleysolic or Organic soils (Wittneben 1986). The area has warm summers and cool, moist winters. In summary, average annual precipitation is 480 mm and daily average temperatures range from -2.3°C in January to 20.2°C in July (Wang et al. 2016).

The weather during the 2017/18 Benchmark study period (October 6, 2017 to May 4, 2018) differed from the long-term average (1981-2010), according to Environment and Climate Change Canada (2018). The weather also differed from the 2016/17 Benchmark study period (Sep 30, 2016 to April 12, 2017) described by Poon and Code (2017). In the 2017/18 period, the fall was drier than average. In the 2016/17 period, the fall was rainier and warmer than average, and the winter was snowier and colder than average (Figs. 2 and 3). As in 2016/17, the 2017/18 winter was colder and more snow fell than in average years. In the November to February period, there was 45% more snowfall in 2017/18 than in 2016/17.

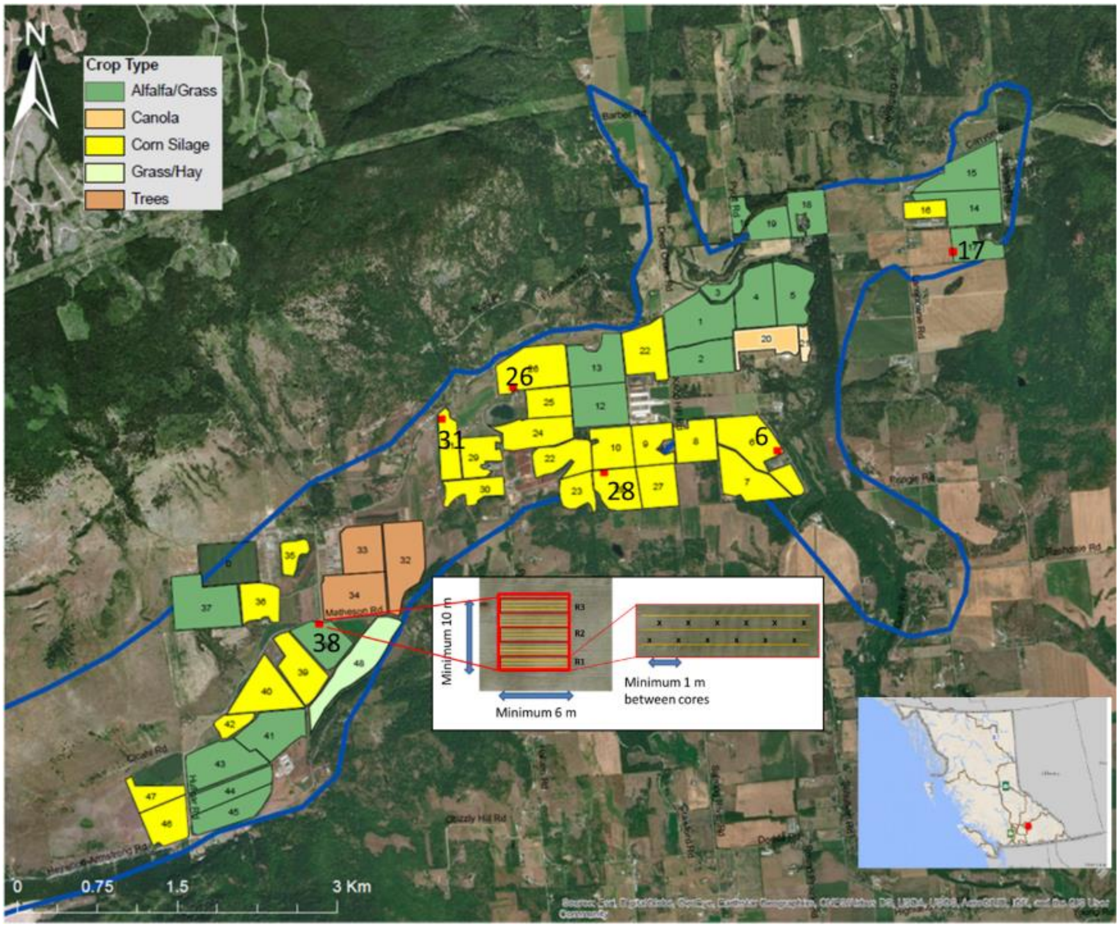

Figure 1. Locations of the six Benchmark Testing sites (red squares; enlarged for visibility), in relation to fields sampled for Post-Harvest Soil Testing and Aquifer 103 (blue outline). Insets: locations of soil sampling cores (x) within each of 3 replicate blocks (R1, R2, R3) of a Benchmark site, and general location in British Columbia.

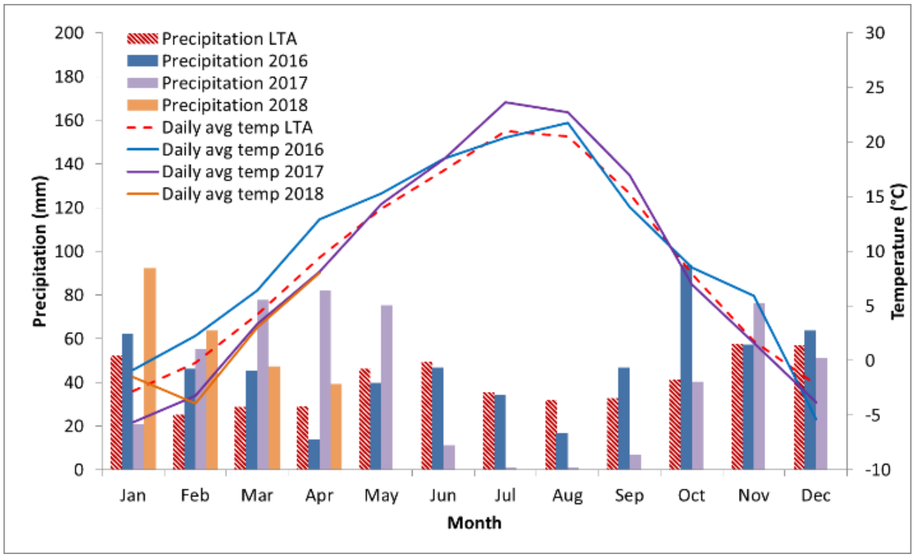

Figure 2. Average daily air temperature and total precipitation by month, compared to the long-term average (1980-2010, LTA) at the North Vernon weather station (50.34, -119.27, 538 m elevation) from January 2016 to April 2018.

