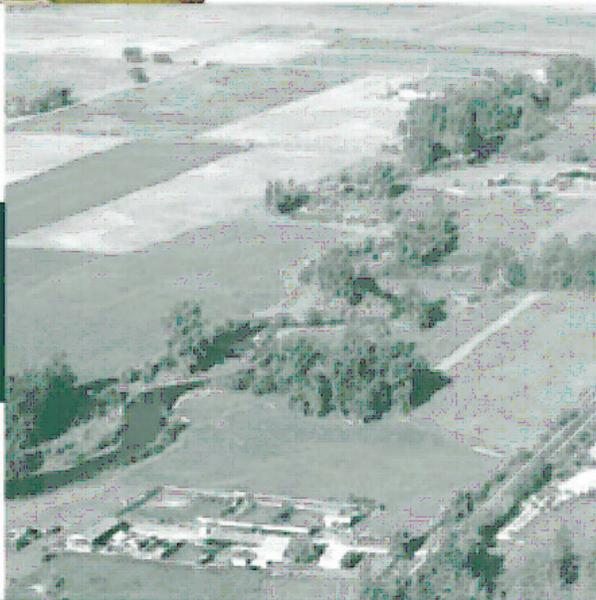


# Fraser Valley Soil Nutrient Study 2005

The Canada – British Columbia  
Environmental Farm Plan Program  
*delivered by the*  
British Columbia Agriculture Council



Canada 





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## A Survey Of The Nitrogen, Phosphorus And Potassium Contents Of Lower Fraser Valley Agricultural Soils In Relation To Environmental And Agronomic Concerns

Prepared by:

C. Grant Kowalenko, PhD, PAg <sup>1</sup>

Orlando Schmidt, PAg <sup>2</sup>

Geoff Hughes-Games, PAg <sup>3</sup>

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<sup>1</sup> Research Scientist, Agriculture and Agri-Food Canada, Pacific Agriculture Research Centre – Agassiz, [kowalenkog@agr.gc.ca](mailto:kowalenkog@agr.gc.ca), 604-796-2221

<sup>2</sup> Environmental Soil Specialist, BC Ministry of Agriculture and Lands, Abbotsford, [orlando.schmidt@gov.bc.ca](mailto:orlando.schmidt@gov.bc.ca), 604-556-3101

<sup>3</sup> Provincial Soil Specialist, BC Ministry of Agriculture and Lands, Abbotsford, [geoff.hughesgames@gov.bc.ca](mailto:geoff.hughesgames@gov.bc.ca), 604-556-3102



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Funding for the project was provided by: Agriculture and Agri-Food Canada, Environment Canada and BC Ministry of Agriculture and Lands.

### Contributors

Over 115 farmers and landowners volunteered to allow access to their fields in order that soil samples could be collected for this project. The project steering committee gratefully acknowledges the contribution of these unnamed individuals.

Project steering committee members included:

- BC Ministry of Agriculture and Lands – Orlando Schmidt (project coordinator), Geoff Hughes-Games, and Kim Sutherland.
- Agriculture and Agri-Food Canada – Grant Kowalenko (lead scientist), Elizabeth Kenney (pedologist), Philip Bergen (finance), Terry Dash (PFRA)
- BC Agriculture Council (Cornie Hertgers – dairy, Allen James – poultry, Brian Baehr – finance)
- Environment Canada – George Derksen
- BC Ministry of Environment – Mike Younie / George Rushworth
- Department of Fisheries and Oceans – John Patterson
- University of British Columbia – Art Bomke
- University College of the Fraser Valley – Rose Morrison

In addition to the steering committee, a number of other employees and contractors carried out the specific tasks required to complete the study. Recruiting of volunteers and coordination of sampling schedules was carried out superbly by MAL coop student **Ella Monro**. Phase A sampling was assisted by **Rob Bouchard** (excavator operator) and **Andrew McGowan** (sampling and backfilling). In addition, PFRA employees **Gary Telford** and **Murray Lewis** came out from Alberta to assist with the Phase A soil descriptions. Phase B sampling crews included **Shamus Baillie, Kevin Point, Eddy Davila, Sonja Ring, Chris Van Kleeck**, and **Natalia Kobylt**. Soil crushing and sieving was conducted by **Andrew McGowan, Shamus Baillie** and **Pamela Babuin**. In the laboratory, Grant Kowalenko had the team of **Dean Babuin, Cornelis Van Laerhoven**, and **Shamus Baillie**.



