Fraser Valley
Soil Nutrient Survey 2012

A Follow-up to a 2005 Survey of Nutrient Status of Agricultural Fields in Relation to Environmental and Agronomic Concerns

Growing Forward 2

BRITISH COLUMBIA

Canada

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A Follow-up to a 2005 Survey of Nutrient Status of Agricultural Fields in Relation to Environmental and Agronomic Concerns

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Disclaimer

Summary

In 2012, 177 agricultural fields were sampled after harvest for soil nutrients as a follow-up to baseline sampling in 2005, in six regions of the Lower Fraser Valley of British Columbia (Fig. A). Among the six crop groups sampled in 2012, blueberries and vegetables had the greatest post-harvest nitrate test (PHNT) values and forage grass fields had the lowest PHNT values (Table A). Average PHNT in raspberry fields was less in 2012 than in 2005; in 2005, raspberries had the greatest average PHNT among the crop groups surveyed. The PHNT values were high or very high (greater than 100 kg NO3-N ha^{-1}, 0-60 cm depth) in 55% of the fields sampled in 2012, compared to 34% in 2005. In 2012, 94% of the fields had high or very high soil test phosphorus (P) (greater than 50 mg P kg^{-1}, Kelowna-extractable). Soil test P increased from an average of 135 mg P kg^{-1} in 2005 to 168 mg P kg^{-1} in 2012 among 109 fields that were sampled in both years. Soil test potassium (K) decreased from 197 mg K kg^{-1} in 2005 to 173 mg K kg^{-1} (Kelowna-extractable) in 2012 among the 109 fields. However, soil test K in forage corn and grass fields was similar in 2005 and 2012, indicating that animal health concerns due to high K forages persisted in 2012. In 2012, concerns of post-harvest nitrate leaching were greatest in blueberry and vegetable fields among the crop groups surveyed. Among the crop groups surveyed, raspberry fields had the greatest source of soil P to be transported by runoff and erosion, but the overall risks of P transport by runoff or erosion were not evaluated. Since fertilizer rates to the berry and field vegetable crops commonly exceeded P fertilizer recommendations based on soil testing, there were likely opportunities to reduce P additions to these crops without risk to crop yield or quality.

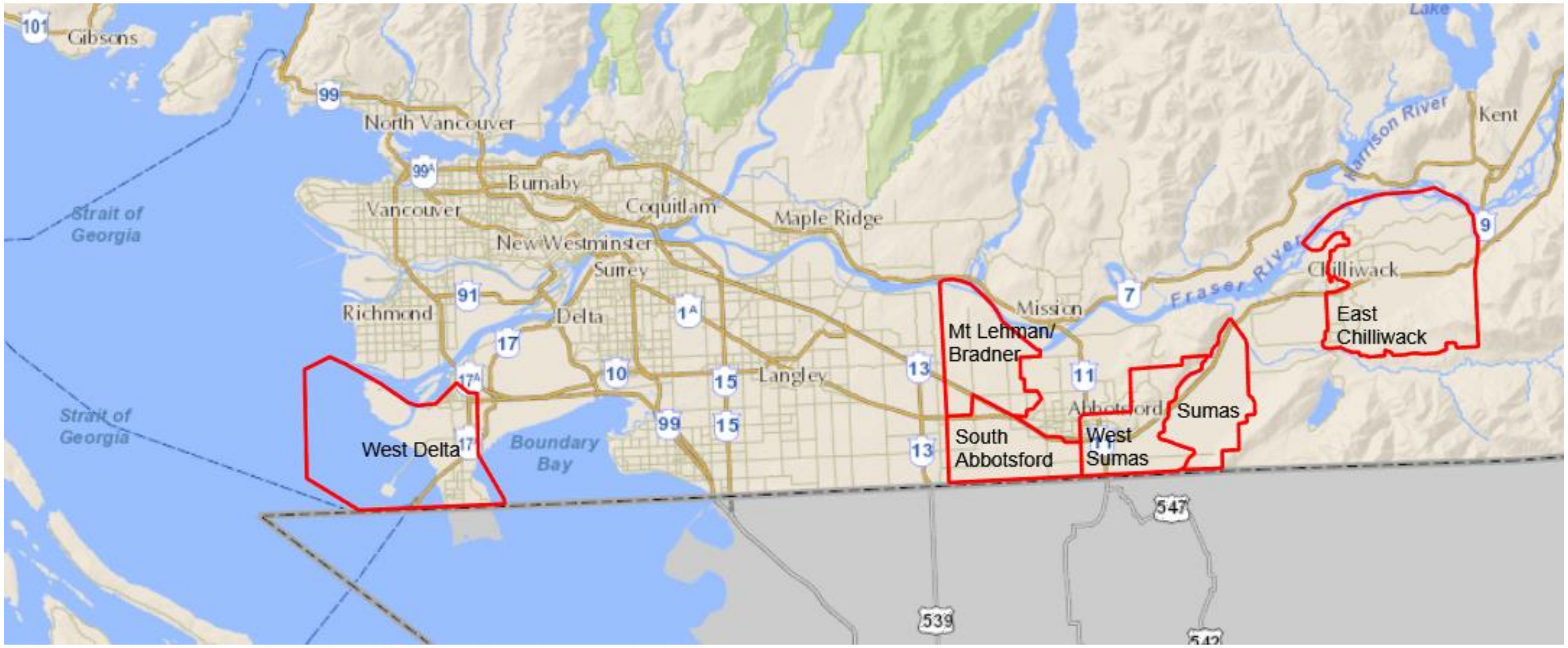

Figure A. Locations of the six regions where agricultural fields were sampled in the 2012 Fraser Valley Soil Nutrient Survey.

Table A. Average soil nutrient test results in 2012 by crop group and region, where n is the number of fields.

	n	**Post-Harvest Nitrate Test** kg NO_3-N ha^{-1} (0-60 cm)	**Soil Test P (Kelowna method)** mg P kg^{-1} (0-15 cm)	**Soil Test K (Kelowna method)** mg K kg^{-1} (0-15 cm)
Crop Group		% of fields in 'High' or 'Very High' rating classes in brackets		
Forage grass	45	88 c* (33%)	140 b (84%)	175 b (42%)
Forage corn	31	137 bc (61%)	168 b (100%)	238 a (62%)
Vegetables	30	173 ab (73%)	187 b (100%)	166 b (47%)
Blueberries	30	215 a (73%)	152 b (97%)	138 b (27%)
Raspberries	19	123 bc (58%)	314 a (100%)	178 ab (47%)
Nursery	22	99 bc (36%)	126 b (91%)	168 b (45%)
Region†		% of fields in 'High' or 'Very High' rating classes in brackets		
West Delta	25	110 ab (48%)	160 b (100%)	222 ab (76%)
Mt. Lehman /Bradner	22	115 ab (55%)	105 b (86%)	137 c (32%)
S. Abbotsford	38	175 a (63%)	253 a (92%)	159 c (37%)
West Sumas	21	140 ab (67%)	165 b (95%)	266 a (63%)
Sumas	34	174 a (71%)	168 b (100%)	136 c (71%)
E. Chilliwack	37	96 b (30%)	145 b (92%)	179 bc (46%)
All fields	177	138 (55%)	172 (94%)	177 (45%)

* Means in the same column followed by the same letters are not significantly different (p <0.05) according to Bonferroni's multiple comparison test.
† Regions as shown in Fig. A.