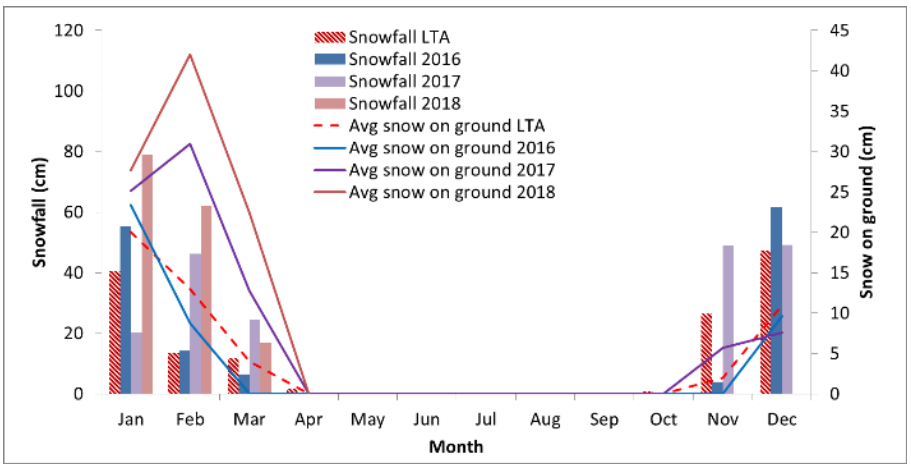

Figure 3. Average snow on ground and total snowfall by month, compared to the long-term average (1980-2010, LTA) at the North Vernon weather station (50.34, -119.27, 538 m elevation) from January 2016 to April 2018.

2.1 Post-Harvest Soil Testing

Field Selection and Sampling Methodology

Thirty-nine fields that were sampled in 2016 for PHNT were re-sampled in the fall of 2017. Each field was managed uniformly (e.g., even manure application rates), and nine of the larger fields were split in two sampling areas for 2017 sampling. The splits were made according to differences in soil types or simply to divide large areas in half so that no sampling area was larger than 25 ha in size. Thus, 48 sampling areas were sampled, and numbered from 1 to 48, to represent the 39 fields in 2017 (Appendix 6.1). The numbering system differed from the one used in the report by Poon and Code (2017).

The sampling methodology for each sampling area was the same in 2017 as in 2016 (Poon and Code 2017). One composite soil sample was taken per field at the 0-15, 15-30, 30-60, and 60-90 cm soil layers. In 2017, PHNT sampling started on September 13 and ended on October 20. In 2016, PHNT sampling started on September 30 and ended on November 4 (Poon and Code 2017).

Analyses

The laboratory and data analyses were the same for the 2017 data as the 2016 data (Poon and Code 2017). Extractable-nitrate concentrations were converted to kg N ha^{-1} for each layer, assuming a soil bulk density 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 0-90 cm nitrate results were categorized into 4 general agronomic categories (0-49 kg N ha^{-1}, Low; 50-99 kg N ha^{-1}, Medium; 100-200 kg N ha^{-1}, High; and ≥200 kg N ha^{-1}, Very High), based on the categories proposed by Kowalenko et al. (2009).

2.2 Benchmark Testing

Six Benchmark sites were established for six rounds of soil sampling in the Hullcar Valley in B.C., from October 6, 2017 to May 4, 2018. The sites were approximately rectangular in shape and were established in 70 to 140 m^2 areas of the larger fields from Post-Harvest Soil Testing (Section 2.1; Fig. 1). The six sites represented a range of soil types in the Hullcar Valley (Table 1) and were within an elevation range of 510 to 520 m. Each site was divided into three replicate blocks. In each block, one composite soil sample was taken from each of three layers: 0-30, 30-60, and 60-90 cm depths. Each composite soil sample consisted of twelve 4.4-cm cores from within the block, excluding vegetation or mulch.

Two of the sites were part of earlier Benchmark Testing in 2016/17 (Poon and Code 2017). The two sites were the alfalfa sites, and they were renamed to match the updated naming convention for the fields in 2017 Post-Harvest Soil Testing (i.e. Site 38 in this report refers to Site 23 from the previous year as described by Poon and Code (2017); Site 17 in this report refers to Site 37 from the previous year).

Table 1. Descriptions of the soils at the Benchmark sites. Bulk density was estimated using measurements of sand%, clay%, and organic matter% as inputs in the pedotransfer function of Saxton and Rawls (2006).

Site/ Layer	Sand%	Clay%	Textural Class	Organic Matter%	Estimated bulk density (kg m^{-3})
Site 6 (harvested corn)					
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)					
0-30 cm	34%	10%	Silt loam	2.5%	1420
30-60 cm	35%	9.4%	Silt loam	0.96%	1560
60-90 cm	53%	5.1%	Sandy loam	0.90%	1570
Site 26 (harvested corn)					
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 28 (harvested corn)					
0-30 cm	16%	8.0%	Silt loam	2.6%	1410
30-60 cm	15%	7.6%	Silt loam	1.8%	1500
60-90 cm	18%	5.0%	Silt loam	1.1%	1540
Site 31 (harvested corn)					
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 (alfalfa)					
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

All of the Benchmark sites were irrigated during the growing season. During the sampling period, four sites were bare with no crop (harvested corn) and two sites had alfalfa (Table 2). There was no irrigation, harvest, tillage, planting, or fertilization during the sampling period, except as noted on three sites in Table 2.

Table 2. Sampling times at the six Benchmark sites.

		Sampling Date					
Site	Crop in 2017	Mid Oct 2017	End Oct 2017	Mid Nov 2017	Early Apr 2017	Mid Apr 2017	Early May 2017
6	Corn	Oct 6	Oct 31	Nov 16	Apr 4	Apr 12	May 4[a]
17	Alfalfa	Oct 18	Oct 31	Nov 15	Apr 4	Apr 13	May 4
26	Corn	Oct 13	Oct 30	Nov 16	Apr 4	Apr 13	May 3
28	Corn	Oct 13	Oct 30	Nov 16	Apr 4	Apr 13	May 3[b]
31	Corn	Oct 6	Oct 30	Nov 15	Apr 4	Apr 12	May 4
38	Alfalfa	Oct 16	Oct 30	Nov 16	Apr 4	Apr 12	May 4[c]

a. Liquid manure was applied on May 1, 2018
b. The site was plowed sometime in the spring of 2018 before May 3, 2018, and granular fertilizer (33 kg N per ha) was surface broadcast on May 3, 2018, immediately before soil sampling.
c. Liquid manure was applied on April 13, 2018; the site was plowed on April 16, 2018; and corn was planted on May 2, 2018.

The period of sampling varied somewhat between sites, with samples taken in early/mid-October, late October and mid-November of 2017 before soil freeze-up, and then samples were taken after spring thaw in early April, mid-April, and early May of 2018. The samples were refrigerated or on ice in a cooler for up to 3 days before they were sent to the laboratory. Extractions were done on field-moist samples. Potassium chloride (KCl)-extractable nitrate and ammonium were measured. Concentrations of nitrate-nitrogen and ammonium-nitrogen were converted to an oven-dry basis.

