


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

2016 Post-Harvest Nitrate Study: Final Report

Growing Forward 2

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Short title: 2016 Post-Harvest Nitrate Study: Hullcar Valley

Final Report

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Disclaimer

Summary

To minimize the amount of nitrate that can leach into the nitrate-contaminated Aquifer 103 in the Hullcar Valley of the North Okanagan, it is important to understand where there are the greatest excesses of soil nitrate relative to crop needs. These excesses can be measured by the post-harvest nitrate test (PHNT). Forty agricultural fields in the Hullcar Valley were sampled to a depth of 90 cm for PHNT between September 30 and November 4, 2016. The post-harvest nitrate test (PHNT) values were 100 kg N ha^{-1} or greater in 45% of the fields sampled, indicating nitrogen (N) can likely be managed more efficiently on these fields. All but one of the fields with high PHNT values were planted to silage corn or cereals, and most of the other 40 fields were planted to alfalfa. The fields with higher PHNT values warrant priority consideration for review of N management practices and continued monitoring of post-harvest soil nitrate.

If the PHNT assesses the potential amount of nitrate that can leach, then weather conditions affect the extent to which that potential is realized. In a separate analysis, changes in soil nitrate concentrations were monitored from the time of PHNT sampling to the start of the next growing season in the Hullcar Valley, to determine the extent of nitrate leaching during this period. In this region, the annual precipitation is 480 mm and daily mean temperature in January is -2.3°C. Four benchmark sites (74 to 140 m^2 in area) were established within the areas of 4 of the 40 agricultural fields that were sampled for PHNT. Two sites were in established alfalfa fields and two sites had no established crop (harvested corn in 2016). Soil types ranged from sandy loam to silt loam. Four rounds of soil sampling were completed at each site during the October 2016 to April 2017 period, with samples collected from 0-30, 30-60, and 60-90 cm soil layers. Soil nitrate concentrations did not exceed 22 mg N per kg of soil in any of the three layers, in any round of sampling. Results indicated that soil nitrate did not leach from any soil layer at the two alfalfa sites, and that nitrate leached from the 0-30 cm to 30-60 cm soil layer in the harvested corn sites. At the soil nitrate concentrations observed, the PHNT soil test did not measure the risk of nitrate leaching below the root zone over the non-growing season in the Hullcar Valley.

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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. In some areas, there may be a time lag of several years between reductions in nitrate leaching from the root zone of soil and decreases in nitrate loading to the water table (Rudolph 2015). The duration of this time lag is an important consideration with respect to setting reasonable timelines for improvements in the aquifer's water quality. No matter the duration of the time lag, it is important to reduce nitrate leaching from the root zone.

In agricultural soils, the nitrate is present because of direct additions of nitrate to soil or because microbial processes transform other forms of soil nitrogen (N) into nitrate (Fig. 1). Nitrogen may be added to soil as a crop nutrient that is required by plants in large amounts, and crops take up N as nitrate from the soil root zone. In addition to plant uptake, microbes can 'immobilize' nitrate and make nitrate part of soil organic N, the largest portion of N in soil, or the nitrate can be lost from the root zone of the soil by leaching or by transformation into gases that escape into the atmosphere. Various factors control the rates of uptake, transformations, or losses of N. For example, favourable soil temperatures and moisture conditions during the growing season promote the microbial conversion of organic N to nitrate and the plant uptake of nitrate (biological processes). Rainfall or irrigation water favours nitrate leaching (physical process) any time the infiltrating water exceeds the water-holding capacity of soil or when the water flows through burrows or cracks in the soil (Jarvis 2007). The producer's goal is to manage nitrate for crop uptake or to keep nitrate in the soil root zone for later crop uptake.

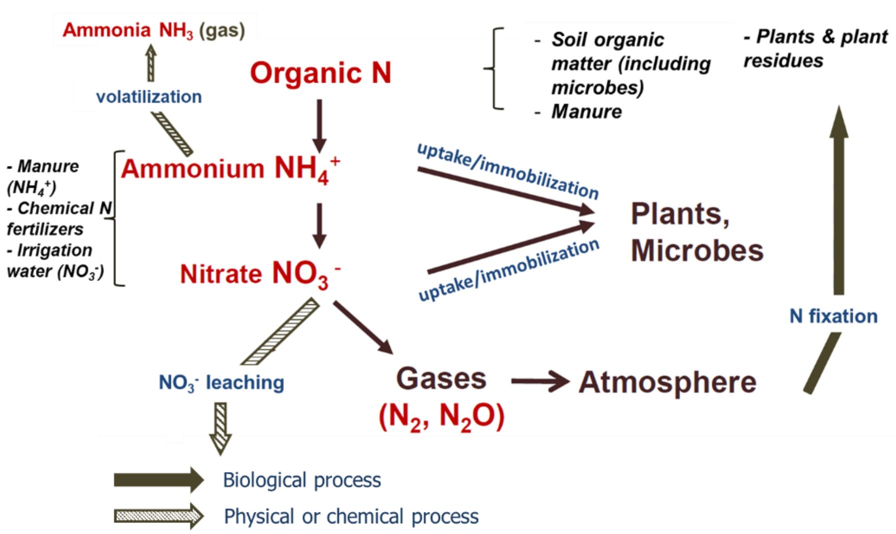

Figure 1. The major processes and forms of nitrogen (red text) in the nitrogen (N) cycle, including possible agricultural N inputs. Source: adapted from a presentation slide from Dr. Craig Cogger (2013).

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

The post-harvest nitrate test (PHNT) is a soil test that was developed to guide decisions about N management. A PHNT test is meant to measure the amount of excess soil nitrate not used by the recently harvested crop (i.e. the post-harvest soil nitrate). For silage corn and grass for hay or silage in coastal B.C., PHNT values that exceed a crop-specific target value can indicate that plant-available N exceeded crop uptake, that N was supplied too late for crop uptake, or that conditions limited crop N uptake (e.g., moisture stress, disease, etc.) (Sullivan and Cogger 2003; BC AGRI 2010). Differences in N uptake efficiency between crops explain why silage corn (78 kg N ha^{-1}) has a higher target value compared to forage grasses (62 kg N ha^{-1}), according to the guidelines for south coastal B.C. (Sullivan and Cogger 2003). Above these target values, reductions in N application rates should be considered. Indeed, silage corn fields had higher PHNT values than grass in Coastal B.C. (Kowalenko et al. 2007; Sullivan and Poon 2016) or alfalfa or alfalfa-grass mixes in the Okanagan Valley of B.C. (Kowalenko et al. 2009). Thus, it is reasonable to expect higher PHNT values for alfalfa than silage corn in the Hullcar Valley.