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List of Abbreviations

ANOVA, Analysis of variance

BC, British Columbia

K, Potassium

KCl, Potassium chloride

LFV, Lower Fraser Valley

N, Nitrogen

NO3-N, Nitrate-nitrogen (nitrogen in the nitrate form)

P, Phosphorus

PHNT, Post-harvest nitrate test (0-60 cm soil depth, expressed as kg NO_3-N ha^{-1})

1 Introduction

In 2005, a soil nutrient survey was conducted in selected agricultural regions of the Lower Fraser Valley (LFV) of British Columbia (B.C.). The objective was to assess the status of soil nutrients that are critical for environmental effects and agricultural production (Kowalenko et al. 2007). The nutrients tested included nitrogen (N), phosphorus (P), and potassium (K), which can impact water quality (N and P) or air quality (N). Elevated K in forages has particular risks for animal health.

The 2005 survey showed values of elevated N and P in agricultural soils across the LFV, at levels of concern to surface water and groundwater. This result was expected from findings of N and P surpluses for the LFV area as a whole, based on agricultural census data from the 1990's and 2001 (Brisbin 1996; Schreier et al. 2003). However, the 2005 soil testing revealed that soil nutrient levels were highest in regions within the LFV that differed from those regions with the greatest nutrient surpluses predicted from the census data (Kowalenko et al. 2007). The International Plant Nutrition Institute summarizes soil test results from private laboratories for P and K for B.C. (IPNI 2016), but the results aggregate all regions of B.C., obscuring areas within the LFV that have high phosphorus levels, and the methodologies leading to the values reported by the laboratories are unclear. Thus, rigorous soil testing is needed periodically to validate soil nutrient levels and associated environmental risk factors across the LFV. Then responses to environmental and agronomic concerns can be better targeted to specific crop types or areas or adjusted over time as needed. The 2005 soil nutrient survey had not been repeated until 2012, when this project was conducted with the following objectives:

- Describe post-harvest nitrate test (PHNT), soil test P, and soil test K in agricultural fields in the LFV in 2012, overall and by crop group and region
- Compare the 2012 results with the 2005 results

2 Materials and Methods

Survey Area

Soils were sampled in the LFV from August 20 to October 24 of 2012 in the same regions that were sampled in the 2005 survey (Kowalenko et al. 2007) (Fig. 1). The climate of the area is humid maritime, with wet mild winters and warm summers. Average annual air temperature is 10°C and average annual precipitation ranges from 1008 mm in Delta to 1788 mm in Chilliwack. June 2012 was cooler and wetter than average, and August and September of 2012 were warmer and drier than average (Appendix A). Abbotsford received just over 10mm of precipitation from August to September 2012, which is less than 10% of the long-term average. It was the driest August to September period for the Fraser Valley on record. The soil orders vary across the valley: mainly Gleysols in West Delta and Sumas; mainly Podzols in Mt. Lehman/Bradner and South Abbotsford; Gleysols, Brunisols, and Luvisols in West Sumas; and Gleysols and Brunisols in East Chilliwack (Bertrand et al. 1991).

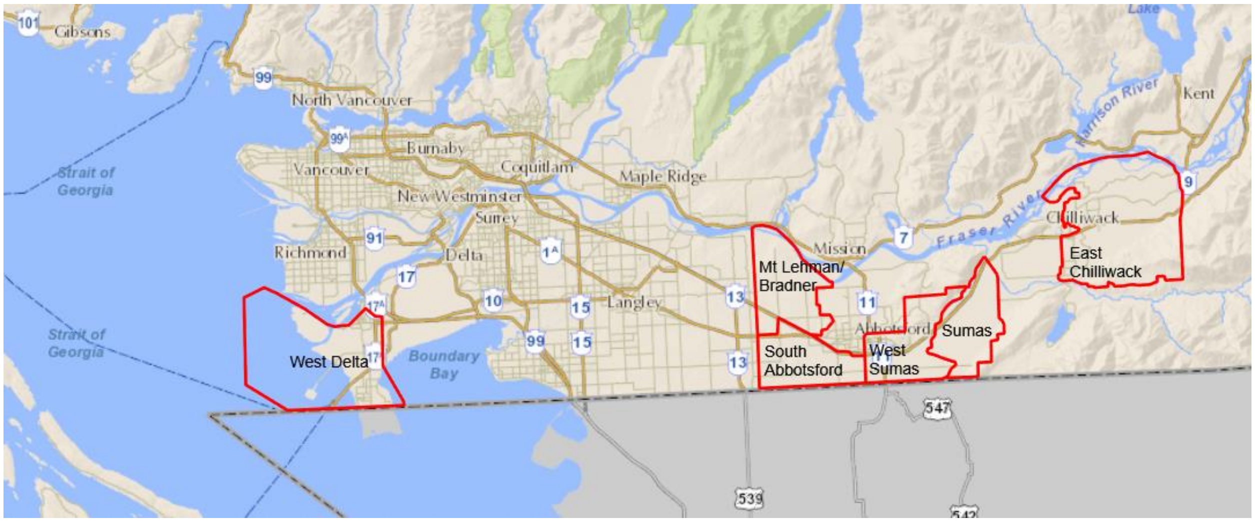

Figure 1. Locations of the six regions where agricultural fields were sampled in the 2012 Fraser Valley Soil Nutrient Survey.

Field Selection and Sampling Methodology

The fields selected for this survey represent the major crop groups and soil types of the LFV. The six sample regions were census areas selected for their economic importance and contrasting nutrient surpluses based on 2001 census data (Brisbin 1996; Schreier et al. 2003). The overall 2012 methodology followed the methods established in 2005, with some adjustments (Table 1). In 2012, sampling was intentionally distributed more evenly across regions and crop groups than in 2005, so only 63% of the fields that were sampled in 2005 were sampled again in 2012. As in 2005, all fields were volunteered by the landowners, and only fields with mineral soils were sampled.

The soil sampling methodology in 2012 was the same as in 2005. In each field, three composite samples were collected to obtain results for the 0-15 cm (0-6 inch) and 0-60 cm (0-24 inch) depths. Each composite was made of at least 15 soil cores (excluding vegetation or mulch at the soil surface). For each composite, the cores were collected from an area no larger than 4.0 hectares (10 acres) that represented the field. As in 2005, the entire field was sampled except with blueberry and raspberry fields. In the berry fields, samples were taken only from the area within and adjacent to the row where nutrients have been applied (Fig. 2).

Table 1. Comparison of the methodology between the 2012 survey and the 2005 'Phase B' survey of Kowalenko et al. (2007).

	2005 survey	2012 survey
Number of fields sampled	172	177
Number of fields sampled both in 2005 and 2012	109	109
Number of fields sampled both in 2005 and 2012 and having the same crop	86	86
Regions (Fig. A)	West Delta, West Matsqui, South Matsqui, West Sumas, Abbotsford, East Chilliwack	Same as in 2005, with renaming: • West Matsqui to Mt. Lehman/Bradner in 2012 • South Matsqui to South Abbotsford in 2012
Crop groups	Forage grass, forage corn, vegetables, blueberries, raspberries, nursery	Same as in 2005
Field selection criteria	Fields per crop group and region were proportional to their acreage in 2005	At least 5 fields per crop group per region
Extraction method for soil test phosphorus (P) and soil test (K) potassium	• Kelowna and Mehlich 3 extractions • Mehlich 3 extraction results were converted to units of the Kelowna extraction* in this report	• Mehlich 3 extraction results were converted to units of the Kelowna extraction*
Assumed soil bulk density to convert soil nitrate values to a volume basis (kg ha^{-1}) from concentrations (mg kg^{-1})	Results were originally estimated using 1100 kg m^{-3}, but re-estimated using 1200 kg m^{-3} in this report	Results were estimated using 1200 kg m^{-3}

* Soil test P and K results were converted from Mehlich 3 to units of the Kelowna extraction by multiplying Mehlich 3 values by 0.72 for soil test P and 0.75 for soil test K, relationships that apply to Lower Fraser valley soils with pH (in water) less than 7.2, according to Kowalenko (2010).