# TABLE OF CONTENTS

## Part 1: Executive Summary

---

1	INTRODUCTION: WHY WE CONDUCTED THE STUDY.....	9
2	METHODOLOGY: WHAT WE DID .....	10
3	DISCLAIMER FOR INTERPRETATION OF RESULTS .....	11
4	KEY FINDINGS: WHAT WE KNOW NOW.....	11
4.1	Phase A: .....	11
4.2	Phase B: .....	11
5	CONCLUSIONS.....	12
5.1	Nitrate-Nitrogen.....	12
5.2	Phosphorus.....	13
5.3	Potassium.....	13
5.4	General Conclusions for all Nutrients.....	13
6	RECOMMENDATIONS: WHAT SHOULD WE DO NEXT? .....	14

## Part 2: Scientific Report

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7	INTRODUCTION.....	17
8	MATERIALS AND METHODS .....	19
9	RESULTS AND DISCUSSION.....	23
9.1	Residual inorganic nitrogen (nitrate and extractable ammonium).....	23
9.1.1	Selection of measurement methods to evaluation the environmental risk of nitrogen .....	23
9.1.2	Effect of sampling time and selected physical and chemical factors on residual measurements.....	23
9.1.3	Selection of environmental risk classes .....	24
9.1.4	Distribution in regions and among crops (Phase B samples) .....	25
9.1.5	Comments .....	27
9.2	Phosphorus.....	28
9.2.1	Proposed environmental status measurement methods and associated risk classes .....	28
9.2.2	Examination of specific environmental assessment methods and association to soil test analyses on Phase A samples.....	29
9.2.3	Distribution of environmental risk potentials of Phase B fields .....	32
9.2.4	Comments .....	33
9.3	Potassium .....	34
9.3.1	Proposed classes for the potassium status of fields and relationship of water extraction and binding measurements with soil test values (A-series samples) ....	34
9.3.2	Comparison of measurements by Mehlich-3 and Kelowna solutions (A-series samples) .....	35
9.3.3	Evaluation of K/Mg ratios (A-series samples).....	36
9.3.4	Distribution according to agronomic classes (B-series samples) .....	36
9.3.5	Comments .....	37

9.4	Comparison of nitrogen, phosphorus and potassium environmental rankings in selected regions.....	37
10	PRACTICAL IMPLICATIONS.....	39
11	REFERENCES.....	39
12	TABLES .....	43

## **Part 1:**

# **Executive Summary**



## 1 Introduction: Why we conducted the study

Soils within the Fraser Valley of British Columbia are among the most fertile in Canada, attracting a diverse range of agricultural production. Optimal crop production in the region requires adequate fertilization, which is supplied by a combination of inorganic fertilizers and animal manures.

As livestock density within the region has increased and land use practices have shifted towards intensive horticulture production, census based nutrient balance models have pointed toward nutrient surpluses within the region. However, there has been a lack of scientific data that quantifies soil nutrient concentrations on a regional basis and by crop type.

Under the guidance of the BC Nutrient Management Working Group, this study was undertaken during the cropping season of 2005 to determine soil nitrogen, phosphorus and potassium status of agricultural soils in the Lower Fraser Valley. This timing means that current Environmental Farm Planning and Beneficial Management Practice program activities would not have had time to impact the study results.

The study was designed to create a baseline data set to monitor the effectiveness of Agriculture Policy Framework activities, including the Canada-British Columbia Environmental Farm Plan (EFP) Program and its Nutrient Management Planning subcomponent. Agencies expect to use the results of the study to help ensure that current and future environmental programs best address environmental needs.

A related objective was to develop new testing procedures for assessing environmental risk associated with soil nutrient concentrations. It was also anticipated that the results of the study would complement the Regional Agri-Environmental Scan completed in early 2003 and provide more detailed input into other APF activities such as NAHARP (National Agri-Environmental Health Analysis and Reporting Program).

The study was authorized by the BC APF Environment Chapter Working Group. Cash funding for the project totalling approximately \$123,300, came from the following government agencies: Agriculture and Agri-Food Canada (\$77,500), Environment Canada (\$23,000) and BC Ministry of Agriculture and Lands (\$22,800).