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. To summarize the relative distribution of PHNT results in a study of multiple cropped fields, rating categories are needed. Kowalenko et al. (2007) proposed 50, 100, and 200 kg N ha^{-1} as the lower limits for medium, high, and very high agronomic ratings of PHNT for field crops in general in South Coastal B.C. Among these limits, the 100 kg N ha^{-1} limit is the lowest value above which reductions in N application rates are recommended for corn and grass in South Coastal B.C. These agronomic ratings were more recently proposed for the Okanagan, where 32% of 56 fields that were mostly in forage crops and were sampled in the North Okanagan, had post-harvest nitrate levels that exceeded 100 kg N ha^{-1} in 2007 (Kowalenko et al. 2009). No matter how the rating categories are defined, knowing which fields have the greatest PHNT values allows the fields to be prioritized according to which deserve the most attention for N management (BC AGRI 2010). Then, for a given field, monitoring PHNT, crop yield and crop quality for year-to-year provides information to minimize excess nitrate over time without compromising crop production goals (BC AGRI 2010).

In addition to guiding decisions about crop N management, the PHNT can be used to measure environmental risk in areas that are humid with mild winters. In Coastal B.C., post-harvest soil nitrate can be assumed to be lost from the root zone if a cover crop is not established by the early fall, because of the region's climate (Kowalenko 2000). The rainfall that is expected to flow through the soil profile is close to 1000 mm of water across the Coastal B.C. region. In this amount of water, 100 kg N ha^{-1} that gets leached would result in 10 mg L^{-1} of N (the Canadian Drinking Water standard) (Kowalenko et al. 2007). Thus, the 100 kg N ha^{-1} is a meaningful PHNT level to measure nitrate leaching risk for Coastal B.C. It is also similar to the 90 kg N ha^{-1} target used in the Flanders region in Belgium (Geypens et al. 2005), another maritime temperate area with humid and mild winters.

In contrast with the B.C. Coast, determining environmental risk using the PHNT soil test is more challenging in regions with cold and dry winters like the Okanagan, because freezing conditions limit soil water movement for a significant part of the time when there is no crop N uptake. In the Lower Yakima Valley of Washington State, where winters can also be considered cold and dry, the PHNT target was effectively set at 350 kg N ha^{-1} in a 2013 order received by dairy operations to address nitrate contamination in groundwater (US EPA 2014). However, Kowalenko et al. (2009) caution against the use of PHNT values alone to describe the risk of nitrate leaching in the Okanagan. On two sites that were monitored, some but not all post-harvest soil nitrate apparently leached within and possibly below the 0-60 cm soil depth during the non-growing season in the North Okanagan, before winter freeze-up (Kowalenko et al. 2009). Apparent leaching below the 60 cm depth was observed during this period only when there were already significant amounts of nitrate (greater than 90 kg N ha^{-1}) in the 30-60 cm depth at the start of the non-growing season, possibly due to over-irrigation during the growing season (Kowalenko et al. 2009). Thus, while the occurrence of high soil permeability over significant portions of Aquifer 103 favours nitrate leaching, the climate in the North Okanagan limits the extent to which that potential is realized or the rate at which nitrate leaches. Therefore, it is unclear if the PHNT level, or the depth distribution of soil nitrate at post-harvest time, accurately indicates the amount of nitrate expected to leach below the root zone during the non-growing season in the Hullcar Valley.

One factor of uncertainty with estimating PHNT on a volume basis (kg N ha^{-1}) is the soil bulk density values that are needed to convert laboratory-measured concentrations of nitrate to kg N ha^{-1}. Soil bulk density is the mass per unit volume of soil, and it depends on soil texture, organic matter, and other factors. The bulk density of soils is usually assumed for soil nitrate testing rather than measured, because the variation in bulk density among mineral soils (as opposed to Organic soils) is typically small relative to the variation or error in soil nitrate sampling and testing (Sullivan and Cogger 2003). A common assumed value for bulk density in the plough layer (0-30 cm depth) is 1300 kg m^{-3}. In previous soil studies in B.C., a bulk density of 1100 kg m^{-3} or 1200 kg m^{-3} was assumed for soil in the 0-60 cm depth (Kowalenko et al. 2007; Kowalenko et al. 2009; Sullivan and Poon 2016). Another way to estimate soil bulk density is to do so for each soil layer measures, using soil textural class (Geypens et al. 2005) and possibly data of other soil properties (Saxton and Rawls 2006).

This report addresses the need to better understand 1) the percentages of fields with different levels of PHNT, to help guide 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 between growing seasons in the Hullcar Valley, to determine if the PHNT soil test has environmental interpretations in this region.

Primary Questions

1. Overlying Aquifer 103 and the nearby area, how many agricultural fields had elevated levels of PHNT in the 0-90 cm depth of soil?
2. Did nitrate leach through the 0-90 cm depth of soil between growing seasons, in the area overlying Aquifer 103?

Secondary questions included the following:

- Did N management practices predict PHNT levels?
- What was the effect of different bulk density values on PHNT values?

Hypotheses

1. Most agricultural fields in the area will be found to have less than 100 kg N ha^{-1} of PHNT (0-90 cm soil depth) in 2016, based on previous PHNT results in corn and perennial forage fields in the North Okanagan.
2. Because soil nitrate can apparently leach within and below the 60 cm soil depth in cropped fields in the North Okanagan during the fall before winter freeze-up, soil nitrate will be found to have leached through the top 90 cm of soil over the 2016/17 non-growing season, as indicated by a decrease in surface soil nitrate concentrations and an increase in subsurface soil nitrate concentrations.

Out of scope

The following were not included in this study:

- Non-cropped areas that can be sources of N or nitrate leaching (e.g., manure storages)
- The period corresponding to the growing season, when crop growth or operations in the field (e.g., tillage, planting, or nutrient application) affect soil nitrate concentrations.
- N transformation processes (e.g., conversion of organic N to nitrate) that explain changes in soil and water nitrate concentrations
- Soil water movement, which is beyond what soil testing alone measures

2 Materials and Methods

Study area

The study area was in the Hullcar Valley of the North Okanagan, mostly overlying Aquifer 103, south of Grindrod, B.C. 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 study period (Sep 30, 2016 to April 12, 2017) differed from the long-term average (1981-2010). The fall of 2016 was rainier and warmer than in most years, the December 2016 to February 2017 period was snowier and colder than average, and the last two weeks of the study period were wet and rainy (Figs. 2 and 3):

- approximately twice as much rain fell in October 2016 as the long-term monthly average
- the November 2016 precipitation was close to the average; however, it fell mostly as rain instead of snow as in the average year
- November 2016 was warmer than average
- March 2017 had more snow and precipitation than average
- rainfall in the first 11 days of April 2017 was about the same amount (25 mm) as in all of April on average.

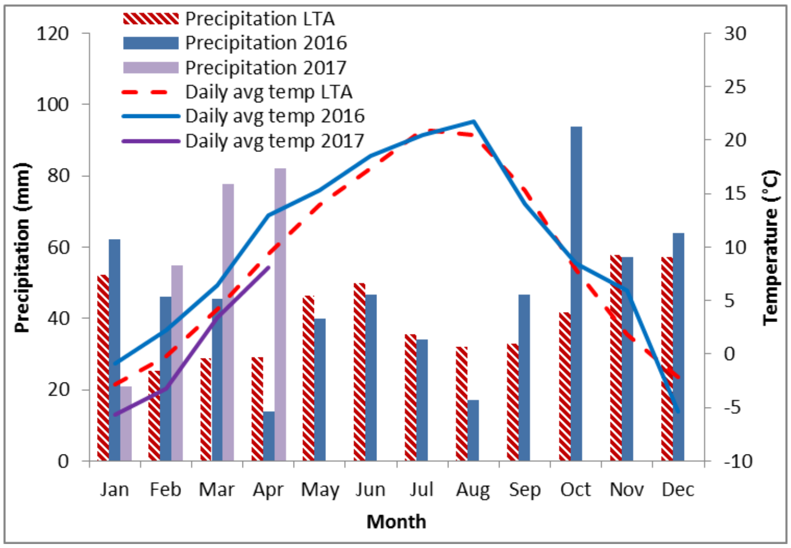

Figure 2. Average daily air temperature and total precipitation by month, compared to the long-term average (1980-2010, LTA) at the North Vernon weather station (50.34, -119.27, 538 m elevation) from January 2016 to April 2017.