The nitrate-N data were analysed separately for the six Benchmark sites, with replicates as random effects, sampling periods as repeated effects and soil layer (depth) as fixed effects. The data were tested for normality using the Statistical Analysis Software (SAS) univariate procedure, and analysis of variance (ANOVA) was performed separately using the Proc Mixed procedure of SAS, version 9.3 (SAS Institute 2010). When the ANOVA was significant, differences between least square means (LSMEANS) for all treatment pairs were tested at a significance level of $P = 0.05$.

3 Results and Discussion

3.1 Post-Harvest Soil Testing

2017 Results

Results support the hypothesis that most (87%) of the 39 fields had less than 100 kg N ha^{-1} PHNT (0-90 cm soil layer) in 2017. More fields had a low PHNT rating (less than 50 kg N ha^{-1}) than any other rating. Only 13% of the fields, representing 64 ha of the 776-ha study area, had greater than 100 kg N ha^{-1}. Only one field had greater than 200 kg N ha^{-1}, although this field was small (5.5 ha; Fig. 1). Overall, crop N management was close to optimal in most fields and most of the study area in 2017, assuming there were no crop N deficiencies. If there were crop N deficiencies in the non-alfalfa fields with low PHNT ratings, and irrigation was optimal, then N application rates in 2017 may have been too low on these fields.

There were differences among crop types in the 2017 PHNT results (Table 3). Among the 48 sampling areas, the area-weighted average PHNT values were highest for the fields that were in annual crops (canola, corn) and lowest in the fields with the perennial crops (alfalfa/grass, grass hay, and nursery trees). These differences were consistent with relative differences in N uptake efficiency between the crop types and previous results in the study area in 2016 (Poon and Code 2017) and the larger Okanagan Valley (Kowalenko et al. 2009).

Table 3. 2017 Post-Harvest Nitrate Test (PHNT) values by crop type.

Crop type	Area sampled (ha)	Number of 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.

Of the nine fields that were split in 2017, six had PHNT levels that were similar between the two sampling areas of each field (Appendix 6.1). These similarities suggest that these six fields could be sampled and managed as one unit. In the three other fields (9&10, 22&23 and 27&28), all planted to corn in 2016, the PHNT level differed between the sampling areas. These differences suggest that these three fields should continue to be split as in 2017 for PHNT monitoring, and if differences persist, N management practices may also need to differ between the two areas of a given field.

Comparisons between 2017 and 2016

Overall, PHNT levels were lower in 2017 than in 2016 (Figs. 4 and 5). In 2016, 54% of the 39 fields had low or medium PHNT values and 46% were in the high or very high range. Year-to-year trends in PHNT levels can be compared directly for a given field if the cropping system is the same between years. All fields that were in alfalfa in both study years, and most fields that were in corn in both study years, had similar or lower PHNT values in 2017 than in 2016 (Figs.4 and 5). Of the corn fields, three had medium PHNT values in 2017 that were greater than in 2016 (Fig. 4). The field with more than 200 kg N ha^{-1} in 2017 had 52 kg NO_3-N ha^{-1} in 2016, although this field was small (5.5 ha). Although unseasonably warm and wet weather conditions during the post-harvest sampling period in 2016 may have increased the PHNT soil nitrate levels in 2016, the results suggest that producers improved crop nitrogen management practices in 2017 in most fields compared to 2016.

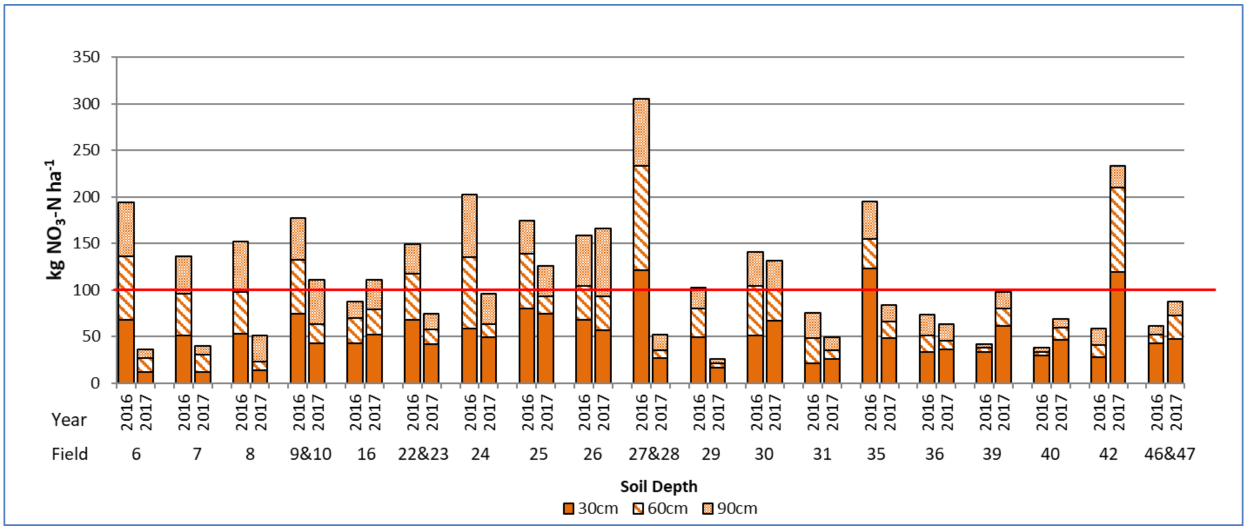

Figure 4. The distribution of post-harvest soil nitrate by soil layer, in 19 fields that were in silage corn in 2016 and 2017. The red line indicates the lower limit (100 kg N ha^{-1}) of the 'high' category of the post-harvest nitrate test.