This Executive Summary outlines some of the key findings from the full scientific report originally prepared by Dr. Grant Kowalenko, titled *Preliminary Report On A Survey Of The Nitrogen, Phosphorus And Potassium Contents Of Lower Fraser Valley Agricultural Soils In Relation To Environmental And Agronomic Concerns* – which now forms the main body of this document.

## 2 Methodology: What we did

The study was specifically designed to capture a statistically representative sample of soil parent materials and cropping practices throughout the geographic extent of the Lower Fraser Valley between the municipalities of Agassiz and Delta. The distribution and number of sampling sites were selected in part to allow for the study to be used in future monitoring of trends in soil nutrient content.

The soil sampling component of this project was broken into two phases. Phase A, which involved collection of samples from soil pits was designed to develop improved testing techniques for assessing environmental risks associated with soil nutrient status, particularly phosphorus and potassium. Samples were collected from 54 fields between May and August 2005.

Phase B, which utilized conventional soil core sampling, was designed primarily as a survey to obtain baseline data on average soil nutrient concentrations for selected areas and crop types. Six different geographic zones (West Delta, West Matsqui, South Matsqui, Abbotsford (divided into two sub-zones: West Sumas and Sumas), and East Chilliwack – see Figure 1), and six major crop groups (forage grass, forage corn, annual horticulture crops, perennial horticulture crops, blueberries, and raspberries) were sampled. The geographic zones selected represent economically important production areas where contrasting surpluses of nutrients were calculated in previous census based studies. Samples were collected between September 21 and October 31, 2005 from 172 fields.

Concurrent with Phase B sampling, weekly sampling was conducted on four benchmark sites to monitor nitrate changes through the sampling period (e.g. due to mineralization, leaching, and denitrification).

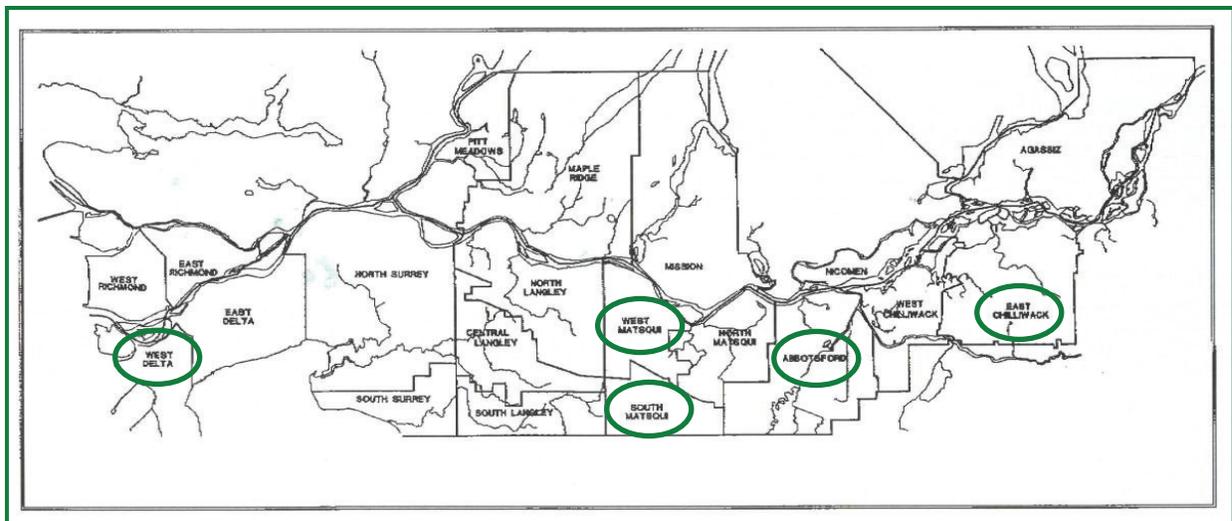


Figure 1: Map of geographic zones sampled in Fraser Valley Soil Nutrient Study (note that in reporting results, the Abbotsford zone was split into West Sumas and Sumas)

### 3 Disclaimer for Interpretation of Results

Great care was taken to follow scientific methods in this study. This included collecting three replicates of samples from each field and use of various quality assurance and control procedures during the laboratory analysis to verify accuracy of results. Nonetheless, there is a substantial degree of inherent variability in soil testing. Further, it must be acknowledged that participation in the study was strictly voluntary and some bias in site selection was possible. In short, caution should be used in interpreting of the results.