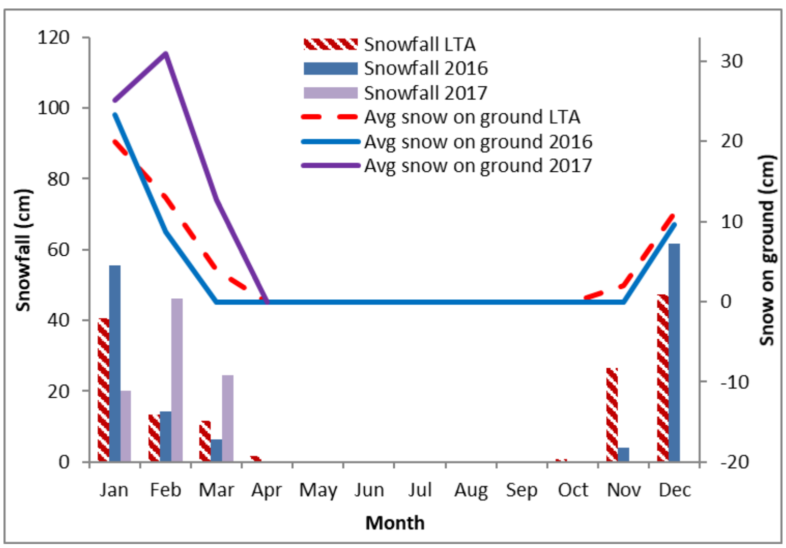

Figure 3. Average snow on ground and total snowfall by month, compared to the long-term average (1980-2010, LTA) at the North Vernon weather station (50.34, -119.27, 538 m elevation) from January 2016 to April 2017.

2.1 Post-Harvest Soil Testing

To determine the percentage of fields with elevated levels of soil nitrate, 40 fields that covered 820 ha and were managed by five agricultural operations were selected in the area over or near Aquifer 103 (Fig. 4). Each of the 40 fields were up to 40 ha in area, 90% of them were under 30 ha, and each was managed uniformly by the producers. Most agricultural fields over the mapped outline of Aquifer 103 were sampled, as well as fields outside the boundary of the aquifer. The sampled area was mostly in corn (56% of the area sampled), whereas the dominant crop over the Aquifer was alfalfa or alfalfa-grass mix (46% of the cultivated area).

One composite soil sample was taken per field at the 0-15, 15-30, 30-60, and 60-90 cm soil depths, from September 30 to November 4, 2016. In each field, sampling occurred within a week of 2016's last harvest, which was later than in most years in some corn fields because of wet weather in October 2016. Each composite soil sample consisted of twenty 4.4-cm cores from randomly selected locations in the field and excluded vegetation or mulch at the soil surface. The samples were refrigerated for up to 3 days until they reached A&L Canada Laboratories (London, ON), where potassium-chloride extractions were then done on air-dried and sieved (<2 mm) samples. Extractable nitrate concentrations were analyzed and provided on an oven-dry basis.

Information about N management practices (manure application rates from 2014 to 2016, N fertilizer application rates in 2016, and previous crop in 2015) was collected for each field. The collected information was then converted to estimates of plant-available N in 2016 for each field, so that it could be determined if there was a relationship between major plant-available N credits and PHNT results.

The uncertainty with soil bulk density values was considered for its effect on the variation of PHNT estimates on a volume basis (kg N ha^{-1}) and for their distribution in the proposed rating categories. Initially, a bulk density of 1150 kg m^{-3} was assumed for each soil layer (BC AGRI 2017) in accordance with previous surveys of post-harvest soil nutrients (Kowalenko et al. 2009; Sullivan and Poon 2016). In this report, 1300 kg m^{-3} was assumed for the 0-30 cm soil layer and 1500 kg m^{-3} was assumed for the 30-60 cm and 60-90 cm soil layers. These bulk density values were estimated from particle size and organic matter content of soils at sites in four of the 40 fields, and the four sites are described in Section 3.2. To describe the relative distribution of results, the agronomic ratings from Kowalenko et al. (2007 and 2009) were used to summarize the PHNT results (low, 0-49 kg N ha^{-1}; medium, 50-99 kg N ha^{-1}; high 100-200 kg N ha^{-1}; very high, greater than 200 kg N ha^{-1}).

2.2 Benchmark Testing

Four Benchmark sites were established for four rounds of soil sampling in the Hullcar Valley in B.C., from October 11, 2016 to April 12, 2017 (Fig. 4). The sites were approximately rectangular in shape and ranged from 74 to 140 m^2 in area. Each site was established in one of the 40 fields from the Post-Harvest Soil Testing phase. The four 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 (Fig. 4). 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.

