Soil Nitrate Survey of Agricultural Fields in the Hullcar Valley in 2022

Final Report

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Short title: 2022 Soil Nitrate Survey: Hullcar Valley

Final Report

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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. By measuring the amount of nitrate in soil following crop harvest, some agronomic inferences can be made about N management over the course of the growing season. Additionally, this measurement can also be used as an environmental tool to determine how much soil nitrate may be at risk of leaching loss to groundwater.

Post-harvest soil sampling after the 2022 growing season was completed on 50 fields lying above Aquifer 103 in the Hullcar Valley of the North Okanagan to a 90-cm depth. The same fields sampled after the 2022 growing season were also sampled after the 2021 growing season. Overall, the area-weighted average soil nitrate value for the entire sampling area for 2022 was lower than for 2021 (72 and 99 kg NO_3-N ha^{-1}, respectively), as was the median soil nitrate value (63 and 82 kg NO_3-N ha^{-1}, respectively). From the 2021 to the 2022 post-harvest periods, the area-weighted average and median soil nitrate values decreased for fields cropped with silage corn and 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 30% and 19% was found in the 30-60 and 60-90 cm layers, respectively.

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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 concentrations 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 (Andrews 2020b). Several studies have been conducted over the past few years to monitor residual soil nitrate after crop harvest in the Hullcar Valley above Aquifer 103 (Andrews 2020a, Andrews 2020b, Andrews 2021, Andrews 2022, Poon and Code 2017, Poon and Code 2018). The results reported for residual soil nitrate in the 0-90 cm of soil after the 2022 crop harvest in this study are a continuation of this work.

Sampling for soil nitrate (NO_3-N) after crop harvest can be used as both an agronomic and an environmental tool. When sampled to a 30-cm depth, the amount of soil nitrate can be used to evaluate the balance between N supply and crop uptake, commonly referred to as a post-harvest nitrate test (PHNT) (B.C. Ministry of Agriculture 2020, Sullivan et al. 2021). In the coastal regions of B.C., the amount of soil nitrate represents NO_3-N susceptible to leaching due to humid, mild winters (Kowalenko 2000). However, recent reports for the Okanagan show that, unlike in coastal regions, not all soil nitrate is susceptible to leaching during the following non-growing season (Andrews 2020a, Andrews 2020b, Poon and Code 2017, Poon and Code 2018).

Sampling in this study includes the zone of soil recommended for agronomic PHNT and deeper zones to monitor presence of nitrate down to 90 cm. The sampling and analysis employed do not allow for the determination of the origin or fate of nitrate.

The objective of this report is to determine the amount and distribution of soil nitrate after crop harvest in sampled fields in the Hullcar Valley in order to inform area producers' decisions on N management.

Primary Questions

1. Overlying Aquifer 103 and the nearby area, how many agricultural fields had elevated levels of soil nitrate in the 0-90 cm layer of soil after crop harvest in 2022?
2. How is nitrate distributed throughout the three soil sampling depths (0-30, 30-60, and 60-90 cm) after crop harvest in 2022?
3. How did soil nitrate levels compare between the 2021 and 2022 sampling periods in fields that had the same crop type?

Hypotheses

1. Most agricultural fields in the area had less than 100 kg ha^{-1} of soil nitrate (0-90 cm soil layer) after crop harvest in 2022.
2. The majority (>50%) of nitrate was found in the 0-30 cm soil layer for each crop type after crop harvest in 2022.
3. The area-weighted average and median soil nitrate values of the entire study area did not increase from the 2021 sampling period.

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
- Updating nutrient management plans, including assessing relationships between nitrogen management practices and post-harvest soil nitrate testing 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 (Andrews 2020b).

The period of N application and management ranged from April through October 2022. During this time, the Salmon Arm CS weather station, approximately 23 km from the study area, observed 164.8 mm of cumulative precipitation, which may be inaccurate due to data collection errors during May, June, August, and October 2022 (Table 1). The data from the Salmon Arm CS weather station was selected for comparison purposes over other weather stations due to having a more complete data set and potential for similar data. The Silver Creek weather station, which was used as a weather data source for previous reports, was decommissioned at the end of October 2021.