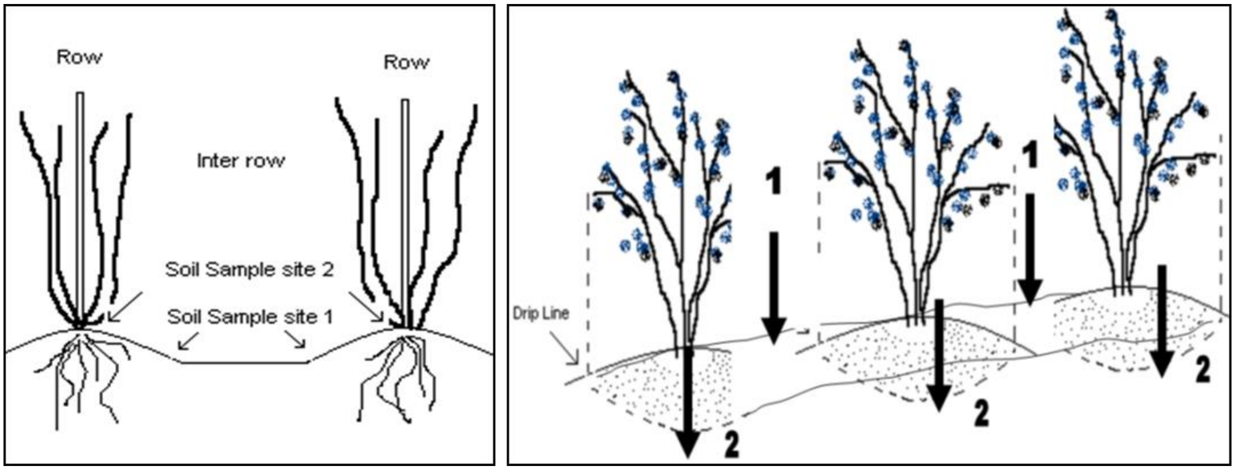

Figure 2. Sampling locations in raspberry (left) and blueberry fields (right). The area between planted rows was not sampled.

Most samples were collected before rainfall could be expected to leach soil nitrate. Of the 177 fields sampled in 2012, 159 were sampled between August 20 and October 11 (5.3 mm accumulated rainfall). Due to time restrictions, the other 18 fields were sampled from October 12 to 24, during which an additional 133 mm of rain fell. The samples were kept on ice in a cooler until they reached the laboratory to be air-dried and then oven-dried (105°C for 24 hours).

Laboratory Analyses

The samples were analyzed using a subset of the methods from the 2005 survey (Kowalenko et al. 2007). Extractions were done on air-dried and sieved (<2 mm) samples: *2N* KCl extractions for nitrate (NO_3) and ammonium (NH_4) and Mehlich 3 extractions (1:10 soil:solution ratio for 5 minutes) for soil test P and soil test K. Analyses of the chemicals in solution were done using a segmented-flow automate chemistry analyzer for nitrate and ammonium and by Inductively Coupled Plasma for soil test P and soil test K. Results were converted to kg NO_3 ha^{-1} (0-60 cm depth) for PHNT, and to Kelowna for soil test P and soil test K based on relationships established by Kowalenko (2010). All results were expressed on an oven-dry basis.

Data Analyses

Descriptive statistics for the nutrient data included averages and standard deviations for various combinations of crop groups and regions. In addition, results were distributed across the rating classes that were previously developed for each of 3 nutrient measures (Table 2): PHNT (0-60 cm depth), soil test P (0-15 cm depth), and soil test K (0-15 cm depth). Because sampling before or after the wet period from October 12 to 24 had no effect on any of the three nutrient measures, all 177 fields were included in the datasets that were analyzed.

Table 2. The 4 rating classes used in this survey for post-harvest nitrate test (PHNT), soil test phosphorus (P), and soil test potassium (K) results, as developed by Kowalenko et al. (2007).

Rating class	**PHNT** kg NO_3-N ha^{-1} (0-60 cm)	**Soil Test P**† mg P kg^{-1} (0-15 cm)	**Soil Test K**† mg K kg^{-1} (0-15 cm)
Low	0 – 49	0 – 20	0 – 80
Medium	50 – 99	21 – 50	81 – 175
High	100 – 200	51 – 100	176 – 250
Very High	> 200	> 100	> 250
What High or Very High values indicate	• high amount of nitrate not used by the recently harvested crop • high environmental risk of nitrate leaching in the Lower Fraser Valley	• high soil P fertility (i.e. most crops not expected to respond to P fertilizer) • high environmental risk of P entering runoff water • not indicative of the risk of runoff	• high soil K fertility (i.e. most crops not expected to respond to K fertilizer) • high risk of excess K uptake from soil into forages

† based on the Kelowna extraction method described by Kowalenko et al. (2007)

The effects of year (2012 vs. 2005), region and crop group on the survey results were determined by nested analysis of variance (ANOVA). In addition, the effect of sampling year (2005 compared with 2012) was determined using t-tests: a Type III t-test was used to compare the means from all fields in both years, and Type I paired t-tests were used to compare the means from the fields that were sampled in 2005 and again in 2012.

Within the ANOVA models, fields were used for the experimental error and replicates within fields (i.e., the three composite samples per field) were used for the sampling error (Appendix B). The General Linear Model procedure in the SAS package (SAS Institute 2003) was used. When an overall ANOVA was significant ($p<0.05$), Bonferroni's multiple comparisons test was used to determine if each average was different from the other(s).

3 Results

3.1 All Fields

The percentage of test results in the high or very high rating classes differed among the soil nutrients. In 2012, 67% of fields surveyed had medium or high PHNT levels, and the percentage of fields with high or very high PHNT levels was 21 percentage points greater in 2012 than in 2005 (Table 3). For soil test P, 94% of fields surveyed in 2012 were in the high or very high rating classes (Fig. 3), an increase of 10 percentage points from 2005 (Table 3). For soil test K, fields were mostly in the medium category (44%), and there was a decrease in the percentage of high or very high fields from 2005 (Table 3).

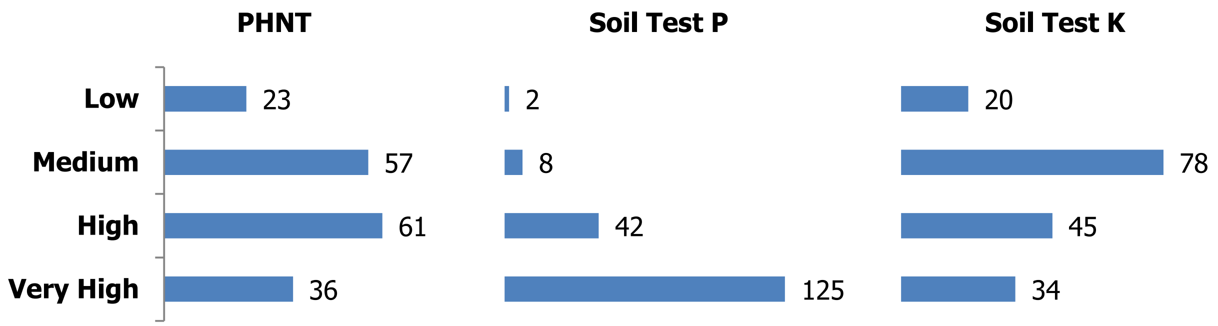

Figure 3. The distribution of the 177 fields surveyed in 2012 across the 4 rating classes for post-harvest nitrate test (PHNT), soil test phosphorus (P), and soil test potassium (K) results. The rating classes are defined in Table 2.