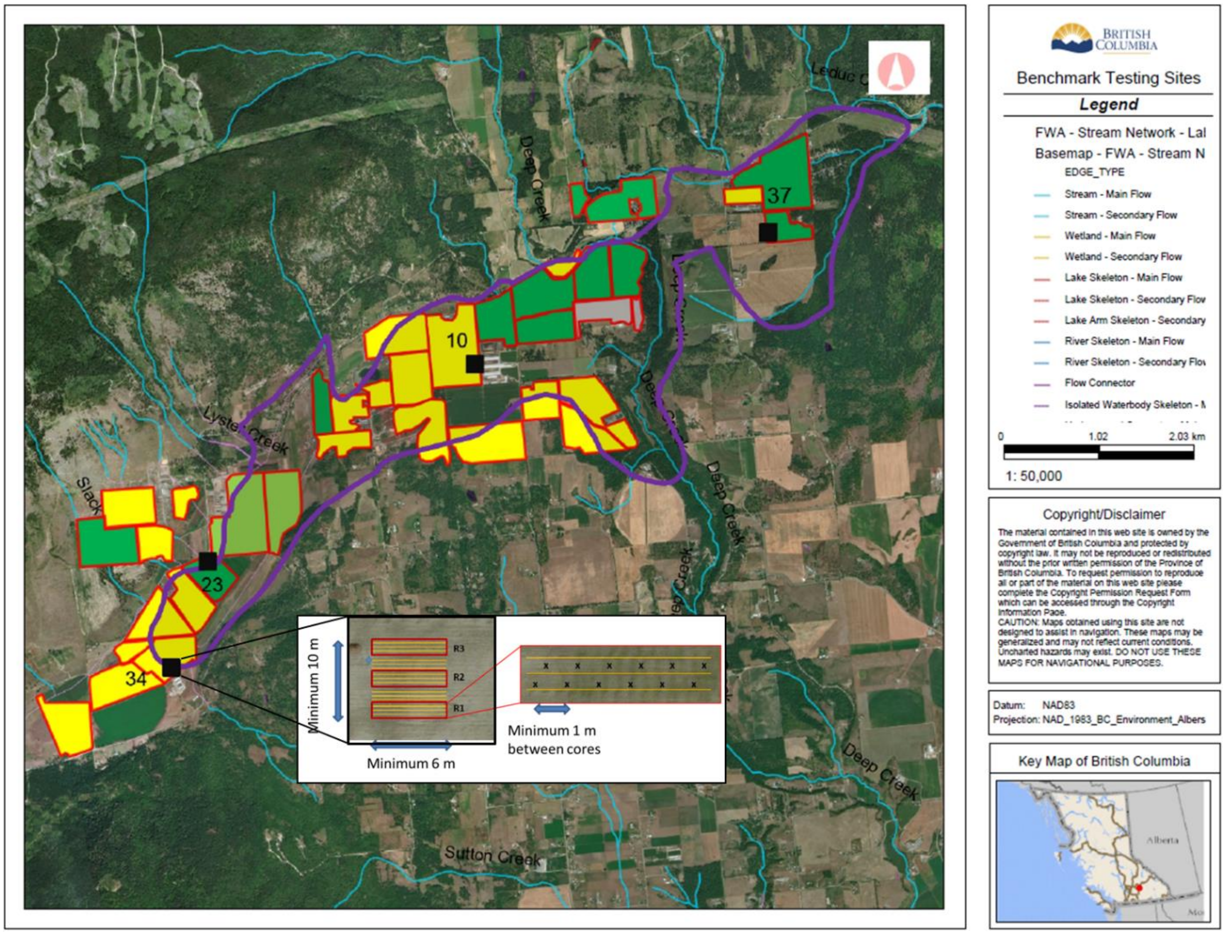

Figure 4. Locations of the four Benchmark Testing sites (black squares; enlarged for visibility), in relation to the field boundaries of fields sampled for post-harvest soil testing (red outline) and Aquifer 103 (purple outline). Colour denotes crop type: green, *alfalfa or grass*; light green, *nursery trees*; yellow, *silage corn*; grey, *spelt (cereal)*. Inset: locations of soil sampling cores (x) within each of 3 replicate blocks (R1, R2, R3) of a Benchmark site.

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 10					
0-30 cm	75%	9.0%	Sandy loam	3.95	1.37
30-60 cm	74%	10%	Sandy loam	1.31	1.54
60-90 cm	82%	5.1%	Loamy sand	0.89	1.53
Site 23					
0-30 cm	33%	20%	Loam	6.45	1.12
30-60 cm	31%	26%	Loam	1.51	1.46
60-90 cm	25%	34%	Clay loam	1.38	1.42
Site 34					
0-30 cm	41%	21%	Loam	5.64	1.22
30-60 cm	50%	20%	Loam	1.22	1.54
60-90 cm	55%	14%	Sandy loam	0.88	1.57
Site 37					
0-30 cm	34%	10%	Silt loam	2.50	1.42
30-60 cm	35%	9.4%	Silt loam	0.96	1.56
60-90 cm	53%	5.1%	Sandy loam	0.90	1.57

All of the Benchmark sites were irrigated during the growing season. During the sampling period, the sites had no crop (harvested corn) or alfalfa (Table 2), and there were no harvest, tillage, or planting operations during the sampling period. None of the sites received manure, chemical fertilizer or other soil amendments after the spring 2016 applications of manure, until after the end of the sampling period.

Table 2. Management practices and sampling times in the four Benchmark sites.

Site	2016 crop (date of last harvest in 2016)	Previous crop in 2015	Estimated yield (dry tonnes ha^{-1})	Spring Manure Application Rates (wet basis)	Sampling Date			
					Mid Oct 2016	Mid Nov 2016	Mid Mar 2017	Mid Apr 2017
10	Corn (Oct 25)	Corn	18	56,000 L ha^{-1} dairy	Oct 27	Nov 22	Mar 21	Apr 12
23	Alfalfa (Oct 12)	Alfalfa	14	67 tonnes ha^{-1} beef feedlot	Oct 13	Nov 22	Mar 23	Apr 12
34	Corn (Sep 20)	Corn	16	None	Oct 11	Nov 22	Mar 21	Apr 12
37	Alfalfa (Oct 6)	Barley	14	112,000 L ha^{-1} dairy	Oct 13	Nov 22	Mar 23	Apr 12

The period of sampling varied somewhat between sites, with samples taken in mid-October and mid-November of 2016, followed by winter freeze-up, and then samples were taken in mid-March when the sampled soils were partially frozen and mid-April of 2017 after soil frost had thawed (Table 2). The samples were refrigerated or on ice in a cooler for up to 3 days before they were air-dried in the laboratory. Extractions were done on air-dried and sieved (<2 mm) samples. Potassium chloride (KCl)-extractable nitrate was measured (Kowalenko et al. 2009). Concentrations of nitrate were converted to an oven-dry basis, and concentrations that were less than the detection limit of the instrument were assumed to be zero for the data analysis.

Nitrate-N data were analysed separately for the four 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

Results supported the hypothesis that most fields (55%) had less than 100 kg N ha^{-1} PHNT (0-90 cm sample depth), the proposed threshold for 'high PHNT' (Fig. 5a; Appendix 6.1). More fields had a medium PHNT rating (50-99 kg N ha^{-1}) than any other rating, and three of 40 fields had a very high PHNT rating or more than 200 kg N ha^{-1} (Fig. 5a). None of the fields had a PHNT value that exceeded the 350 kg N ha^{-1} target that was set in a 2013 order to dairies in the Yakima Valley of Washington State (US EPA 2014). Using the 100 kg N ha^{-1} threshold that indicates most clearly there was excess plant-available N, there were three groups of results:

- Annual crops, harvested and sampled earlier (before October 13, 2016): among annual crop fields, 8 of the 13 that were sampled between September 30 and October 13, 2016 had less than 100 kg N ha^{-1} PHNT
- Annual crops, harvested and sampled later (after October 13, 2016): among annual crop fields, 12 of the 13 that were sampled between October 25 and November 4, 2016 had greater than 100 kg N ha^{-1} PHNT
- Perennial crops, harvested and sampled earlier (before October 13, 2016): among perennial crops, all were sampled between September 30 and October 13, 2016 and 13 of the 14 had less than 100 kg N ha^{-1} PHNT

Annual versus Perennial Crops

A difference in the average PHNT value (kg N ha^{-1}) between the two groups that were sampled early was expected because of the greater efficiency of perennial forage crops with N uptake relative to corn and cereals (Fig. 5a). Among the 'early sampled fields,' the 13 fields in annual crops had on average 108 kg N ha^{-1} and the 14 perennial forage fields had on average

68 kg N ha^{-1}. Greater PHNT values have been consistently observed for silage corn compared to intensively managed perennial forages in different agricultural regions of B.C. (Kowalenko et al. 2007; Kowalenko et al. 2009; Sullivan and Poon 2016). The apparent difference between crop groups is consistent with the expected patterns of N uptake and soil nitrate accumulation between crop types. Whereas corn typically stops taking up N about 4 weeks before harvest (or more if harvest is delayed), the alfalfa or grass crops can continue to take up N after final crop harvest (Sullivan and Cogger 2003). The PHNT for corn reflects not only the balance between the N supply from the producer and crop uptake, but also the net additions of nitrate to the soil from microbial activity late in the growing season after corn N uptake is complete. Thus, it was reasonable for target values of PHNT for the Hullcar Valley to be higher for the corn and cereal crops than for the alfalfa and grass crops.