Table 1. Cumulative precipitation and average temperature for spring through fall of 2020 - 2022 values at the Salmon Arm CS weather station (approximately 23 km from the study area).

	Cumulative precipitation (mm)			Temperature (°C)		
Month	2020	2021	2022	2020	2021	2022
April	N/A	4.3	9.2	7.7	8.8	7.1
May	N/A	15.1[a]	38.4[a]	13.6[a]	12.8[a]	11.4[a]
June	N/A	17.5	52.1[a]	15.5[a]	19.4	16.5[a]
July	29.8	12.1[a]	33.5	19.0	22.2[a]	21.6
August	8.7	14.5[a]	12.8[a]	19.2	18.9[a]	21.8[a]
September	27.3	29.7	7.0	16.0	14.2	15.6
October	68.4	44.9	11.8[a]	7.2	7.6	10.3[a]
Total	N/A	138.1[a]	164.8[a]	-	-	-

Data: Environment Canada 2023.

[a] Incomplete data

Due to analytical errors associated with samples taken in September through October 2022, the data in this report are from samples collected in February 2023. Soil NO_3-N concentrations from the February 2023 sampling is not expected to be substantially different than those from the original September/October 2022 sampling as the cumulative amount of rainfall and snowmelt infiltration is likely within the thresholds recommended for post-harvest NO_3-N sampling (B.C. Ministry of Agriculture 2020; Sullivan et al. 2021). This is further evidenced by measured cumulative precipitation and mean temperatures from September 2022 through February 2023 that indicate potentially low cumulative amounts of rainfall and snowmelt infiltration, which is unlikely to leach NO_3-N below the sampling zone (Table 2). Additionally, NO_3-N leaching below the 90-cm depth has rarely been observed in previous studies in the North Okanagan (Andrews 2020b, Kowalenko 2009, Poon and Code 2017, Poon and Code 2018).

Table 2. Cumulative total precipitation, snow depth at the end of the month, and average temperature values for September 2022 through February 2023 at the Salmon Arm CS weather station (approximately 23 km from the study area).

Month	Total precipitation (mm)	Snow depth – end of month (cm)	Mean temperature (°C)
September	7.0	0	15.6
October[a]	11.8	0	10.3
November	34.9	0	-1.9
December[a]	64.7	23	-6.8
January	54.7	10	-1.0
February	41.1	24	-1.2
Total[a]	214.2	-	-

Data: Environment Canada 2023.

[a] Incomplete data

Field Selection and Sampling Methodology

Fifty agricultural fields above Aquifer 103 were selected for sampling after crop harvest 2022, which were the same fields sampled as part of the survey in 2021. Field delineation was based on consistent N management within the area and to keep total field size under 25 hectares. The total study area was 775 hectares, with 242 hectares (16 fields) of the area cropped with alfalfa/grass and 533 hectares (34 fields) of the area cropped with silage corn. In 2021, the study area was cropped with 332 hectares (22 fields) of alfalfa/grass and 443 hectares (28 fields) of silage corn.

The soil sampling methodology was consistent with those used previously from 2016 to 2022, with the exception of the sampling date as described above (Andrews 2020a, Andrews 2020b, Andrews 2021, Andrews 2022, 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.

Analyses

The laboratory and data analyses were the same as in previous years (Andrews 2020a, Andrews 2020 b, Andrews, 2021, 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 the Analytical Chemistry Services (NRL) Laboratory (Victoria, B.C.).

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 (modified from 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 ($\geq$200 kg NO_3-N ha^{-1}).

The environmental risk categories originally described by Kowalenko et al. (2007, 2009) classified total nitrate-nitrogen for the 0-60 cm sampling depth. However, the category names and ranges used in this study are based on a 0-90 cm sampling depth, which may increase the total measured amount of NO_3-N for each field and increase the likelihood of a field being placed into a higher NO_3-N category.