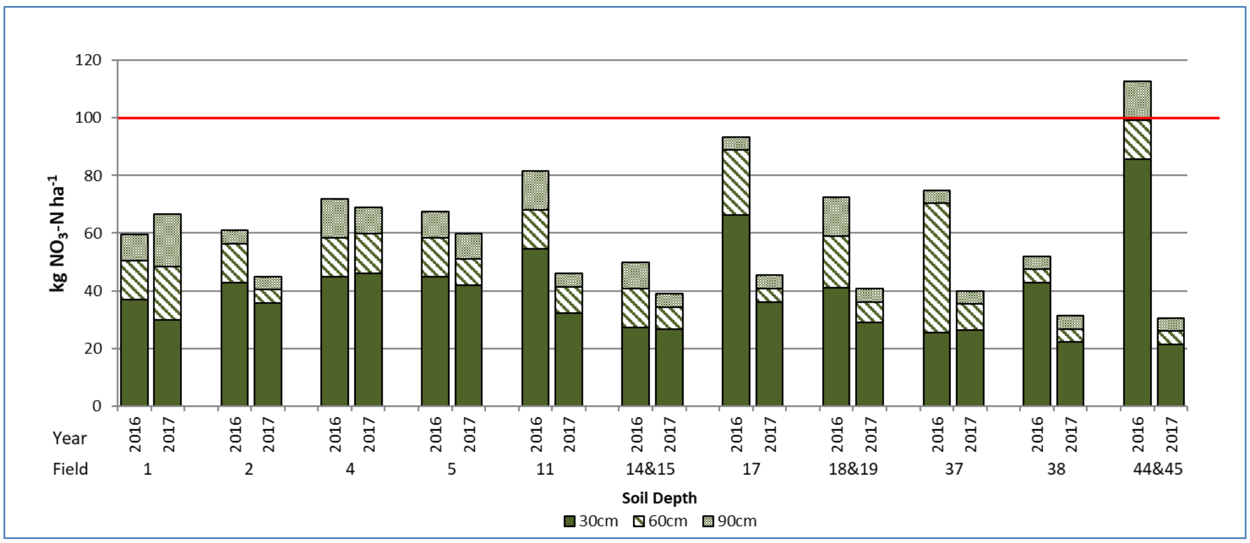

Figure 5. The distribution of post-harvest soil nitrate (NO_3-N) by soil layer, in 11 fields that were in alfalfa or an alfalfa/grass mix in 2016 and 2017. The red line indicates the lower limit (100 kg N ha^{-1}) of the 'high' category of the post-harvest nitrate test.

3.2 Benchmark Testing

Results partially supported the hypotheses about the changes in nitrate concentrations over the non-growing season (final harvest of 2017 to spring thaw in 2018). The nitrate concentrations in the surface soil (0-30 cm layer) decreased during this period, except at Sites 31 and 38 where soil nitrate concentrations were very low (less than 5 mg N kg^{-1}) to begin with in October 2017 (Fig. 6; Appendix 6.2). The lack of decrease at these two sites was likely due to mineralization and nitrification in the early spring of 2018, which offset slight decreases in nitrate concentrations due to leaching of small amounts of nitrate. However, results suggest that nitrate leached at all sites from the 0-30 cm layer over the non-growing season, as in the bare (harvested corn) sites from the 2016/17 Benchmark study (Poon and Code 2017).

The nitrate concentrations in the 30-60 cm or 60-90 cm soil layers increased during the non-growing season at some sites as expected but did not change at other sites (Fig. 7; Appendix 6.2). Results for Sites 17 and 26 best indicate how soil texture affected nitrate leaching, since these two sites had the highest nitrate concentrations in October 2017 (33 mg N kg^{-1} and 14 mg N kg^{-1}, respectively). At Site 17, the increases in nitrate concentrations showed that nitrate leached from the surface layer by April 2018, and mostly to the 60-90 cm layer below the primary root zone (top 60 cm). At Site 26, the coarser-textured soil facilitated faster movement of water down the soil profile, relative to the finer-textured soil at Site 17. Consequently, increases in nitrate concentrations were not observed in the 30-60 or 60-90 cm layers at Site 26, but nitrate had likely leached below the 90 cm depth cm by April 2018, based on the net loss of approximately 28 kg NO_3-N ha^{-1} from the 0-90 cm profile during the monitoring period (Table 1; Appendix 6.2). Indeed, increases in nitrate concentrations in the 30-60 cm and 60-90 cm layers occurred only at the three sites (Sites 17, 28, and 38) where soil textures were finer-textured (silt loam to clay loam) than at the other three sites (Sites 6, 26, and 41; sandy loam to sand). The effect of soil texture on the depth of nitrate leaching was consistent with observations in southern Ontario, where Drury et al. (2016) and Reynolds et al. (2016) found that the minimum saturated hydraulic conductivity (K_{sat}) within a soil profile controlled nitrate leaching from the top 60 cm of soil over the non-growing season. In a mineral soil layer, soil texture is an important factor that influences K_{sat}, with coarser-textured soil favouring greater values of K_{sat}.

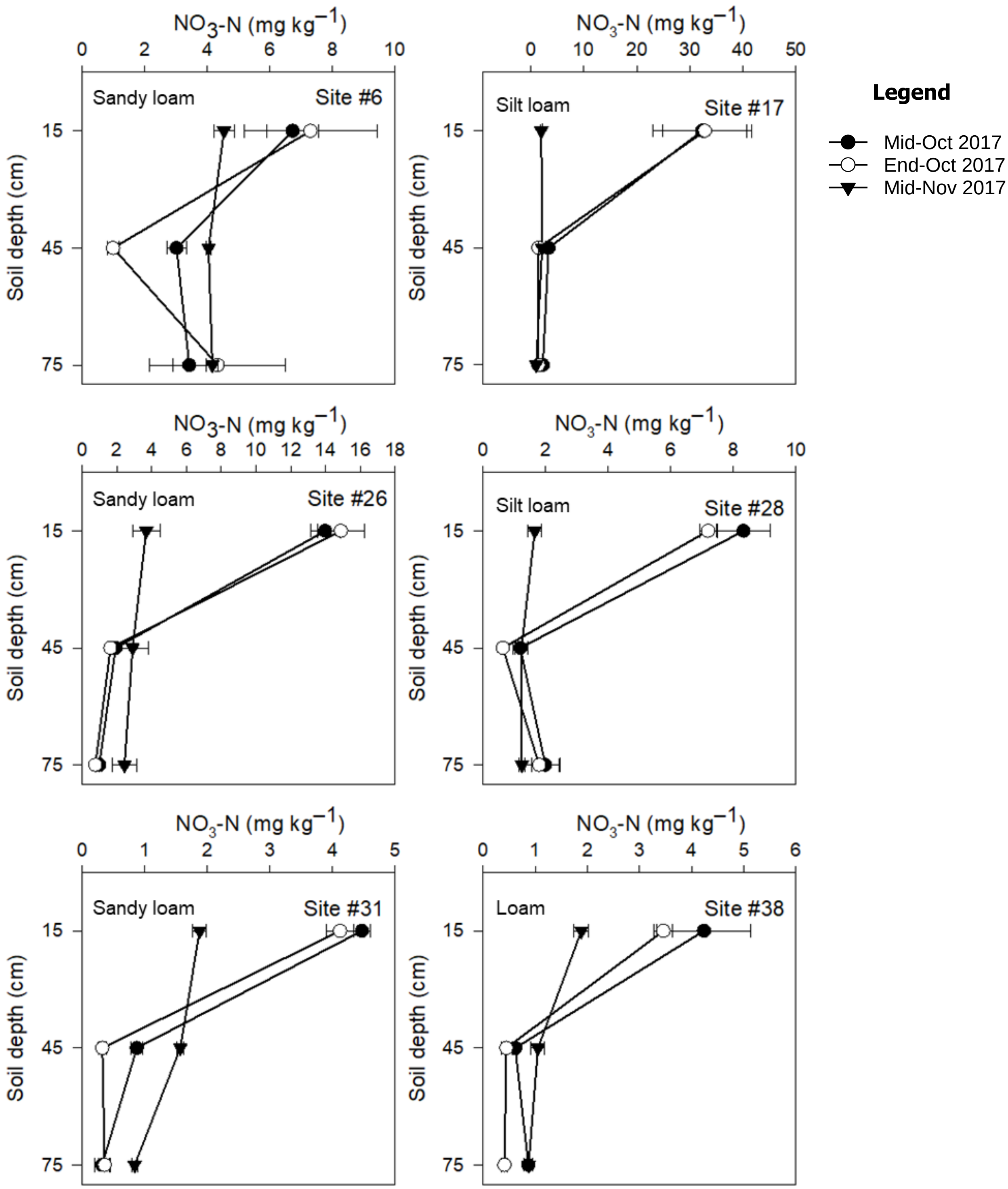

Figure 6. Changes during the autumn of 2017 in soil nitrate-nitrogen (NO_3-N) concentrations at six sites, at the midpoint of the 0-30, 30-60, and 60-90 cm layers. The soil textural class describes the 0-30 cm layer. Error bars represent standard deviations.