Earlier versus Later Sampled Fields of Annual Crops

Among all 26 fields with annual crops in 2016, the nitrate in the 60-90 cm layer as a proportion of the total nitrate in the top 90 cm tended to increase, from 7 to 36%, with increases in PHNT (kg NO_3-N ha^{-1}) in the top 90 cm (Fig. 5a, 5b). In the 2007 Okanagan Agricultural Soil Study, post-harvest nitrate testing to a depth of 60 cm was apparently too shallow in some fields because it excluded nitrate that had leached below 60 cm prior to sampling, probably due to irrigation and precipitation during the growing season (Kowalenko et al. 2009). Alternatively, some of the nitrate in the 60-90 cm layer in this study could have originated from leaching that happened more than one year prior to sampling. In either case, the bulk of mature corn and cereal roots extend down to 90 cm and these roots can take up soil water and nitrate regardless of whether it was from previous years, although the effectiveness of nitrate uptake decreases at greater depth (Fan et al. 2016). Thus, sampling to a 90 cm depth as in Belgium (Geypens et al. 2005) was appropriate in this study to describe the amount of nitrate not used by the crop, particularly if a field had high PHNT values.

The later-sampled annual crop fields had greater PHNT values (0-90 cm) than the earlier-sampled annual crop fields (Fig. 5a). The later-sampled group had an average PHNT of 169 kg N ha^{-1} PHNT with a median value of 158 kg N ha^{-1}, and the early-sampled group had an average PHNT of 108 kg N ha^{-1} and a median value of 82 kg N ha^{-1}. During the period between sampling of the two groups, there was time for microbial activity to increase the amount of soil nitrate. However, it was unlikely that this microbial activity explained the greater PHNT values in the later-sampled group relative to the earlier-sampled group. In the later-sampled group, the amount of nitrate was greater in all soil layers compared to the earlier-sampled group. Since the organic matter in the subsurface layers was low compared to the 0-30 cm layer in all fields (BC AGRI 2017), nitrate in the subsurface 30-60 and 60-90 cm layers was likely a result of nitrate leaching from the surface layer rather than a result of microbial activity. Thus, the PHNT results of the later-sampled and earlier-sampled annual crops can be compared despite the difference in sampling period between the two groups.

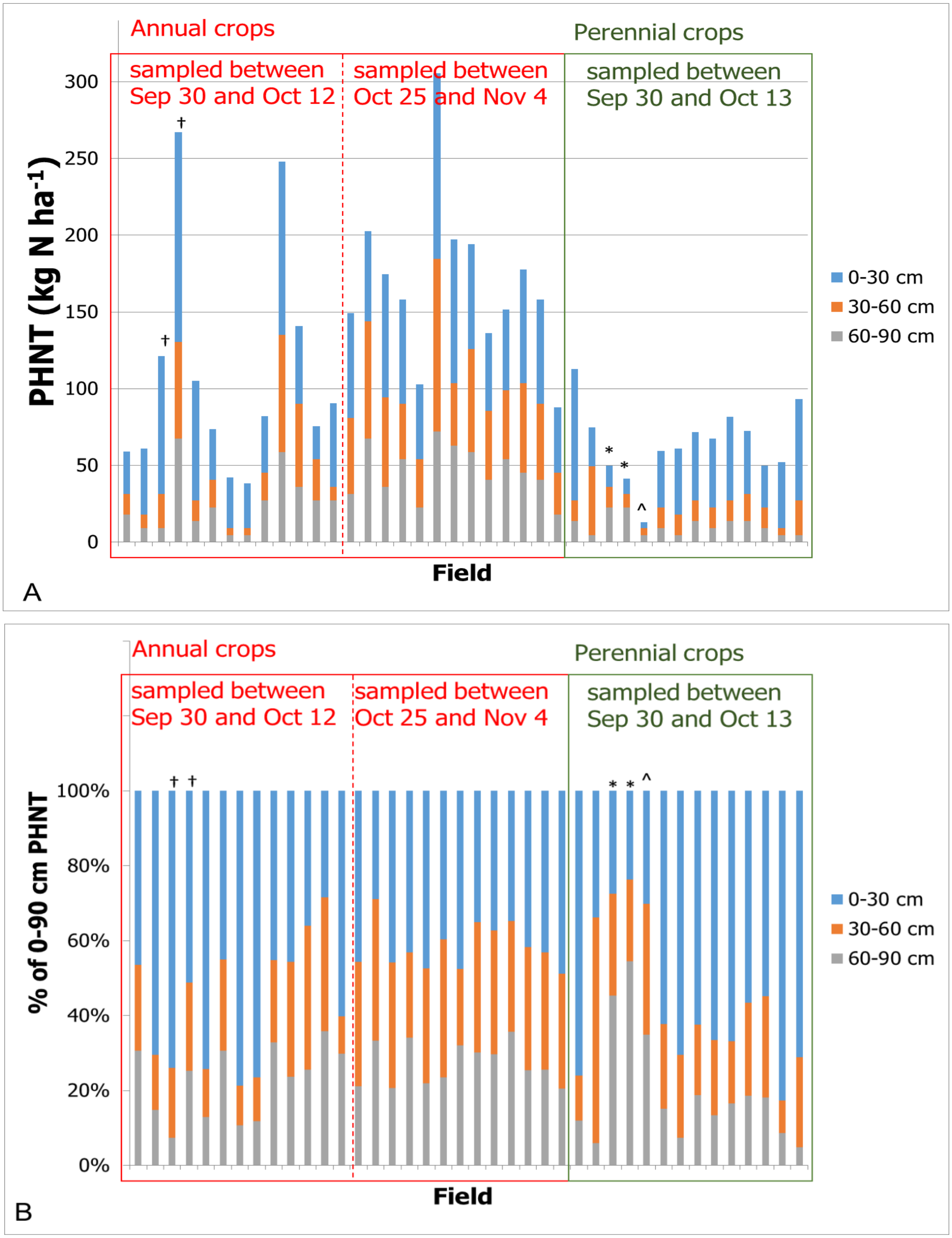

Figure 5. Distribution by depth of A) post-harvest nitrate test (PHNT, kg N ha^{-1}) and B) percentage distribution of soil nitrate, for 40 fields. Annual crops included silage corn and cereals (†), and perennial crops included alfalfa, nursery trees (*), and pasture grass (^).