Comparing all fields surveyed in 2012 and 2005, the average soil nutrient level did not differ between the two survey years for any nutrient according to the ANOVA (Table 3, Appendix C). However, comparing the *same* fields sampled in both years, average soil test P and soil test K (but not PHNT) differed between the survey years (Table 3). The average soil test P value increased 25% to 168 mg P kg^{-1} from 2005 to 2012 among the 109 fields that were surveyed in both years. The percentage increase of soil test P was similar (24%) for the 86 fields that were surveyed and had the same crop in both years. Conversely, the average soil test K level decreased 12% to 173 mg K kg^{-1} from 2005 to 2012 among the 109 fields (Table 3), or 17% for the 86 fields. In both comparisons (of the 109 fields or the 86 fields), soil test K decreased from the high range to the upper end of the medium range. However, excluding the blueberry and raspberry fields, the average soil test K did not differ between 2005 and 2012.

According to the t-test, average PHNT and soil test P of all fields surveyed in 2012 and 2005 differed between the two survey years (p=0.0037 for PHNT; p=0.0019 for soil test P). Unlike the ANOVA, the t-test excluded the influence of sampling region or crop group. The average PHNT was 35% greater in 2012 than in 2005, and average soil test P was 29% greater, for all the fields surveyed. Average PHNT of the 109 fields surveyed in both years was also greater in 2012 than in 2005 according to the t-test (p=0.0703).

Table 3. Comparison between 2012 and 2005 of average post-harvest nitrate test (PHNT), soil test phosphorus (P), and soil test potassium (K) results.

			PHNT	**Soil Test P**	**Soil Test K**
Comparison	Year	**n**	kg NO_3-N ha^{-1} (0-60 cm)	mg P kg^{-1} (0-15 cm)	mg K kg^{-1} (0-15 cm)
All fields	2012	177	138a† (55%)‡	172a (94%)	177a (45%)
	2005	172	102a (34%)	134a (84%)	192a (49%)
Same fields	2012	109	125a	168a	173b
	2005	109	102a	135b	197a
Same fields same crop	2012	86	126a	175a	162b
	2005	86	112a	141b	195a

† Averages within columns and the same comparison followed by the same letter are not significantly different (p <0.05) according to Bonferroni's multiple comparison test.
‡ Brackets contain the percentage of fields in High or Very High rating classes, as defined in Table 2.

3.2 2012 Results by Crop Group and Region

Average PHNT, soil test P and soil test K in 2012 differed by crop group (Table 4). Among the crop groups surveyed, blueberries and vegetables had the greatest average PHNT values in 2012, at 215 and 173 kg NO_3-N ha^{-1}, respectively. Forage grass fields had the lowest average PHNT values of all crops surveyed, approximately half the average PHNT values of blueberry and vegetable fields (Table 4). Forage grass fields also had the lowest percentage of fields (36%) in the high or very high PHNT rating classes, followed by fields in nursery crops at 33%.

The differences in PHNT by crop group were unrelated to the crop groups with the highest soil test P or soil test K values. Raspberry fields had the greatest average soil test P (314 mg P kg^{-1}), more than twice the concentration as in nursery or forage grass fields. Forage corn fields had the highest average soil test K values (238 mg K kg^{-1}).

Table 4. Average soil nutrient test results in 2012 by crop group and region, where n is the number of fields.

	N	Post-Harvest Nitrate Test kg NO_3-N ha^{-1} (0-60 cm)	Soil Test P (Kelowna method) mg P kg^{-1} (0-15 cm)	Soil Test K (Kelowna method) mg K kg^{-1} (0-15 cm)
Crop Group		% of fields in High or Very High rating classes in brackets‡		
Forage grass	45	88 c* (33%)	140 b (84%)	175 b (42%)
Forage corn	31	137 bc (61%)	168 b (100%)	238 a (62%)
Vegetables	30	173 ab (73%)	187 b (100%)	166 b (47%)
Blueberries	30	215 a (73%)	152 b (97%)	138 b (27%)
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Nursery	22	99 bc (36%)	126 b (91%)	168 b (45%)
Region†		% of fields in High or Very High rating classes in brackets		
West Delta	25	110 ab (48%)	160 b (100%)	222 ab (76%)
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E. Chilliwack	37	96 b (30%)	145 b (92%)	179 bc (46%)
All fields	177	138 (55%)	172 (94%)	177 (45%)

* Means in the same column followed by the same letters are not significantly different (p <0.05) according to Bonferroni's multiple comparison test.
† Regions as shown in Fig. 1.
‡ High or Very High rating classes are defined in Table 2.

The average soil nutrient values also differed by region (Table 4). In some cases, the results by region were consistent with the results by crop group. For example, East Chilliwack had the lowest average PHNT value (96 kg NO_3-N ha^{-1}) and most of the fields surveyed in East Chilliwack had forage grass or nursery crops, both of which had low average PHNT values (Table 5). Both blueberries and vegetables were sampled in Sumas, and Sumas had one of the highest average PHNT values. Sampling in South Abbotsford included the largest number of blueberry fields (n=14), and the region had the highest average PHNT value. Half of the fields surveyed in South Abbotsford were also in the P-rich raspberry group, and South Abbotsford had the highest average soil test P value (253 mg P kg^{-1}).

Potassium results differed by region. The regions with high or very high average soil test K values were not correlated with the crop groups (forage corn, raspberries and forage grass) that had the highest average soil test K values. West Delta and West Sumas had the highest average soil test K values among the regions at 222 and 266 mg K kg^{-1}, respectively, but the two regions only had forage grass in common (Table 5). Forage corn had the highest soil test K result, but there were no forage corn fields surveyed in West Delta. This suggests the K results in West Delta and West Sumas were influenced by factors other than crop type.

Information about nutrient application rates was collected from growers who volunteered their fields for the 2012 survey. The application of manure explains some variation in the PHNT results (Table 5, Appendix D). The average PHNT value of vegetable fields in West Delta (Table 5) was high in part because three of these fields had PHNT values greater than 200 kg NO_3-N ha^{-1}. Excluding these three fields would have decreased the average PHNT of vegetable fields in West Delta from 134 to 93 kg NO_3-N ha^{-1}. Across the LFV, the PHNT value in manured vegetable fields was more than double the value in non-manured fields. Similarly, manured blueberry fields increased the variation in results. The standard deviation for PHNT values of blueberry fields in South Abbotsford was very large (223 kg NO_3-N ha^{-1}), and the average PHNT value would have decreased 10% if the two manured fields were excluded (BC Ministry of Agriculture 2015a).

Table 5. Soil nutrient test results in 2012 by region-croup group combinations, for post-harvest nitrate (PHNT), phosphorus (P), and potassium (K) results.