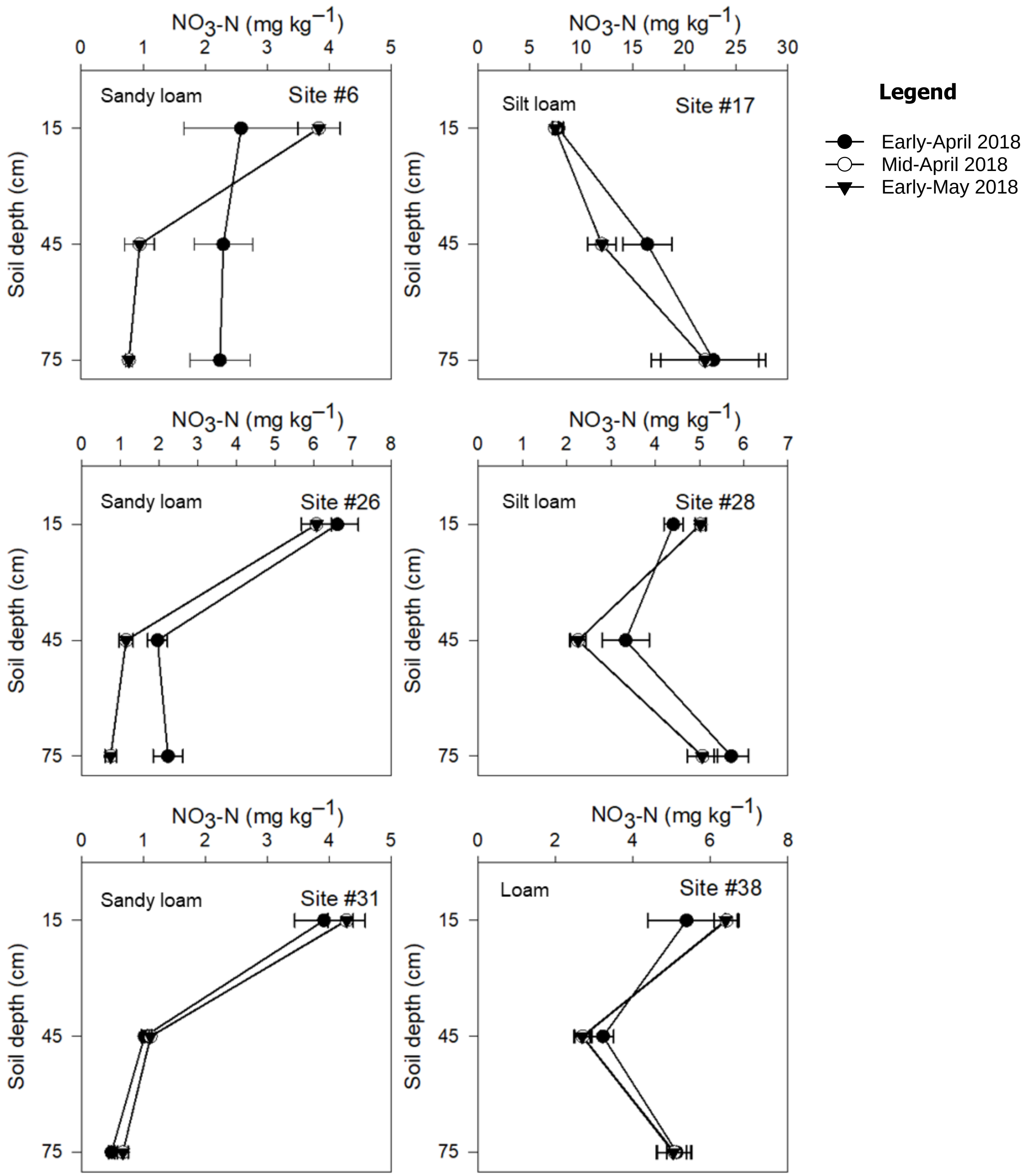

Figure 7. Changes during the spring of 2018 in soil nitrate-nitrogen (NO_3-N) concentrations at six sites, at the midpoint of the 0-30, 30-60, and 60-90 cm layers. The soil textural class describes the 0-30 cm layer. Error bars represent standard deviations.

In addition to soil texture or K_{sat}, the weather also influences the depth to which nitrate leaches. The Hullcar Valley received nearly 50% (85 to 90 mm) more precipitation from November to February in 2017/18 compared to the 1980-2010 average or the previous winter in 2016/17. Unlike in 2017/18, nitrate did not leach below the 60-cm depth over the winter of 2016/17 at four Benchmark sites, including the two alfalfa sites monitored in 2017/18 (Poon and Code 2017). Kowalenko et al. (2009) also observed that nitrate leaching was limited to within the top 60 cm in the North Okanagan at different sites over the non-growing season of 2007/08, when the weather was drier and closer to long-term average. The additional precipitation in the Hullcar Valley in 2017/18 compared to 2016/17 led to more snowmelt and percolation of water, as evidenced by the greater subsurface soil moisture in the spring at Site 17 (Table 6.3). However, precipitation amounts do not explain why nitrate concentrations in the 0-30 cm soil layer decreased from mid-October to mid-November in 2017 across the Benchmark sites, since the fall of 2017 had less precipitation than average. During the fall of 2017, soil nitrate may have transformed within the root zone, rather than being lost from the root zone. This explanation is consistent with the lack of a net loss of nitrate at the sites of finer-textured soil over the entire non-growing season, based on the estimated soil bulk densities (Table 1) and observed nitrate concentrations. Immobilization of soil nitrogen during soil freeze-up is possible (Cookson et al. 2002; Drury et al. 2016) and would have transformed nitrate into organic nitrogen, at least temporarily during the monitoring period.