Caution should also be used in considering proposed environmental risk classes. The study focused strictly on the potential for nutrients being lost from the soil assuming theoretical knowledge about processes and relationships but did not assess impacts of nutrient concentrations on receiving environments (e.g. ground water or surface water).

## 4 Key Findings: What we know now

### 4.1 Phase A:

A key finding from Phase A was that phosphorus results with the Kelowna soil extraction method (an agronomic test) correlated well with the water extractable phosphorus test (an environmental test). In short, this means that the Kelowna soil test has good potential for use as a measure of environmental risk.

Based on Phase A results, it was proposed that agronomic rating classes (e.g. low, medium, high, very high) according to Kelowna extraction would be suitable for proposed environmental risk classes for phosphorus and potassium in interpreting Phase B results.

### 4.2 Phase B:

Summary Table 1 below presents the proposed environmental risk classes for assessment of soil nitrogen, phosphorus and potassium. Summary Table 2 presents the average results from Phase B sampling, sorting the data by region and crop.

<b>Summary Table 1: Proposed Environmental Risk Classes for Interpretation of Phase B Results</b>			
<b>Nutrient</b>	<b>Nitrate - Nitrogen</b>	<b>Kelowna Test Phosphorus</b>	<b>Kelowna Test Potassium</b>
Unit of Measure	kg NO <sub>3</sub> -N ha <sup>-1</sup> (0 – 60 cm depth)	mg P kg <sup>-1</sup> (0 – 15 cm depth)	mg K kg <sup>-1</sup> (0 – 15 cm depth)
<b>Proposed Environmental Risk Classes</b>			
Low	0 – 49	0 – 20	0 – 80
Medium	50 – 99	20.1 – 50	81 – 175
High	100 – 200	50.1 – 100	176 – 250
Very High	> 200	> 100	> 250

<b>Summary Table 2: Average Soil Nutrient Contents by Location and by Crop for Phase B</b>				
<b>Nutrient</b>		<b>Nitrate - Nitrogen</b>	<b>Kelowna Test Phosphorus</b>	<b>Kelowna Test Potassium</b>
Unit of Measure		kg NO <sub>3</sub> -N ha <sup>-1</sup> (0 – 60 cm depth)	mg P kg <sup>-1</sup> (0 – 15 cm depth)	mg K kg <sup>-1</sup> (0 – 15 cm depth)
<b>By Location</b>				
	# of fields	(percent high to very high environmental risk class in parentheses)		
West Delta	23	128 ab <sup>1</sup> (43%)	158 ab (91%)	253 a (87%)
West Matsqui	27	97 b (41%)	66 e (55%)	141 c (26%)
South Matsqui	30	149 a (43%)	184 a (80%)	199 b (56%)
West Sumas	17	104 b (47%)	120 cd (82%)	224 ab (59%)
Sumas	28	57 c (11%)	110 d (89%)	126 c (14%)
East Chilliwack	47	56 c (17%)	138 bc (83%)	197 b (51%)
<b>Overall</b>	<b>172</b>	<b>93 (31%)</b>	<b>131 (80%)</b>	<b>187 (47%)</b>
<b>By Crop</b>				
	# of fields	(percent high to very high environmental risk class in parentheses)		
Grass	84	54 d (14%)	102 d	167 c
Forage corn	22	114 c (50%)	153 b	239 a
Annual horticulture	28	102 c (33%)	128 bc	190 c
Perennial horticulture	10	105 c (60%)	111 cd	166 c
Raspberries	12	219 a (58%)	285 a	237 ab
Blueberries	16	153 b (50%)	157 b	190 bc
<b>Overall</b>	<b>172</b>	<b>93 (31%)</b>	<b>131 (80%)</b>	<b>187 (47%)</b>
<sup>1</sup> Values within columns, for location and for crop, followed by the same letter are not significantly (P=0.05) different according to Least Significant Difference statistical test				

## 5 Conclusions

This study reflects the current status of soil nutrient levels over the study area prior to the full implementation of the Environmental Farm Planning Program and prior to the potential effects of implemented BMP's (Beneficial Management Practices) carried out under the National Farm Stewardship Program. Both of these programs were initiated under the Agricultural Policy Framework of 2003.