Region	Crop Group	n*	PHNT kg NO_3-N ha^{-1} (0-60 cm depth)			Soil Test P mg P kg^{-1} (0-15 cm depth)			Soil Test K mg K kg^{-1} (0-15 cm depth)		
			Average	Median	SD†	Average	Median	SD	Average	Median	SD
West Delta	Forage grass	5	17a‡	10	17	176a	172	23	215a	212	77
	Vegetables	15	134a	114	116	162a	155	55	230a	227	44
	Blueberries	5	132a	100	97	137a	107	64	204a	185	71
Mt. Lehman /Bradner	Forage grass	10	110ab	106	56	123a	102	78	131a	110	92
	Blueberries	5	199a	180	130	99a	112	41	151a	146	48
	Nursery	7	62b	69	38	85a	81	52	135a	137	60
South Abbotsford	Forage grass	5	95b	77	75	177a	150	168	192ab	222	118
	Blueberries	14	276a	219	223	197a	129	161	121b	106	50
	Raspberries	19	123b	102	82	314a	258	216	178a	164	63
West Sumas	Forage grass	9	117a	99	76	140a	94	102	258a	254	134
	Forage corn	12	157a	146	73	184a	168	87	271a	296	106
Sumas	Forage grass	5	99a	91	27	191ab	146	149	157ab	150	70
	Forage corn	8	163a	125	112	119ab	95	79	207a	134	136
	Vegetables	15	213a	195	119	211a	204	55	102b	83	55
	Blueberries	6	156a	167	86	105b	88	65	110ab	98	38
East Chilliwack	Forage grass	11	68a	54	68	101b	108	58	129b	132	63
	Forage corn	11	95a	91	49	187a	156	85	223a	245	117
	Nursery	15	117a	87	79	145ab	130	74	183ab	179	55

* n, number of fields

† SD, Standard deviation

‡ Averages in the same column and within a region followed by the same letters are not significantly different (p<0.05) according to Bonferroni's multiple comparison test.

There was an interaction between crop group and year for PHNT (p=0.023) but not for soil test P or soil test K. The PHNT values differed between survey years for vegetables and raspberries but in opposite directions: the average PHNT was greater in 2012 than 2005 for vegetables, and lesser for raspberries (Fig. 4). The PHNT was similar between 2005 and 2012 for the other crop groups surveyed.

There was also an interaction between region and year for PHNT (p=0.007) but not for soil test P or soil test K. In Sumas, the PHNT was greater in 2012 than in 2005 by 180% or 112 kg N ha^{-1} for all crop groups.

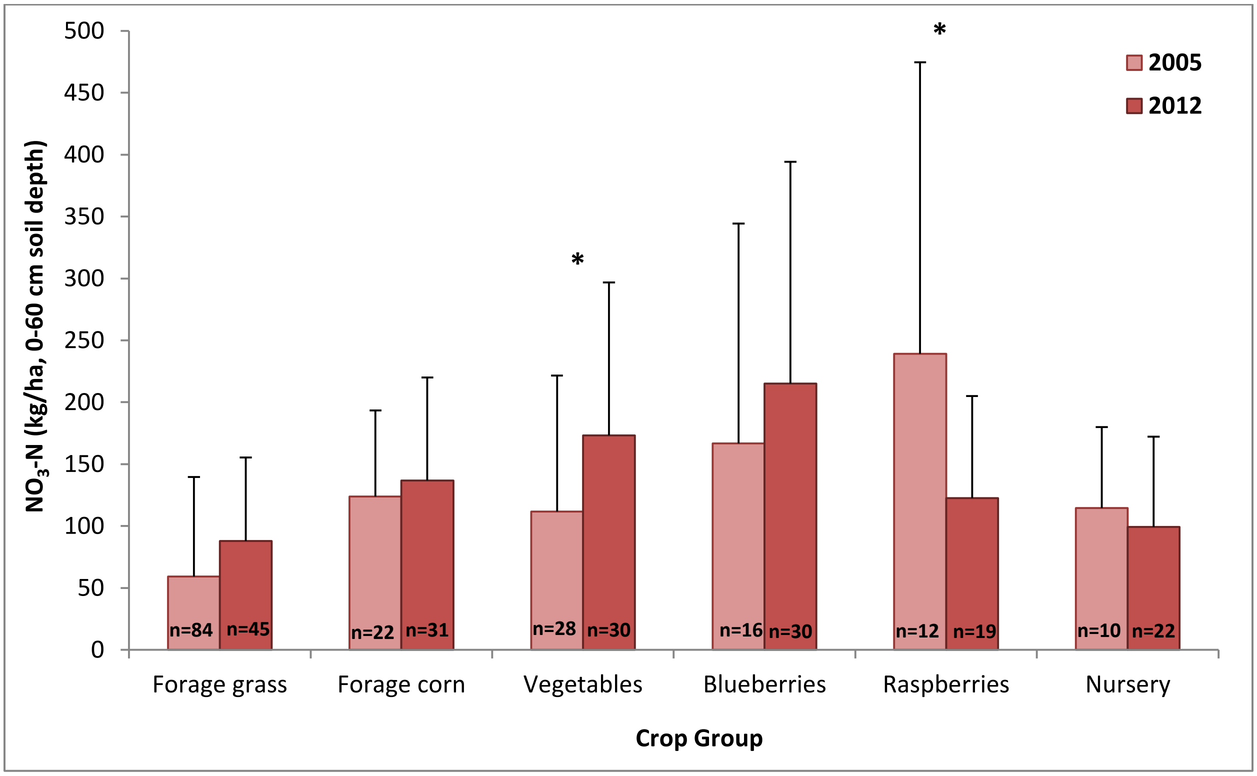

Figure 4. Average post-harvest nitrate test results by crop group and year. An asterisk (*) indicates averages that differ between the two years for a given crop group. Black bars indicate standard deviation.

4 Discussion

4.1 Nitrogen

Even if producers followed production recommendations and applied nutrients at agronomic N rates, greater PHNT values may be expected for some crop groups relative to others. Any comparison of PHNT values between crop types must recognize that different crops have different abilities to take up soil nitrate. This is why Cogger and Sullivan (2003) provide different PHNT interpretations for forage corn and forage grass in the Pacific Northwest (including the LFV), and they provide interpretations for no other crops. Low PHNT values are favoured in some cropping systems, which may take up N in excess of their requirements or have a long duration of N uptake relative to other crops (e.g., forage grasses). In contrast, high PHNT results are favoured in other cropping systems such as highbush blueberries (*Vaccinium corymbosum),* which have relatively shallow roots and prefer not to take up nitrate as an N source (Darnell and Hiss 2006). Not surprisingly, blueberries had the highest average PHNT value among the crop groups surveyed in 2012 and forage grasses had the lowest.

With blueberry fields, very high PHNT values in 2012 were consistent with results of the 2005 survey, particularly when comparing the non-manured fields in both years (Kowalenko et al. 2007; BC Ministry of Agriculture 2014b). Previously, acidic soil conditions that are typical in blueberry fields were thought to inhibit nitrification and thus nitrate accumulation. More recently, Zebarth et al. (2015) found that such inhibition occurs only at pH levels below 4.2. Only 15% of the blueberry fields sampled had soil pH (0-30 cm) below 4.2, and the ratio of nitrate to ammonium in the PHNT samples was greater in the blueberry samples than in samples of other crop types (data not shown). Thus, the high PHNT results in blueberry fields suggest nitrate accumulation (from nitrification of excess ammonium fertilizer) and minimal crop uptake of nitrate.