Across the Hullcar Valley, most if not all residual nitrate remaining in the soil after the 2017 growing season leached below the primary root zone (60 cm depth) before it was available for crop uptake in 2018. However, the risk to groundwater quality from nitrate leaching was low in most fields since residual nitrate concentrations were low across most fields. Likewise, the average ammonium-N concentration (not shown) at all Benchmark sites was only 1 mg N kg^{-1} in any soil layer tested in October 2017, so ammonium leaching was not evaluated.

4 Conclusions

Overall, producers managed N optimally in most fields in 2017 and there was less post-harvest (residual) soil nitrate in 2017 than in 2016. Although nitrate leached to a shallower depth at sites with finer-textured soil, weather conditions during the 2017-18 winter caused a significant portion of the residual nitrate to leach below the root zone by the spring of 2018 at six sites. Results of the six sites can likely be extended to all fields in the Hullcar Valley, but not to every year or every non-growing season. In this study region, soil properties and weather conditions need to be factored into predictions of the amount of nitrate leached from the root zone in this region, rather than assuming that all or none of the nitrate will be leached over a non-growing season. The PHNT has been assumed to represent the amount of plant-available soil nitrate at the start of the following growing season in dry and cold climates. However, results suggest that the North Okanagan region may be too wet to be considered “dry and cold” in years with above-average amounts of spring snowmelt. Regardless of winter weather conditions in the future, it would be prudent to continue to minimize the amount of residual nitrate at the end of every growing season.

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6 Appendices

6.1 Post-Harvest Soil Testing

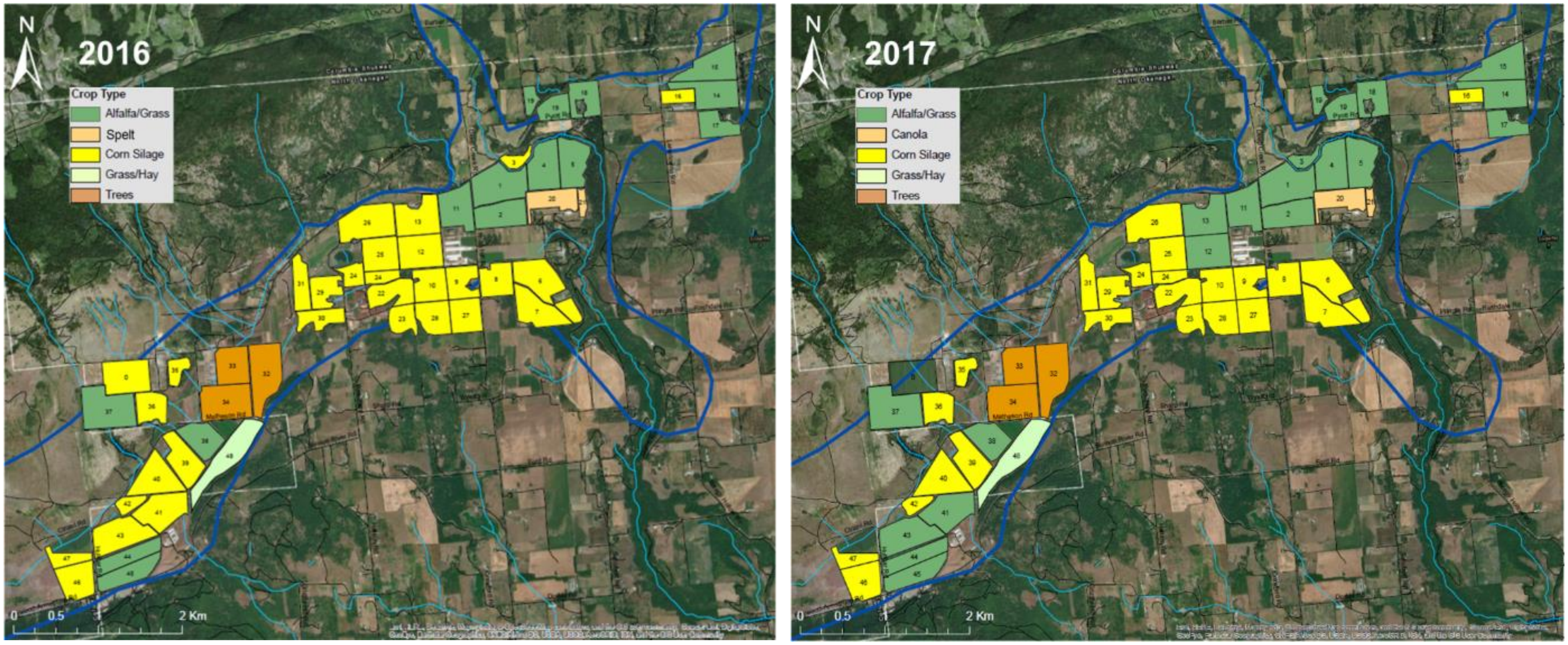

Figure 6.1. Crop types during the 2016 and 2017 growing seasons in the study area, in relation to Aquifer 103 (blue outline). The numbers represent the sampling areas that were sampled in 2017, and the numbering system differs from that used by Poon and Code (2017) in 2016. "Field 0" was sampled only in 2016.