Effect of Nitrogen Management Practices on PHNT in Corn Fields

The difference in PHNT values between earlier and later-sampled annual crop fields was not likely due to the different times of sampling, but the difference was partly explained by reported N management practices (Fig. 6). Among the 24 corn fields sampled, which were assumed to have similar crop N uptake efficiencies, the PHNT value tended to increase with increasing supply of plant-available N in a weak but significant relationship (Fig. 6, $p = 0.003$, $r^2 = 0.33$). Estimates of plant available N were based on reported manure and N fertilizer applications, as well as whether the 2015 crop was a legume that provided N to the 2016 corn field (Appendix 6.2). Other potential N sources such as soil organic matter were excluded and could have contributed significant rates of plant-available N to each field. The use of literature values for manure nutrient content in many cases, instead of laboratory analyses, contributed to uncertainty in the absolute values of estimated plant available N (kg N ha^{-1}). An alternative approach to predicting residual N is to consider the effects of crop N removal in harvested yields on the overall N balance (Drury et al. 2007). However, the variation in harvested yields was small (26 tonnes ha^{-1}; standard deviation of 1.4 tonne ha^{-1} (fresh weight)) compared to the variation in plant-available N, so accounting for yield data did not improve the relationship between plant available N and PHNT (data not shown). Thus, high rates of plant available N partly explained the high PHNT values in the later-sampled corn fields.

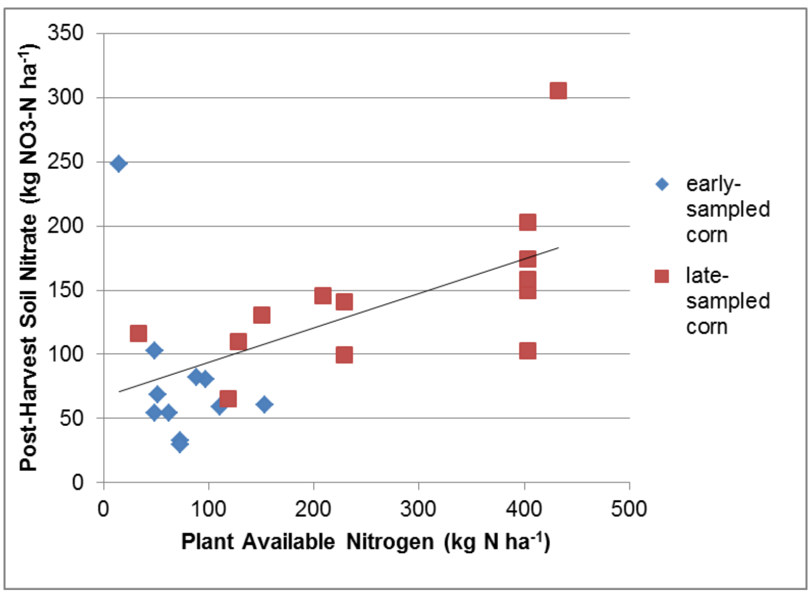

Figure 6. Post-harvest soil nitrate in the 0-90 cm depth increased with increasing supply of plant availabe nitrogen to corn fields, regardless of the sampling period (early, between September 30 and October 12, 2016; late, between October 13 and November 4, 2016).

Soil Bulk Density Values and Implications for Interpretations

As indicated earlier, higher soil bulk density values were used in this report than the 1150 kg m^{-3} used initially (BC AGRI 2017). The increase in the assumed bulk density values resulted in PHNT estimates (kg N ha^{-1}, 0-90 cm depth) that were 21% greater on average than initially reported. The differences in the PHNT estimates were greater for those fields in which nitrate concentrations in the 30-60 and 60-90 cm layers were higher. The proposed ratings of five fields increased by one category: two fields' ratings changed from low to medium and three from medium to high. However, as experience with PHNT testing and N management increases in the Okanagan, the agronomic ratings and their management suggestions should be reviewed to develop crop-specific target values in the region. Furthermore, the increase in the assumed bulk density values did not change the ranking of fields according to 2016 PHNT values. Thus, the increase in the assumed bulk density values did not change the decisions about which fields should receive the most attention to fine-tune N management efforts (e.g., additional soil testing, on-farm trials of different N rates, improvements in irrigation management).

3.2 Benchmark Testing

Results partially supported the hypothesis that nitrate leached during the non-growing season, but not below the 60 cm depth, and only in the harvested corn sites (Fig. 7; Appendix 6.3). Among the four Benchmark sites, there were different patterns of changes in soil nitrate concentrations at the 0-30 cm and 30-60 cm layers as the non-growing season progressed (Fig. 7). For sites #10 and #34 (harvested corn), soil nitrate concentrations in the 0-30 cm layer decreased as the non-growing season proceeded, from 21.0 mg N kg^{-1} soil in Mid-October 2016 to 12.8 mg N kg^{-1} in Mid-April 2017. During the same period, soil nitrate concentrations in the 30-60 cm layer increased as the non-growing season proceeded from 5.8 mg N kg^{-1} in Mid-October 2016 to 11.5 mg N kg^{-1} in Mid-April 2017. The increase in soil nitrate concentrations in the 30-60 cm layer during the non-growing season indicates a downward movement of nitrate from the surface layer. The soil nitrate concentration at the 60-90 cm layer did not change at either site #10 (4.4 mg N kg^{-1}) or site #34 (8.0 mg N kg^{-1}) during the non-growing season.