### 5.1 Nitrate-Nitrogen

- About 1/3 of farms were in the high to very high environmental risk class for residual nitrate-nitrogen. While many farms are demonstrating good nitrogen management, some cautions need to be raised.

- Non-grass crops (intensive horticulture and forage corn) were significantly higher than perennial grassland (131 versus 53 kg NO<sub>3</sub>-N ha<sup>-1</sup>).
- Crops with greatest soil nitrate contents were raspberries and blueberries. Sampling method may have introduced slight bias towards higher values.
- Variability was quite high for nitrate nitrogen. This is not surprising as nitrogen is not stable in the soil and numerous factors, some outside of the control of the farmer, can influence residual nitrate levels.
- Data from benchmark sites indicates some leaching of nitrates below the sampling depth (60 cm) likely occurred after mid-October. Much of the sampling in Sumas and East Chilliwack occurred after this, which could partially explain lower residual nitrate values in those regions.
- Definition of environmental risk classes for residual soil nitrate is debatable and needs careful consideration.

## **5.2 Phosphorus**

- 80% of all fields were in the high to very high environmental risk class for phosphorus in the 0-15 cm depth. These represent immediate risk due to surface runoff.
- Crops with greatest soil phosphorus contents were raspberries, blueberries and forage corn.

## **5.3 Potassium**

- 47% of all fields were in the high to very high Kelowna extractable potassium classes in the 0-15 cm depth. Environmental implications are not clear.
- There are potentially important agronomic implications for high potassium in soils (e.g. high potassium forages can result in cattle health impacts).

## **5.4 General Conclusions for all Nutrients**

- A small percentage of fields with extremely high nutrient values strongly influenced average values upwards.
- Overall, there was not a very good correlation between predicted nutrient surpluses from census based information with actual soil nutrient concentrations. However, both the soil nutrient assessment and the budget calculation show that there needs to be serious attention to accumulations of nitrogen, phosphorus and potassium.

## 6 Recommendations: What should we do next?

The excellent cooperation from producers in this study demonstrates the interest by farmers in gathering data that can help to better manage nutrients, with the ultimate goal of protecting air, soil, and water quality in the region. Just as producers assisted in collecting this data, producer input is important in identifying solutions to concerns that have been highlighted.

The scientific report does not provide management recommendations but makes some suggestions on further work to better understand the implications of this study. They include:

- Conduct more detailed examination of study results, particularly for fields with very high nutrient contents.
- Conduct additional alternative laboratory measurements.
- Further refine and develop soil analysis procedures and methods.
- Other field studies to better understand actual linkages between soil nutrients and surface or ground water impacts.

## **Part 2:**

# **Scientific Report**



## 7 INTRODUCTION

The combination of the mild climate and fertile soils of the Lower Fraser Valley is highly suitable for the production of a wide range of agricultural products. The area contains a large population and considerable industrial activity resulting in high land values. These pressures on available land require production of a large amount of high value agricultural products to be economically sustainable, such that intensive management is used. Several studies have calculated that large quantities of nutrients are applied to the land, especially those associated with animal production, to the point where there are excesses relative to crop requirements (Brisbin 1996; Schreier et al. 2003). These calculations have been based on Census of Canada data, but the implications of what is happening to the soil have not been examined. This study, then, attempts to determine if three primary plant nutrients (nitrogen, phosphorus and potassium) are accumulating in Lower Fraser Valley soils to result in current or imminent agronomic or environmental problems.

The agronomic problems that could occur from the accumulation of these nutrients include reduced yields and poor quality of crops, resulting in direct and indirect economic losses. Environmental problems include the pollution of air and water (both surface and subsurface). There has been considerable research (Kowalenko 2000) and policy attention has been given to nitrogen especially as a result of nitrate pollution of the Abbotsford-Sumas aquifer. Phosphorus is known to result in the eutrophication of surface freshwaters, however, the implications of increased contents in agricultural soils of the coastal region of the Fraser Valley has received limited attention (Schendel et al. 2004, Yuan and Lavkulich 1995). Elevated potassium concentrations in forage grass have been documented with evidence that these feeds are affecting the health of dairy cattle (Fisher et al. 1994), thus a current economic problem rather than an environmental concern.