Vegetable fields had similarly high PHNT values as blueberry fields in 2012. The PHNT values from the 15 vegetable fields sampled in Sumas were higher in 2012 than 2005, which can partly be explained by the effect of weather conditions leading up to sampling. In Sumas in 2005, PHNT was likely underestimated due to late sampling in the region after heavy rainfall had leached some nitrate: a total of 245 mm of rain fell before the end of the field vegetable sampling period in 2005 (BC Ministry of Agriculture 2014c; Kowalenko et al. 2007). In the 2012 survey, there were no signs of nitrate leaching within the 60 cm profile during the wet sampling period after October 11 (Appendix E), suggesting that PHNT was described accurately in 2012.

With raspberry fields, there were lower risks of overwinter nitrate leaching during the winter of 2012/13 than in 2005/06. Nonetheless, there needs to be continued attention to the potential for in-season nitrate leaching by over-irrigation and leaching during autumn renovation of bare fields using non-stable N sources (e.g., manure). PHNT does not describe the potential for either of these nitrate leaching possibilities.

Producers were not necessarily less efficient with their use of nitrogen inputs in 2012 than in 2005. High air temperatures in the summer of 2012 (Appendix A) relative to 2005 would have favoured a greater proportion of fields with high or very high PHNT values in 2012 than in 2005. These higher temperatures would have favoured a greater degree of nitrification, which would have increased PHNT (nitrate) values while decreasing ammonium. Indeed, there was 25% less ammonium at the time of soil sampling in 2012 than in 2005 on average, and the total mineral N (nitrate plus ammonium) was similar between the two survey years (Appendix F).

Efforts to improve N management in the LFV should not be limited to reducing manure applications to forage crops or transporting more manure to vegetable fields in Delta. The need to address high PHNT values and predict N availability is particularly warranted for blueberries and field vegetables, even if only chemical fertilizer is applied but especially if manure is used. Annually, 425 kg N ha^{-1} from manure was applied on average to 14 of the 30 vegetable fields sampled in 2012 (BC Ministry of Agriculture 2014c). That rate exceeds the N recommendations for any vegetable crop by two times or more, contributing to an average PHNT in the 14 fields that was 85 kg N ha^{-1} greater than in the other vegetable fields. The blueberry acreage in the LFV also increases the need to optimize N management in blueberries: over the vulnerable Abbotsford-Sumas Aquifer in South Abbotsford, blueberry fields cover an area that is 70% of the raspberry acreage (BC Ministry of Agriculture 2013, unpublished data). Across the LFV, blueberry acreage has increased over 75% to more than 20,000 acres from 2006 to 2011 (Statistics Canada 2016).

Because the amount of soil nitrate on a given field may fluctuate substantially through time, more sampling is required from several years representing dry and wet, and warm and cold growing seasons, to describe multi-year trends in PHNT. Another limitation of the sampling method used in this survey, as in the 2005 survey, was that inter-row areas between planted rows of blueberries or raspberries were not sampled. Thus, while PHNT results can be used to indicate the amount of nitrate in the root zone not used by a crop, the PHNT results for the two berry crop groups likely overestimate the risk of overwinter leaching on a whole-field basis relative to the other crops.

4.2 Phosphorus and Potassium

Phosphorus (P)

Whereas soil nitrate is expected to be leached from the soil profile over the winter in the humid climate of the Lower Fraser Valley (Kowalenko 2007), soil P is rather immobile and year-to-year increases in soil test P indicate net accumulation of P. Among the 109 fields that were surveyed in 2005 and again in 2012, there was an annual average increase of 4.7 mg P kg^{-1} (Kelowna method). Although the relationship between soil test P increases and field P surpluses likely depends on multiple factors including tillage system and soil type (Messiga et al. 2015), the 2005 to 2012 increase in soil test P in the LFV was within the range predicted by an annual surplus of 24 to 60 kg P ha^{-1}, based on relationships between crop P surpluses and soil test P increases in Quebec soils (Giroux et al. 1996). Indeed, the annual P surplus in horticultural field crops in the LFV was estimated recently to be 28 kg P ha^{-1} (Bittman et al. 2016, submitted). As long as field P inputs exceed crop P removal, it is expected that risk of P losses from most agricultural fields in the LFV will continue to increase.

There are likely opportunities to reduce unnecessary fertilizer P costs, particularly for high value horticultural crops. More than 50% of the raspberry fields sampled did not receive chemical P fertilizer, but those that did received an average of 33 kg P ha^{-1} (67 lb P_2O_5 ac^{-1}) in 2012 (BC Ministry of Agriculture 2014b). More than 75% of the vegetable fields in the 2012 survey received chemical fertilizer at an average rate of 60 kg P ha^{-1} (122 lb P_2O_5 ac^{-1}), in some cases in addition to manure P (BC Ministry of Agriculture 2014c). Since all of these fields had high or very high soil test P ratings, the P fertilizer provided little to no economic benefit according to the B.C. Ministry of Agriculture's fertilizer recommendations (Gough 1991). About 60% of the blueberry fields sampled received fertilizer P (BC

Ministry of Agriculture 2015a), but any economic benefit of these applications is unclear since soil test P alone is not a reliable predictor of blueberry crop response to fertilizer P (Hart et al. 2006).

Although a higher rating of soil test P indicates a greater potential for soil P to enter into runoff water (Kowalenko et al. 2007), the soil test does not fully describe the environmental risk. The extent to which that potential is realized depends on runoff and erosion losses that transport the P from the field. Raspberry fields may have high soil test P values, but the well-drained soils in which most raspberry fields are planted in the LFV do not favour runoff and erosion losses. In contrast, runoff and erosion can be significant for other soil types following crop harvest, particularly if the field is bare or poorly covered by vegetation. If the goal is to mitigate environmental risks with agricultural P, mitigation efforts should aim to control increases in soil test P (hazard factor) as well as reduce runoff and erosion losses from fields to surface waters (exposure factors).

Potassium (K)

The high soil test K values in West Delta and West Sumas were consistent with the effects of soil type or land use history. The soils in West Delta have a relatively high clay content and K-fixation capacity, favouring soil test K. Both West Delta and West Sumas have a long history of forage crop production, which favours the accumulation of K in the soil. Indeed, the percentage of forage corn and forage grass fields with high or very high soil test K increased from 44% in 2005 to 50% in 2012 (data not shown). These observations are consistent with the suggestion by Kowalenko et al. (2007) that the effect of crop-specific management practices on soil K accumulation varies by soil type across the LFV, based on patterns in soil test K at the 0-15 cm and 30-60 cm depths.

The decrease in the percentage of 'high K' fields from 2005 to 2012 was related to the greater number of berry fields sampled in the 2012 survey: 44% of blueberry fields in 2005 (n=16) had high or very high soil test K compared to 27% in 2012 (n=30), and 83% of raspberry fields in 2005 (n=12) had high or very high soil test K compared to 47% in 2012 (n=19) (data not shown). Soil test K decreased in 10 of the 11 blueberry fields that were sampled in both survey years, yet the reported K fertilizer rates from 2009 to 2012 on those fields (at least 48 kg K ha^{-1} or 51 lb K_2O ac^{-1}) exceeded crop K removal (up to 22 kg K ha^{-1} or 23 lb K_2O ac^{-1}, assuming a mature crop with a yield of 22 tonnes ha^{-1} or 10 tons ac^{-1}; Bryla and Strik 2015). Further research is needed to understand what factors (e.g., irrigation) would have decreased soil test K in the berry fields, if K fertilization rates exceeded K removal rates.