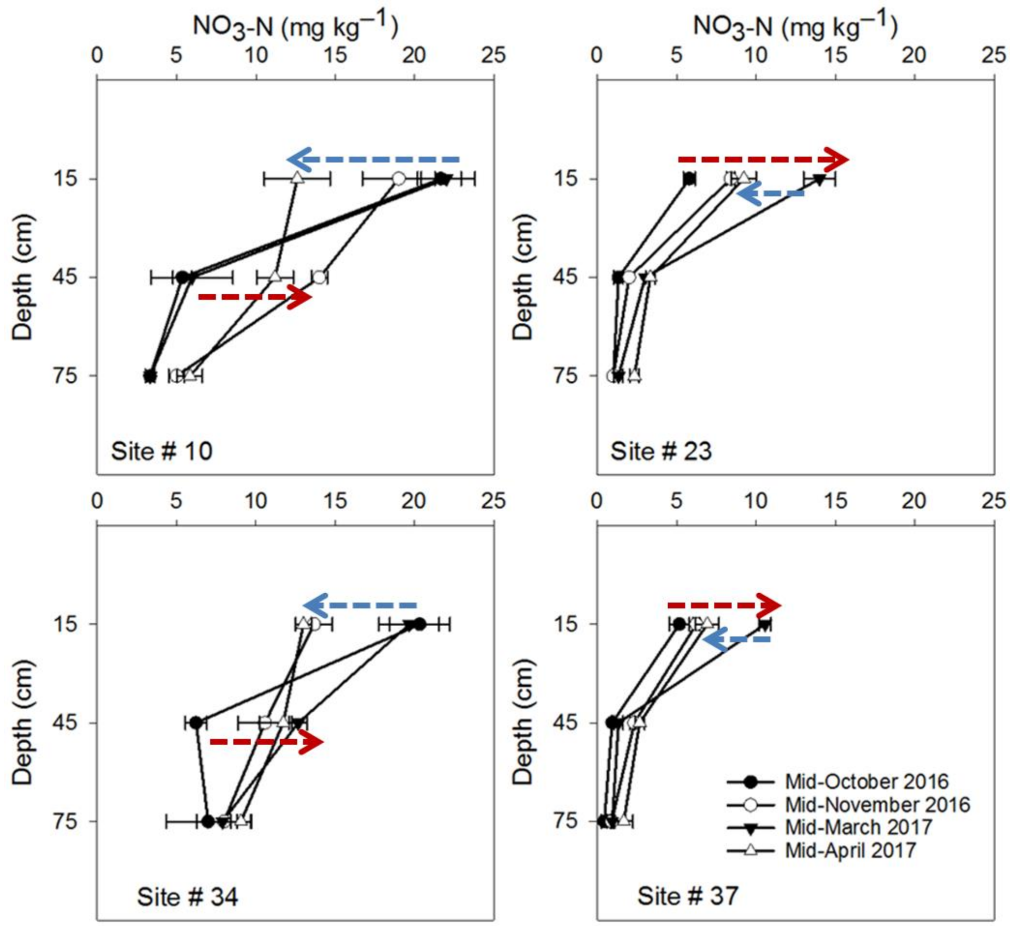

Figure 7. Changes in soil nitrate-nitrogen (NO_3-N) concentrations at four sites and the midpoints of three depths (0-30, 30-60, and 60-90 cm layers). Error bars represent standard deviations. Arrows represent decreases (blue) or increases (red) in soil nitrate concentrations as the non-growing season progressed.

For sites #23 and #37 (alfalfa), soil nitrate concentrations in the 0-30 cm layer increased during the first part of the non-growing season from 5.5 mg N kg^{-1} in Mid-October 2016 to 14.0 mg N kg^{-1} soil for site #23 and 10.6 mg N kg^{-1} for site #37 in mid-March (Fig. 7). Surprisingly, soil nitrate concentrations decreased slightly during the last part of the Benchmark period, to 9.2 mg N kg^{-1} for site #23 and 6.9 mg N kg^{-1} for site #37. In contrast, soil nitrate concentrations did not significantly vary in the 30-60 cm or 60-90 cm layer during the entire non-growing season, indicating no downward movement of residual soil nitrate. The changes in soil nitrate concentration in the surface layer were likely due to microbial transformations of N. In the non-growing season of cold climates, dormant forage stands provide substrates to soil microbes for conversion to nitrate or nitrous oxide (emissions) during freeze-thaw cycles (Clark et al. 2009; Virkajarvi et al. 2010). Determining the processes responsible for the changes in soil nitrate concentrations was outside the scope of this study.

At the PHNT concentrations observed, results do not support the use of the PHNT in the Hullcar Valley as a measure of the risk of nitrate leaching below the 90 cm depth over a non-growing season. There was no evidence of nitrate leaching in the alfalfa sites, perhaps due to late-season (2016) or early-season (2017) N uptake by alfalfa. In the bare fields of the harvested corn sites, a maximum of 22 mg N kg^{-1} was present in any 30-cm thick layer, and there were 130 or 136 kg NO_3-N ha^{-1} in the whole 0-90 cm depth at the start of the sampling period, based on the estimated bulk densities at each site (Table 1). At these soil nitrate levels, it is unlikely nitrate would have leached deeper into the 60-90 cm layer if the non-growing season weather conditions were closer to average, since the weather conditions were wetter than average during the study period. Compared to long-term average conditions for this region, rainfall was high in October 2016 and the volume of snowmelt was high from March to April, suggesting that the degree of leaching was relatively high for the region but still limited overall between growing seasons. However, leaching below the 60 cm depth might have occurred if initial soil nitrate concentrations were greater, or if nitrate concentrations were high in the subsurface layer at the start of the sampling period. In separate Benchmark studies during the 2007/2008 non-growing season in the B.C. Okanagan, soil nitrate was partially leached from the 0-30 cm layer or 30-60 cm layer when the nitrate concentration was 27 mg N kg^{-1} or greater in one or both of these layers at the time of crop harvest (Kowalenko et al. 2009). Additional monitoring is needed to determine if soil nitrate concentrations at high levels or in subsurface layers indicate the amount of nitrate leaching below the root zone between growing seasons.

The fate of the nitrate in the early part of the growing season was unclear and is influenced by multiple factors. It is possible that the soil nitrate can be recovered by a crop in the following growing season, particularly if over-irrigation is avoided. However, nitrate is more vulnerable to leaching if plant roots are shallow or have not yet extended to their full depth in the early spring. Whether nitrate leaches depends in part on whether spring thaw and snowmelt favour overland runoff or percolation of water through the soil, which in turn depends on the depth and continuity of soil frost in the winter. Shallow soil frost under snow tends to favour leaching in the spring (Saarijarvi et al. 2007), and additional work is needed to measure the amount and nitrate content of the leachate during the spring thaw.

4 Conclusions

Results of the Post-Harvest Soil Testing provided a baseline against which improvements in crop N management over Aquifer 103 can be measured annually. In turn, improvements in crop N management will reduce the source of soil nitrate that can leach from the root zone, no matter if or how nitrate leaches from the root zone. Of the 40 fields tested that were over or near the Hullcar Aquifer, 45% had 2016 PHNT levels that exceeded 100 kg N ha^{-1}, and most of these fields were in silage corn or cereals. Not surprisingly, PHNT levels tended to increase with increasing supply of plant available N among corn fields with similar yields. Increasing the assumed soil bulk density values increased the estimates of kg N ha^{-1} of soil nitrate relative to initial estimates using lower bulk density values. The increases did not affect the order of fields in terms of increasing PHNT level or priority for review of nitrogen management practices.

Results of the Benchmark Testing indicated that soil nitrate leached in bare (harvested corn) fields within but not below the top 60 cm of soil during the non-growing season in the Hullcar Valley. The post-harvest nitrate test did not measure the risk of nitrate leaching below the root zone during the non-growing season in the Hullcar Valley, likely because of limited water movement during this period. Nitrate did not leach in alfalfa sites, perhaps because the crop took up N during the late fall and early spring. Results can be generalized to the weather conditions of most years, since the weather conditions during the study period promoted more leaching conditions than in most years. Additional monitoring is needed in sites with higher soil nitrate concentrations than observed in the Benchmark sites (a maximum of 22 mg N kg^{-1} in any 30-cm depth increment), to determine whether the amount or depth distribution of post-harvest soil nitrate influences nitrate leaching. Additional monitoring of nitrate and water movement during the early part of the growing season is also needed to determine if the spring thaw leaches nitrate from the root zone.

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6 Appendices

6.1 Post-Harvest Soil Nitrogen Results

Table 3. Soil nitrate (NO_3) and ammonium (NH_4) amounts in kg N ha^{-1}, converted from soil nitrate concentrations using bulk density values of 1300 kg m^{-3} (0-30 cm) or 1500 kg m^{-3} (30-60 cm or 60-90 cm layers).