3 Results and Discussion

Overall, 36% of the total sampled land area had a ‘Low’ rating (18 fields), 48% had a ‘Medium’ rating (25 fields), 11% had a ‘High’ rating (5 fields), and 5% had a ‘Very High’ rating (2 fields). 84% of the total sampled land area, a total of 43 fields, had less than 100 kg NO_3-N ha^{-1}, which supports the hypothesis (Hypothesis 1) that the majority of fields had soil nitrate values below 100 kg NO_3-N ha^{-1}.

There were differences in average soil nitrate (0-90 cm) between the two crop types for the 2022 post-harvest period (Table 3). Silage corn had the highest area-weighted average soil nitrate value of 86 kg NO_3-N ha^{-1} and accounted for the greatest proportion of sampled land area, 69%. Alfalfa/grass accounted for the remaining 31% of the sampled land area and had an area-weighted average soil nitrate value of 42 kg NO_3-N ha^{-1}.

Table 3. Sampling area and soil nitrate test statistics for the 2022 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	16	242	42	90	35	15
Silage corn	34	533	86	220	75	17
All crops	50	775	72	220	63	15

[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.

For the 2022 post-harvest period, 51% of the total area-weighted average soil nitrate for each field was found in the uppermost 0-30 cm sampling zone (Table 4), supporting the hypothesis (Hypothesis 2) that the majority of nitrate would be found in this sampling zone. At lower depths, 30% and 19% of the total area-weighted average soil nitrate was found at the 30-60 and 60-90 cm depths, respectively.

Table 4. The proportion of all nitrate found in the 0-30 cm, 30-60 cm, and 60-90 cm sampling depths for the 2022 post-harvest sampling period.

Crop	0-30 cm	30-60 cm	60-90 cm
Alfalfa/grass	62%	25%	14%
Silage corn	48%	31%	21%
All crops	51%	30%	19%

To interpret the 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.

The amount of nitrate found in the soil after crop harvest can be used to make inferences about N application rates and use (Sullivan et al. 2021). Based on the range of soil nitrate values it appears that most fields 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 were managed for optimal crop uptake (Sullivan et al. 2021).

Kowalenko et al. (2009) cautions against the use of PHNT values alone to describe the risk of nitrate leaching in the Okanagan. Recent studies during the non-growing season in the Hullcar Valley show that movement of NO_3-N through the soil is fairly limited, and that NO_3-N can be expected to be present at planting the following year (Poon and Code 2017, Poon and Code 2018, Andrews 2020a, Andrews 2020b). In this area, producers should expect some soil NO_3-N to be present at the beginning of the growing season and incorporate it into their N management strategies for the next season. Monitoring PHNT values, crop yield, and crop quality on an annual basis provides information to minimize excess nitrate over time without compromising crop production goals (Poon and Code 2017).

Comparisons between years

The area-weighted average and median soil nitrate value for the study area was lower in the 2022 post-harvest period in comparison to the 2021 period (Table 5). In the 2021 sampling period, the area-weighted average and median soil nitrate value was 99 and 82 kg NO_3-N ha^{-1}, respectively. In the 2022 sampling period, these values were 72 and 63 kg NO_3-N ha^{-1}, respectively. This represents a 27 kg NO_3-N ha^{-1} decrease in the area-weighted average soil nitrate value from 2021 to 2022, and a 19 kg NO_3-N ha^{-1} decrease in the median soil nitrate value from 2021 to 2022. While this result may be due to improved N management in the study area, it may also be due to weather conditions that limited N mineralization from soil organic matter or another factor. Nonetheless, these values support the hypothesis that the area-weighted average and median soil nitrate did not increase from the 2021 sampling period (Hypothesis 3).

From the 2021 post-harvest period to the 2022 period, the area-weighted average soil nitrate value decreased for alfalfa/grass, from 75 to 42 kg NO_3-N ha^{-1}, while the median value decreased from 50 to 35 kg NO_3-N ha^{-1} (Table 5). Both the area-weighted average and median soil nitrate values decreased for silage corn, from 117 and 109 kg NO_3-N ha^{-1}, to 86 and 75 kg NO_3-N ha^{-1}, respectively. As noted above, observed decreases from the 2021 post-harvest period to the 2022 post-harvest period may be due to several factors, such as improved N rate or timing of application, conditions that led to improved crop N uptake, or reduced N mineralization of soil organic matter.