While there are no known environmental risks associated with potassium losses from soils, there are animal health concerns with elevated K in forages (grasses) fed to animals. Despite an overall decrease in the soil test K from 2005 to 2012, the proportion of fields in the conventional grass-corn rotation that had high or very high soil test K was actually higher in 2012 than in 2005. Thus, producers still need to pay attention to the accumulation of potassium in forages produced in the LFV.

5 Conclusions

To improve N management on agricultural lands in the LFV, efforts should not be limited to forage crops that are most commonly associated with dairy farms. Overall, high post-harvest nitrate levels in blueberry and vegetable fields suggest the need to improve N management practices is greatest in these crop groups, particularly those fields that receive manure. Specifically over the Abbotsford-Sumas Aquifer in South Abbotsford, concerns with fall and winter N leaching cannot be addressed by exclusively targeting raspberry fields as has been done in the past, since the blueberry acreage is 70% of the raspberry acreage over the B.C. portion of this aquifer. However, it is unclear how efficient N fertilization can be in the soil-plant systems of the berry and vegetable crops, or how much PHNT can be reduced without significant risks to crop production. Regular monitoring of PHNT would provide valuable feedback to individual growers about the effectiveness of their N management programs, particularly for those fields with a history of high PHNT values.

Phosphorus presents different challenges compared to N. From a grower's financial perspective, the costs of off-farm P inputs (e.g. fertilizer, manure) could most likely be reduced with little risk to crop yield or quality for many of the raspberry, vegetable, or blueberry fields in the LFV, and this could be confirmed by demonstrating the effects of lower P rates in trials on fields with high soil test P. It is expected that repeating the 2005 or 2012 soil nutrient surveys will show additional increases in soil test P as long as P inputs exceed P removal on agricultural fields in the LFV. Among the crop groups surveyed, raspberry fields had the greatest source of soil P to be transported to surface water. However, actual P transport may be greatest from those fields (of any crop group) that are most vulnerable to runoff and erosion, since all crop groups were rich sources of soil P. In addition to limiting field P surpluses, future efforts to mitigate P pollution should focus on understanding and controlling P transport, particularly where receiving waters are most sensitive to P loading.

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7 Appendices

7.1 Appendix A: Climate and 2012 Weather

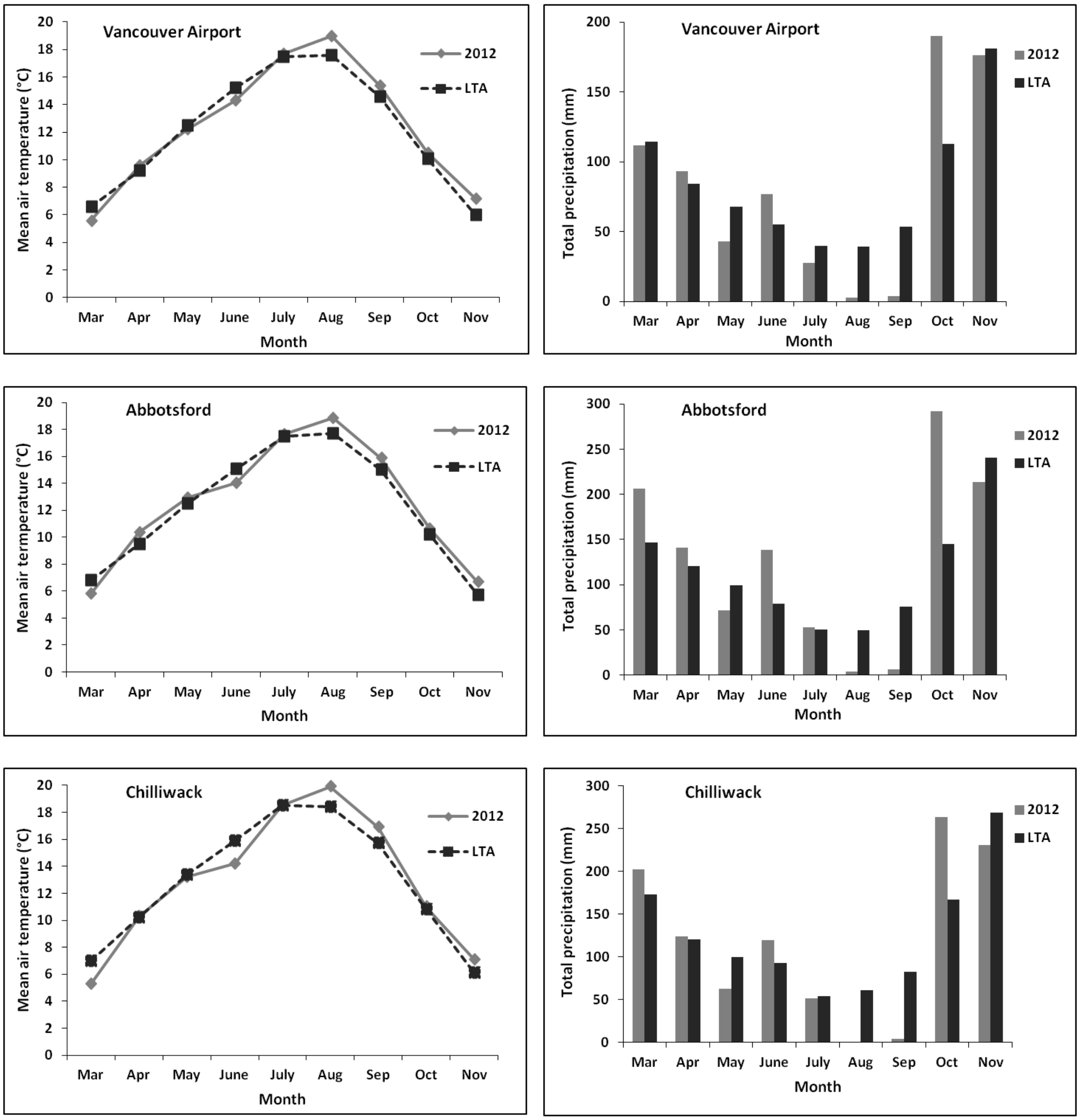

Figure B.1. Monthly average air temperature and total precipitation in 2012 as compared to the long-term average (1980-2010, LTA) at the weather stations closest to the Delta (Vancouver Airport), Abbotsford, and East Chilliwack regions.

7.2 Appendix B: ANOVA Models

Legend

X, response variable (e.g. soil nitrate-N, soil test P, or soil test K)
μ, the overall mean
R, the effect of Region
C, the effect of Crop Group
F, the effect of Field (experimental error)
SSR, the Sum of Squared Residuals, i.e. sum of squared errors of prediction (SSE) associated with

The following was used to determine effects of Region and Crop on the 2012 data:

1. $X = \mu + R + C(R) + F(R*C) / SSR$ [comparing all Crop Groups sampled per Region]

Of the 177 fields sampled in 2012 and the 172 sampled in 2005, 109 fields were sampled in both survey years and 86 had the same crop and were sampled in both survey years.

The following was used to compare the 2012 and 2005 data (all fields):

2. $X = \mu + Y + R(Y) + C(Y*R) + F(Y*R*C) / SSR$

The following was used to compare the 2012 and 2005 subsets of data (109 or 86 fields):

3. $X = \mu + R + C(R) + F(R*C) + Y + R*Y + Y*C(R) + Y*F(R*C) / SSR$

7.3 Appendix C: ANOVA Probability Tables

Table C.1. Probability levels of the nested ANOVA for the effect of Region and Crop Group on post-harvest nitrate test (PHNT), ammonium-nitrogen (N), soil test phosphorus (P), and soil test potassium (K) results in all fields sampled in 2012 (n=177).