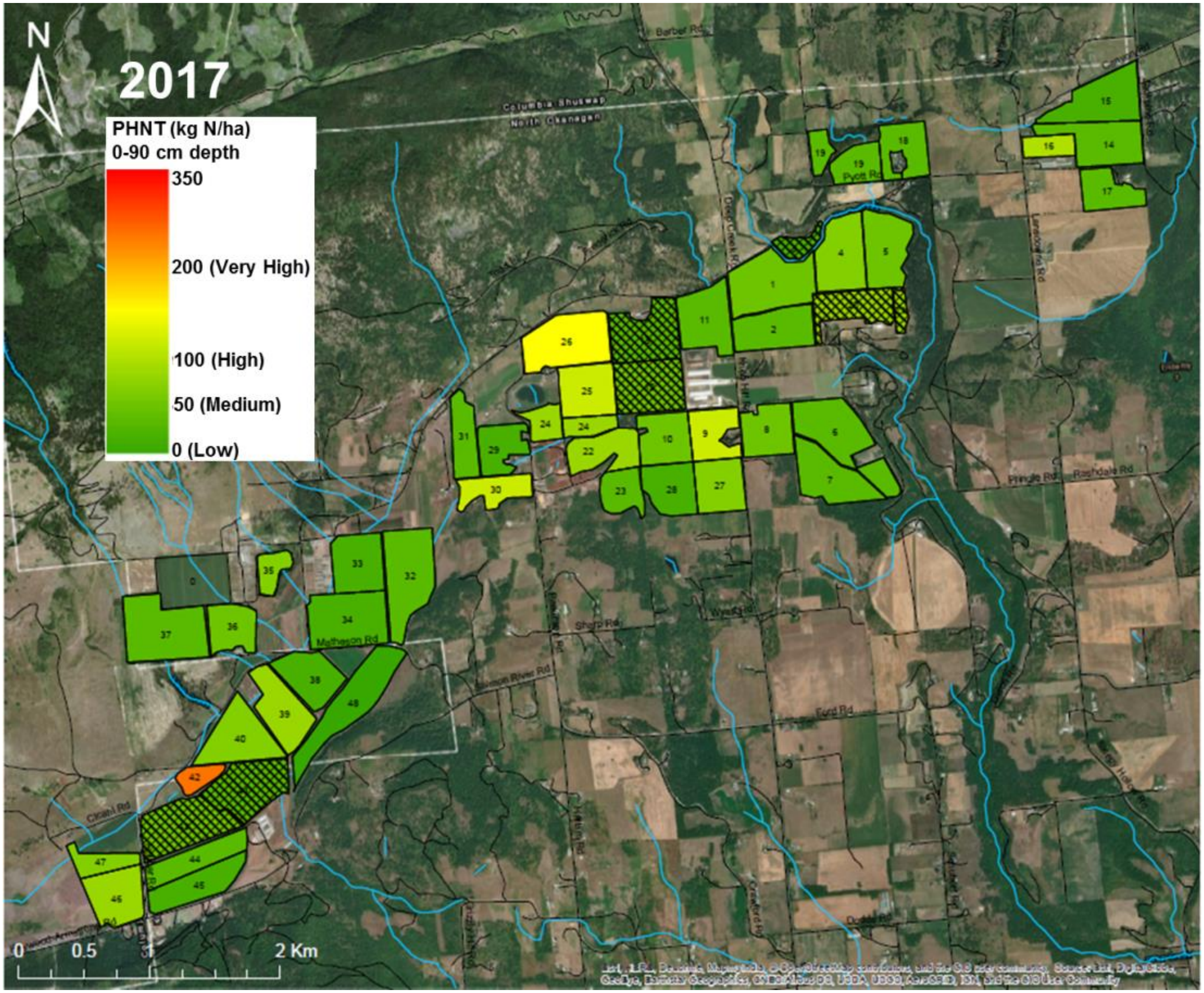

Figure 6.2. Post-Harvest Nitrate Test (PHNT) levels in fall of 2017. Sampling areas with a cross-hatch pattern had a different crop type in 2016 than in 2017. The polygons (and numbers) indicate the sampling areas in 2017.

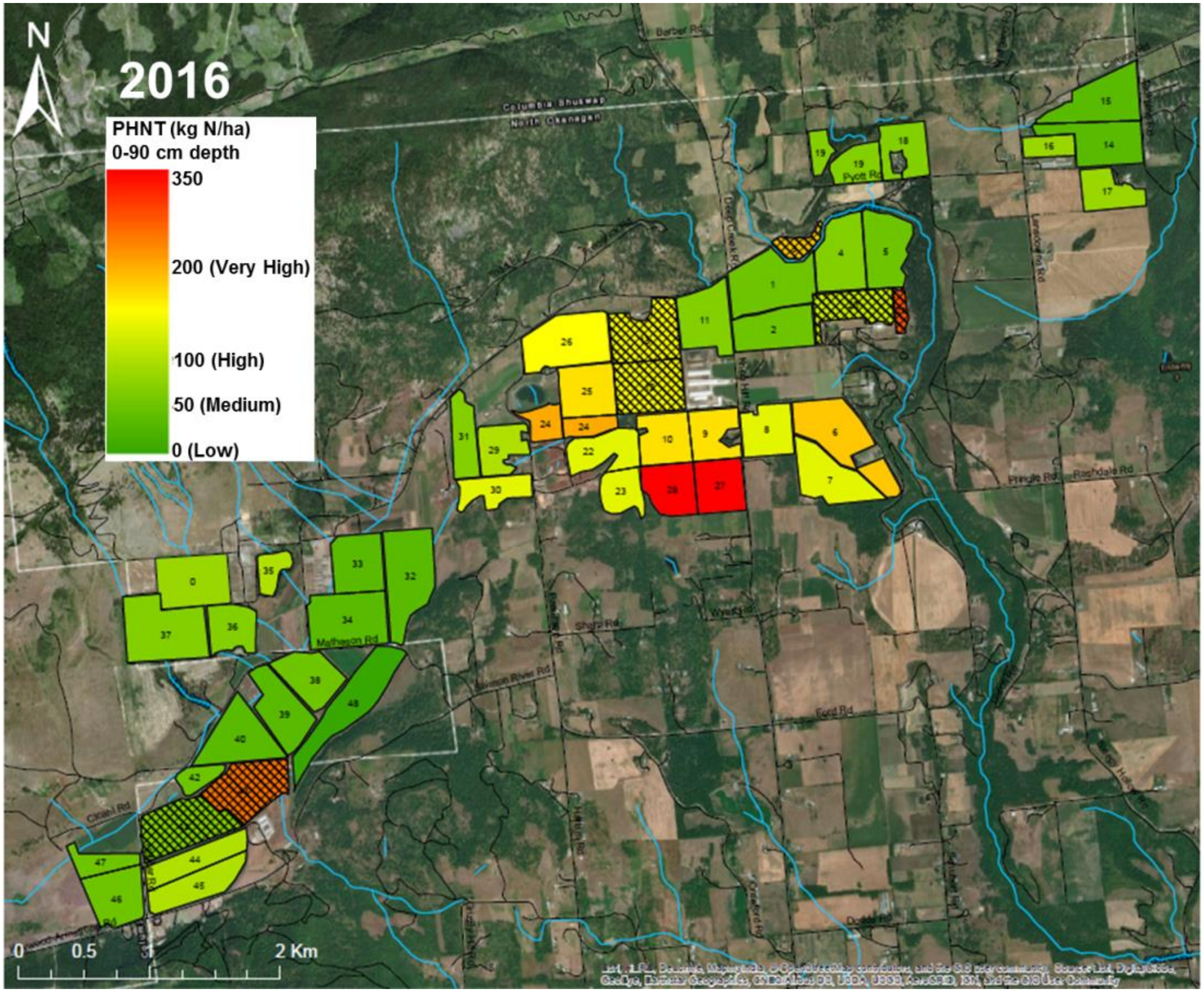

Figure 6.3. Post-Harvest Nitrate Test (PHNT) levels in fall of 2016. Sampling areas with a cross-hatch pattern had a different crop type in 2017 than in 2016. The polygons (and numbers) indicate the sampling areas in 2017.

Table 6.1. 2017 Post-Harvest Nitrate Test (PHNT) levels in fields that were split into two sampling areas.