	Sample depth (cm)						Complete depth (cm)	
	0-30 cm		30-60		60-90		0-90	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
All fields (40 fields)								
Mean	54.6	18.4	31.1	15.5	26.9	15.6	112.5	49.6
St Dev[z]	29.3	7.6	25.1	7.0	21.0	15.1	67.8	25.0
Median	49.7	17.6	20.3	13.5	22.5	13.5	89.3	46.5
Min	3.9	7.6	25.1	7.0	21.0	15.1	67.8	25.0
Max	136.5	48.8	112.5	40.5	72.0	103.5	305.4	175.2
Annual crops (26 fields): silage corn or cereals								
Mean	63.2	16.4	39.6	15.8	35.7	15.9	138.4	48.1
St Dev	29.5	6.5	26.7	8.2	21.0	18.4	69.7	29.8
Median	56.6	15.6	38.3	13.5	33.8	13.5	138.5	41.6
Min	21.5	5.9	4.5	4.5	4.5	4.5	38.3	19.4
Max	136.5	48.8	112.5	40.5	72.0	103.5	305.4	175.2
Annual crops, sampled before October 13, 2016 (13 fields): silage corn or cereals								
Mean	57.5	20.9	25.6	19.4	24.9	21.5	108.0	61.7
St Dev	36.1	5.1	23.6	8.7	19.6	25.1	72.6	36.4
Median	42.9	21.5	18.0	18.0	22.5	18.0	82.1	59.4
Min	21.5	13.7	4.5	9.0	4.5	9.0	38.3	31.7
Max	136.5	31.2	76.5	40.5	67.5	103.5	267.0	175.2
Annual crops, sampled after October 13, 2016 (13 fields): silage corn								
Mean	68.9	12.0	53.7	12.1	46.4	10.4	168.9	34.5
St Dev	20.9	4.3	22.5	5.9	16.9	2.8	53.4	11.5
Median	68.3	11.7	49.5	13.5	45.0	9.0	158.3	34.2
Min	42.9	5.9	27.0	4.5	18.0	4.5	87.9	19.4
Max	120.9	19.5	112.5	27.0	72.0	13.5	305.4	54.2
Perennial crops (14 fields): alfalfa or nursery trees								
Mean	41.3	22.4	15.9	14.9	11.1	14.9	68.3	52.1
St Dev	20.5	8.7	9.7	4.3	6.3	6.2	19.7	12.5
Median	42.9	19.5	13.5	13.5	9.0	13.5	67.4	49.1
Min	9.8	15.6	4.5	9.0	4.5	9.0	41.3	33.6
Max	85.8	48.8	45.0	22.5	22.5	31.5	112.8	77.4

z. St Dev, Standard Deviation

6.2 Estimates of Plant-Available Nitrogen on Corn Fields in 2016

The following assumptions were used to derive rough estimates of plant available nitrogen credits (kg N ha^{-1}) from reported nitrogen management practices, for corn fields in 2016:

- Composition of manure nitrogen (fresh weight basis) was obtained from book values[a] of manure nutrient analyses, which can vary significantly among farms:
  - 0.15% total N and 811 ppm NH4-N for liquid dairy manure
  - 0.41% total N and 498 ppm NH4-N for solid dairy manure
  - 0.42% total N and 44 ppm NH4-N for beef feedlot manure
  - 1.91% total N and 3095 ppm NH4-N for chicken broiler manure
  - For some manure applications, nitrogen analyses of spring, liquid dairy samples for the 'H.S. Jansen and Sons Farm Ltd.' available at http://www2.gov.bc.ca/gov/content/environment/air-land-water/site-permitting-compliance/hullcar-aquifer
- Manure was incorporated into soil within 24 hours of application.
  - 50% of the NH4-N in solid manure was plant-available in 2016
  - 70% of the NH4-N in solid manure was plant-available in 2016
- Certain percentages of the Organic N fraction of manure (total N minus NH4-N) was plant-available in 2016:
  - 35% of Organic N was available from 2016's applications of liquid manure, or 20% for solid manure
  - 15% of Organic N was available from 2015's applications of liquid manure, or 5% for solid manure
  - 7% of Organic N was available from 2014's applications of liquid manure, or 1% for solid manure
- If the 2015 crop in a particular field was alfalfa, it was assumed the alfalfa provided 100 kg ha^{-1} of plant-available nitrogen to the corn crop in 2016.

The estimates of plant available nitrogen excluded estimates of a nitrogen fertility factor (or estimated nitrogen release from soil organic matter).

a. http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/soil-nutrients/nutrient-management/bc_manure_and_crop_nutrients_report.pdf#page=38

6.3 Benchmark Testing: Soil Nitrate Results

Table 4. Post-harvest changes in soil nitrate-nitrogen concentrations (mg kg^{-1}) in four Benchmark sites.

Site 10		Depth		Accumulated precipitation[z]	Soil temperature at 5 cm depth
Date	0-30 cm	30-60 cm	60-90 cm	(mm)	(°C)
27-Oct-16	21.7a[y]	5.4b	3.3a	0	7.9
22-Nov-16	19.0a	14a	5.0a	46	5.5
21-Mar-17	22.0a	6.0b	3.3a	[55.2][x]	0.2
12-Apr-17	12.6b	11.2a	5.8a	[114.4]	5.2

Site 23		Depth		Accumulated precipitation	Soil temperature at 5 cm depth
Date	0-30 cm	30-60 cm	60-90 cm	(mm)	(°C)
13-Oct-16	5.8c	1.3b	1.0b	0	n.d.[w]
22-Nov-16	8.4b	2.0ab	1.0b	102.6	5.5
23-Mar-17	14.0a	3.0a	1.3ab	[55.2]	n.d.
12-Apr-17	9.2b	3.3a	2.3a	[114.4]	6.3

Site 34		Depth		Accumulated precipitation	Soil temperature at 5 cm depth
Date	0-30 cm	30-60 cm	60-90 cm	(mm)	(°C)
11-Oct-16	20.3a	6.2b	7.0a	0	n.d.
22-Nov-16	13.7b	10.6a	8.0a	109.2	4.0
21-Mar-17	19.7a	12.7a	7.9a	[55.2]	0.3
12-Apr-17	13.0b	11.7a	9.1a	[114.4]	4.6

Site 37		Depth		Accumulated precipitation	Soil temperature at 5 cm depth
Date	0-30 cm	30-60 cm	60-90 cm	(mm)	(°C)
13-Oct-16	5.2c	0.9b	0.4b	0	n.d.
22-Nov-16	6.2bc	2.3a	0.9b	102.6	5.8
23-Mar-17	10.6a	1.3b	0.9b	[55.2]	n.d.
12-Apr-17	6.9b	2.7a	1.7a	[114.4]	6.8

z. Precipitation at the Vernon North weather station (50.34, -119.27) (Environment Canada 2017)
y. Values within each depth increment followed by the same letter are not significantly different ($P<0.05$) according to Least Square Means test.
x. Precipitation values in brackets are cumulative from March 1, 2017
w. n.d., not determined

Raw laboratory data for the Benchmark Testing phase is available online in a supplementary file: Benchmark Testing results.xlsx