Source of variation	df	PHNT kg NO_3-N ha^{-1} (0-60 cm)	Ammonium-N kg NH_4-N ha^{-1} (0-60 cm)	Soil Test P mg P kg^{-1} (0-15 cm)	Soil Test K mg K kg^{-1} (0-15 cm)
Region	5	0.0115	0.0287	0.0038	<.0001
C(R)‡	12	<.0001	0.045	0.0452	0.0287

‡ Crop Group within Region

Table C.2. Probability levels of the nested ANOVA for the effect of Year, Region, and Crop Group on post-harvest nitrate test (PHNT), ammonium-nitrogen (N), soil test phosphorus (P), and soil test potassium (K) results in all fields sampled in 2005 (n=172) and 2012 (n=177).

Source of variation	df	PHNT kg NO_3-N ha^{-1} (0-60 cm)	Ammonium-N kg NH_4-N ha^{-1} (0-60 cm)	Soil Test P mg P kg^{-1} (0-15 cm)	Soil Test K mg K kg^{-1} (0-15 cm)
Year	1	0.1864	<.0001	0.0509	0.2626
R(Y)‡	10	0.0055	<.0001	<.0001	<.0001
C(R*Y)§	23	<.0001	<.0001	0.0003	0.0538

‡ Region within Year
§ Crop Group within Region and Year

Table C.3. Probability levels of the nested ANOVA for the effect of Year and Region on post-harvest nitrate test (PHNT), ammonium-nitrogen (N), soil test phosphorus (P), and soil test potassium (K) results in the fields sampled in both 2005 and 2012 (n=109).

Source of variation	df	PHNT kg NO_3-N ha^{-1} (0-60 cm)	Ammonium-N kg NH_4-N ha^{-1} (0-60 cm)	Soil Test P mg P kg^{-1} (0-15 cm)	Soil Test K mg K kg^{-1} (0-15 cm)
Region	5	0.1319	0.0002	0.0106	0.0008
Year	1	0.0653	<.0001	<.0001	0.0048
R*Y	5	0.0033	0.0105	0.2028	0.0993
F(R)‡	103	0.0001	0.0578	<.0001	<.0001

‡ Field within Region

Table C.4. Probability levels of the nested ANOVA for the effect of Year, Region, and Crop Group on post-harvest nitrate test (PHNT), ammonium-nitrogen (N), soil test phosphorus (P), and soil test potassium (K) results in the fields sampled in both 2005 and 2012 with the same crop both years (n=86).

Source of variation	df	PHNT kg NO_3-N ha^{-1} (0-60 cm)	Ammonium-N kg NH_4-N ha^{-1} (0-60 cm)	Soil Test P mg P kg^{-1} (0-15 cm)	Soil Test K mg K kg^{-1} (0-15 cm)
Region	5	0.7025	0.0020	0.0489	0.0049
C(R)‡	11	0.5456	0.0811	0.7165	0.1085
Year	1	0.3838	0.0002	<.0001	<.0001
R*Y	5	0.4109	0.0105	0.5832	0.0080
C*Y(R)§	11	0.2114	0.2007	0.6564	0.0001

‡ Crop within region
§ Crop by year within region

7.4 Appendix D: Descriptive Statistics by Region

Table D.1. 2012 Post-harvest nitrate test by region.

Rating category (kg NO_3-N ha^{-1})	West Delta	Mt Lehman /Bradner	South Abbotsford	West Sumas	Sumas	East Chilliwack	All Regions
	Percentage (%) of fields in each rating class						
Low (0-49)	24	23	8	0	3	22	23
Med. (50-99)	28	23	29	33	27	48	57
High (100-200)	32	45	34	43	41	19	61
V. high (>200)	16	9	29	24	29	11	36
Statistic	kg NO_3-N ha^{-1} (0 to 60 cm)						
Mean	110	115	175	140	174	96	138
Std Deviation[a]	110	90	168	77	109	70	108
Minimum	3	18	23	53	22	8	3
1st quartile	47	54	89	89	91	52	68
Median	81	103	106	110	136	82	102
3rd quartile	125	156	223	199	270	112	178
Maximum	436	326	676	281	366	261	676

a. standard deviation based on a sample

Table D.4. 2012 Soil test phosphorus (Kelowna method) by region.

Rating category (mg P kg^{-1})	West Delta	Mt Lehman /Bradner	South Abbotsford	West Sumas	Sumas	East Chilliwack	All Regions
	Percentage (%) of fields in each rating class						
Low (0-20)	0	5	0	0	0	3	1
Med. (21-50)	0	9	8	5	0	5	5
High (51-100)	16	36	16	28	32	16	23
V. high (>100)	84	50	76	67	68	76	71
Statistic	mg P kg^{-1} (0 to 15 cm)						
Mean	160	105	253	165	168	145	172
Std Deviation	53	65	200	95	93	80	123
Minimum	86	17	23	43	53	14	14
1st quartile	105	66	103	69	95	100	35
Median	155	98	189	133	167	130	147
3rd quartile	199	143	326	255	232	165	222
Maximum	253	284	874	336	463	381	874

Table D.3. 2012 Soil test potassium (Kelowna extraction) by region.

Rating category (mg K kg^{-1})	West Delta	Mt Lehman /Bradner	South Abbotsford	West Sumas	Sumas	East Chilliwack	All Regions
	Percentage (%) of fields in each rating class						
Low (0-80)	0	23	13	0	20	8	12
Med. (81-175)	24	45	50	29	59	46	44
High (176-250)	48	27	26	14	12	27	25
V. high (>250)	28	5	11	57	9	19	19
Statistic	mg K kg^{-1} (0 to 15 cm)						
Mean	222	137	159	266	136	179	177
Std Deviation	58	74	74	118	92	88	92
Minimum	122	30	60	96	45	32	30
1st quartile	176	82	98	157	83	112	104
Median	226	135	149	286	106	166	160
3rd quartile	258	185	217	342	160	240	236
Maximum	332	298	314	476	489	477	489

7.5 Appendix E: Distribution of Nitrate by Soil Depth in Fields Sampled Late

Table E.1. Soil nitrate by depth in the six fields sampled on October 22 or 24 of 2012, after 150 mm of rainfall accumulated since September 1, 2012.

		mg NO_3-N kg^{-1} in October 2012		
Region	**Field # / Crop**	**0-15 cm**	**15-30 cm**	**30-60 cm**
Mt Lehman /Bradner	1 / Forage grass	55	19	6
	2 / Forage grass	34	11	9
South Abbotsford	3 / Blueberries	117	47	25
West Sumas	4 / Forage grass	24	7	2
Sumas	5 / Forage corn	16	20	14
	6 / Vegetables	17	21	15

7.6 Appendix F: Soil Ammonium-Nitrogen during Post-Harvest Nitrate Sampling

Table F.1. Comparison between 2012 and 2005 of average mineral nitrogen (N) at the time of the post-harvest nitrate test in both surveys.

			Ammonium-N	**Nitrate + Ammonium-N**
Comparison	Year	**n**	kg N ha^{-1} (0-60 cm)	kg N ha^{-1} (0-60 cm)
All fields	2012	177	23 b†	161
	2005	172	39 a	141
Same fields	2012	109	22 a	147
	2005	109	38 b	140
Same fields same crop	2012	86	24 b	150
	2005	86	40 a	152

† Averages within columns and the same comparison followed by different letters are different ($p<0.05$) according to Bonferroni's multiple comparison test (lower case letters).