Paired Sampling Areas				Fields (Combined Sampling Areas[a])		
Sampling Area #	Area (ha)	PHNT kg NO_3-N ha^{-1}	Agronomic PHNT rating[b]	Field	PHNT kg NO_3-N ha^{-1}	Agronomic PHNT rating
9	13	131	High	9&10	94	Medium
10	15	62	Medium			
12	20	54	Medium	12&13	49	Low
13	21	45	Low			
14	20	48	Low	14&15	38	Low
15	21	28	Low			
18	14	45	Low	18&19	40	Low
19	15	36	Low			
22	15	93	Medium	22&23	71	Medium
23	10	40	Low			
27	15	74	Medium	27&28	47	Low
28	15	20	Low			
33	17	25	Low	33&34	22	Low
34	24	20	Low			
44	14	40	Low	44&45	29	Low
45	16	20	Low			
46	17	97	Medium	46&47	92	Medium
47	8	82	Medium			

a. The PHNT results are area-weighted averages of the two sampling areas of a field

b. Ratings: 0-49 kg N ha^{-1}, Low; 50-99 kg N ha^{-1}, Medium; and 100-200 kg N ha^{-1}, High

6.2 Benchmark Testing

Table 6.2. Change in soil nitrate-nitrogen concentrations (mg kg^{-1}) over 2017/18, at six Benchmark sites with varying soil texture in the 0-30 cm layer.

	Soil layer		
Date	0-30 cm	30-60 cm	60-90 cm
Site 6 (sandy loam)			
06-Oct-17	6.7a[z]	3.0ab	3.4a
31-Oct-17	7.3a	1.0b	4.3a
16-Nov-17	4.5ab	4.0a	4.2a
04-Apr-18	2.6b	2.3ab	2.2ab
12-Apr-18	3.8b	0.94b	0.77b
04-May-18	3.8b	0.94b	0.77b
Site 17 (silt loam)			
18-Oct-17	32.3a	3.4b	2.3b
31-Oct-17	32.8a	1.5b	1.5b
15-Nov-17	2.0b	2.1b	1.0b
04-Apr-18	7.8b	16.4a	22.8a
13-Apr-18	7.5b	12.0a	22.0a
04-May-18	7.5b	12.0a	22.0a
Site 26 (sandy loam)			
13-Oct-17	14.0a	1.9a	1.0a
30-Oct-17	14.9a	1.6a	0.75a
16-Nov-17	3.7c	2.9a	2.4a
04-Apr-18	6.6b	2.0a	2.2a
13-Apr-18	6.1b	1.2a	0.76a
03-May-18	6.1b	1.2a	0.76a
Site 28 (silt loam)			
13-Oct-17	8.3a	1.2bc	2.0b
30-Oct-17	7.2a	0.6c	1.8b
16-Nov-17	1.7c	1.2bc	1.3b
04-Apr-18	4.4b	3.3a	5.7a
13-Apr-18	5.0b	2.3ab	5.1a
03-May-18	5.0b	2.3ab	5.1a
Site 31 (sandy loam)			
06-Oct-17	4.5a	0.87bc	0.32a
30-Oct-17	4.1ab	0.32c	0.36a
15-Nov-17	1.9c	1.6a	0.84a
04-Apr-18	3.9b	1.0b	0.49a
12-Apr-18	4.3ab	1.1b	0.67a
04-May-18	4.3ab	1.1b	0.67a
Site 38 (loam)			
16-Oct-17	4.2bc	0.62b	0.87b
30-Oct-17	3.5c	0.45b	0.41b
15-Nov-17	1.9d	1.1b	0.88b
04-Apr-18	5.4ab	3.2a	5.1a
12-Apr-18	6.4a	2.7a	5.1a
04-May-18	6.4a	2.7a	5.0a

z. Values within each soil layer followed by the same letter are not significantly different ($P<0.05$) according to Least Square Means test.

Table 6.3. Change in percent field moisture (%) over 2017/18, at six Benchmark sites.

		2017/18				**2016/17**	
		Soil layer				Soil layer	
Date	0-30 cm	30-60 cm	60-90 cm	Date	0-30 cm	30-60 cm	60-90 cm
Site 6 (not tested in 2016/17)				**Site 10 (not tested in 2017/18)**			
06-Oct-17	10.7	8.6	11.0	27-Oct-16	24.6	17.1	11.4
31-Oct-17	12.8	9.6	9.8	22-Nov-16	26.9	18.0	13.3
16-Nov-17	19.8	8.8	8.4	21-Mar-17	35.3	17.7	14.0
04-Apr-18	33.1	21.9	20.2	12-Apr-17	22.8	16.6	13.7
12-Apr-18	25.0	20.8	19.4				
04-May-18	19.4	15.8	15.2				
Site 17 (Site 37 in 2016/17)				**Site 23 (Site 38 in 2017/18)**			
18-Oct-17	13.0	11.9	14.2	13-Oct-16	23.9	10.8	11.7
31-Oct-17	15.2	12.5	14.0	22-Nov-16	29.3	17.3	14.0
15-Nov-17	19.8	12.8	13.9	23-Mar-17	38.7	18.6	21.2
04-Apr-18	31.9	32.9	35.2	12-Apr-17	25.7	19.6	21.5
13-Apr-18	28.5	33.5	36.7				
04-May-18	24.3	28.8	35.3				
Site 26 (not tested in 2016/17)				**Site 34 (not tested in 2017/18)**			
13-Oct-17	21.8	12.0	5.3	11-Oct-16	29.3	20.4	18.3
30-Oct-17	22.4	11.9	5.8	22-Nov-16	30.5	23.7	20.2
16-Nov-17	19.2	11.9	7.6	21-Mar-17	38.9	26.9	25.8
04-Apr-18	29.2	14.9	9.6	12-Apr-17	27.3	25.5	25.3
13-Apr-18	24.0	13.2	7.4				
03-May-18	20.6	12.6	6.7				
Site 28 (not tested in 2016/17)				**Site 37 (Site 17 in 2017/18)**			
13-Oct-17	11.9	6.6	5.4	13-Oct-16	15.4	6.5	5.1
30-Oct-17	13.1	6.5	5.7	22-Nov-16	22.1	16.0	6.0
16-Nov-17	20.1	6.4	5.3	23-Mar-17	29.6	18.1	15.2
04-Apr-18	31.7	24.1	23.9	12-Apr-17	23.8	18.0	14.6
13-Apr-18	26.1	22.9	24.0				
03-May-18	19.1	20.8	21.8				
Site 31 (not tested in 2016/17)							
06-Oct-17	17.8	8.2	4.7				
30-Oct-17	20.8	9.2	4.9				
15-Nov-17	19.9	10.9	6.8				
04-Apr-18	27.9	12.5	7.1				
12-Apr-18	23.4	12.2	6.6				
04-May-18	18.0	9.3	5.4				
Site 38 (Site 23 in 2016/17)							
16-Oct-17	18.9	11.7	10.4				
30-Oct-17	21.7	11.4	10.6				
15-Nov-17	21.1	16.1	15.5				
04-Apr-18	25.3	19.7	20.7				
12-Apr-18	26.9	19.5	20.1				
04-May-18	23.9	18.2	20.0				