4 Conclusions

The 2022 post-harvest period's area-weighted average and median soil nitrate values of the study area were lower than the 2021 period's values. On a crop type basis, both silage corn and alfalfa/grass had a lower area-weighted average and median soil nitrate value than in 2021. Decreases in soil nitrate measures may be due to several factors, such as improved N rate or timing of application, conditions that led to improved crop N uptake, or reduced N mineralization of soil organic matter. However, due to the position of the fields above the aquifer, soil nitrate and N management practices should continue to be monitored to ensure the efficient uptake of applied N and minimize the amount of nitrate vulnerable to leaching loss.

Table 5. Sampling area and post-harvest nitrate test statistics for the 2021 and 2022 post-harvest sampling periods.

Crop type	2021 No. of sampling areas	2021 Area sampled	2021 Area-weighted average PHNT[a]	2021 Median PHNT	2022 No. of sampling areas	2022 Area sampled	2022 Area-weighted average PHNT[a]	2022 Median PHNT
	-	(ha)	---kg NO_3-N ha^{-1}---		-	(ha)	---kg NO_3-N ha^{-1}---	
Alfalfa/grass	22	332	75	50	16	242	42	35
Silage corn	28	443	117	109	34	533	86	75
All crops	50	775	99	82	50	775	72	63

[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.

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6 Supplemental Materials

Supplemental Table 1. Post-harvest nitrate by soil layer (depth) in sampling areas that were silage corn in 2022.

Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}
0-15	7.8	15.2	0-15	5.1	9.9	0-15	28.2	55.0
15-30	5.3	10.3	15-30	5.0	9.8	15-30	23.3	45.4
30-60	3.4	15.3	30-60	3.8	17.1	30-60	10.1	45.5
60-90	2.3	10.4	60-90	2.1	9.5	60-90	16.4	73.8
0-15	4.3	8.4	0-15	13.3	25.9	0-15	1.2	2.3
15-30	5.4	10.5	15-30	9.5	18.5	15-30	13.3	25.9
30-60	2.4	10.8	30-60	6.4	28.8	30-60	12.5	56.3
60-90	0.7	3.2	60-90	2.7	12.2	60-90	6.2	27.9
0-15	9.7	18.9	0-15	11.6	22.6	0-15	6.1	11.9
15-30	5.6	10.9	15-30	10.2	19.9	15-30	7.3	14.2
30-60	5.1	23.0	30-60	5.3	23.9	30-60	3.1	14.0
60-90	1.5	6.8	60-90	1.8	8.1	60-90	4.1	18.5
0-15	16.7	32.6	0-15	3.9	7.6	0-15	4.6	9.0
15-30	13.1	25.5	15-30	18.0	35.1	15-30	11.0	21.5
30-60	6.2	27.9	30-60	6.9	31.1	30-60	6.5	29.3
60-90	3.5	15.8	60-90	4.4	19.8	60-90	3.0	13.5
0-15	3.3	6.4	0-15	8.9	17.4	0-15	45.2	88.1
15-30	13.2	25.7	15-30	7.7	15.0	15-30	31.7	61.8
30-60	7.2	32.4	30-60	5.5	24.8	30-60	8.9	40.1
60-90	3.6	16.2	60-90	6.5	29.3	60-90	3.7	16.7
0-15	6.7	13.1	0-15	16.3	31.8	0-15	13.2	25.7
15-30	3.9	7.6	15-30	3.8	7.4	15-30	18.5	36.1
30-60	2.8	12.6	30-60	3.2	14.4	30-60	8.2	36.9
60-90	1.5	6.8	60-90	2.0	9.0	60-90	4.1	18.5

Supplemental Table 2. Post-harvest nitrate by soil layer (depth) in sampling areas that were silage corn in 2022 (continued).

Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}
0-15	1.7	3.3	0-15	2.8	5.5	0-15	4.0	7.8
15-30	8.8	17.2	15-30	7.2	14.0	15-30	10.0	19.5
30-60	3.8	17.1	30-60	6.3	28.4	30-60	5.4	24.3
60-90	1.1	5.0	60-90	4.3	19.4	60-90	4.5	20.3
0-15	11.6	22.6	0-15	6.0	11.7	0-15	1.8	3.5
15-30	13.7	26.7	15-30	11.3	22.0	15-30	5.7	11.1
30-60	6.9	31.1	30-60	8.1	36.5	30-60	4.8	21.6
60-90	3.1	14.0	60-90	2.9	13.1	60-90	3.4	15.3
0-15	12.0	23.4	0-15	8.6	16.8	0-15	6.3	12.3
15-30	14.0	27.3	15-30	5.6	10.9	15-30	18.3	35.7
30-60	5.2	23.4	30-60	3.9	17.6	30-60	5.7	25.7
60-90	3.8	17.1	60-90	3.8	17.1	60-90	11.5	51.8
0-15	1.7	3.3	0-15	2.2	4.3	0-15	21.1	41.1
15-30	2.8	5.5	15-30	12.5	24.4	15-30	16.1	31.4
30-60	1.0	4.5	30-60	3.9	17.6	30-60	11.2	50.4
60-90	0.8	3.6	60-90	3.8	17.1	60-90	5.3	23.9
0-15	12.2	23.8	0-15	13.7	26.7	0-15	2.2	4.3
15-30	12.9	25.2	15-30	9.1	17.7	15-30	11.5	22.4
30-60	5.2	23.4	30-60	4.2	18.9	30-60	2.7	12.2
60-90	3.7	16.7	60-90	2.6	11.7	60-90	2.1	9.5
0-15	11.1	21.6						
15-30	14.8	28.9						
30-60	3.7	16.7						
60-90	1.7	7.7						

Supplemental Table 3. Post-harvest nitrate by soil layer (depth) in sampling areas that were alfalfa/grass in 2022.

Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}	Depth (cm)	NO_3-N (ppm)	kg NO_3-N ha^{-1}
0-15	4.6	9.0	0-15	9.2	17.9	0-15	0.0	0.0
15-30	3.5	6.8	15-30	7.3	14.2	15-30	7.0	13.7
30-60	1.6	7.2	30-60	2.1	9.5	30-60	3.3	14.9
60-90	0.7	3.2	60-90	1.2	5.4	60-90	0.6	2.7
0-15	13.8	26.9	0-15	3.2	6.2	0-15	0.9	1.8
15-30	6.6	12.9	15-30	1.0	2.0	15-30	9.2	17.9
30-60	2.9	13.1	30-60	1.3	5.9	30-60	2.2	9.9
60-90	1.1	5.0	60-90	0.3	1.4	60-90	2.0	9.0
0-15	4.8	9.4	0-15	13.9	27.1	0-15	5.1	9.9
15-30	8.6	16.8	15-30	11.4	22.2	15-30	2.6	5.1
30-60	3.7	16.7	30-60	3.2	14.4	30-60	1.9	8.6
60-90	1.6	7.2	60-90	1.7	7.7	60-90	0.3	1.4
0-15	11.0	21.5	0-15	5.4	10.5	0-15	2.0	3.9
15-30	3.6	7.0	15-30	3.3	6.4	15-30	7.0	13.7
30-60	0.5	2.3	30-60	1.1	5.0	30-60	2.1	9.5
60-90	0.5	2.3	60-90	0.3	1.4	60-90	6.2	27.9
0-15	11.8	23.0	0-15	7.6	14.8	0-15	0.6	1.2
15-30	2.4	4.7	15-30	2.0	3.9	15-30	7.8	15.2
30-60	0.0	0.0	30-60	0.5	2.3	30-60	3.8	17.1
60-90	0.2	0.9	60-90	0.8	3.6	60-90	0.8	3.6
0-15	27.8	54.2						
15-30	10.7	20.9						
30-60	2.3	10.4						
60-90	0.9	4.1						