The general knowledge about the behaviour of nitrogen in coastal British Columbia has been relatively well defined, however, soil tests for either agronomic or environmental interpretations have been limited to analyses of nitrate (Kowalenko 2000). Nitrate is the net product of numerous biological, chemical and physical processes, making it very dynamic in the humid climate of the coast, thus requiring cautious interpretation. Most attention to phosphorus and potassium in British Columbia has been on soil testing for agronomic purposes, hence, additional research and development of other analysis methods are required to extend the interpretation to environmental implications. This study, then, required attention to the evaluation and development of chemical analysis methods in addition to the primary objective to evaluate the relative status of nitrogen, phosphorus and potassium for agronomic and environmental purposes. Interpretation of the soil nutrient assessment information and subsequent use for recommendations or policy development must consider the validity of the methods selected for measurement.



## 8 MATERIALS AND METHODS

Three sets of soil sampling were conducted in order to examine the three different nutrients, and to develop methodologies and their interpretations. One set was sampled 4 May to 16 August 2005 and involved digging pits such that the soil could be precisely defined according to the Canadian System of Classification. This type of sampling was conducted in order to allow an examination of influence of soil classification characteristics on nutrient contents. The focus of this sampling was on phosphorus and potassium and it was assumed that time of sampling would have a minor influence on these nutrients compared to the effect of soil characteristics and histories of nutrient applications. In this set, 54 fields were sampled that were selected to provide a distribution of soils that were derived from different parent materials that predominate in the area that have been influenced by different climatic and soil forming conditions. Attempts were made to sample fields of each soil type that had contrasting histories of high versus low nutrient applications. Within each field, three pits (i.e., replicates within the field) were dug to represent the predominant soils of the field. In all three pits of the 54 fields, the soil was sampled according to depths (0-15, 15-30 and 30-60 cm) usually taken for general soil test or research field plot purposes. This resulted in 486 samples and these are called Phase A depth samples. In 29 selected pits of Phase A fields, an additional set of samples were taken to at least 1 m that represented the various diagnostic horizons as traditionally done for soil classification purposes (153 samples and are called Phase A horizon samples). The Phase A horizon samples are to be used for supplemental analyses, but no analyses have been completed for this report.

The second set of sampling was conducted 21 September to 31 October 2005 to coincide with post-harvest period to facilitate measurement of residual soil nitrate. These samples were taken with soil core devices as is traditionally done for soil test purposes. Each replicate was taken from locations that would represent the entire field, except for raspberries and blueberries. In those fields, the samples were taken only from the area within and adjacent to the row where fertilizer and sometimes manure is placed specifically. These samples would not have included the area between the rows where less nutrient may occur from the amendment, thus contents measured would be biased towards greater quantities. A total of 172 fields were sampled each in triplicate to 0-15, 15-30 and 30-60 cm depths resulting in 1548 samples and are called Phase B samples. Five "Census" regions (East Chilliwack, Abbotsford (i.e., Sumas Prairie), South Matsqui, West Matsqui and West Delta) were selected to correspond with 5 of 20 Census regions of previous nutrient budget calculations. The specific regions sampled in this study were chosen to examine areas of contrasting application surpluses with a proportional distribution of fields that represent the predominate crops grown in each region. For this report, the Abbotsford region was split into two areas, West Sumas and Sumas. The Sumas portion of the area includes a large portion recovered from draining former Sumas Lake and contains relatively coarse soils. West Sumas includes soils with a wide range in texture.

During the autumn (Phase B) soil sampling period, four Benchmark fields were selected for sequential sampling to monitor the effect of time of sampling on the nutrients, especially nitrate. The fields were selected to represent coarse and fine soils from west to east in the sampled area. The sites were designated as Delta, Abbotsford, Sumas and Chilliwack, and relate to West Delta, South Matsqui, Sumas and East Chilliwack regions. Triplicate samples were taken from each

site, however, during the first two times of sampling the replicates were bulked during the sampling (72 of 180 samples) whereas they were kept separate during the last five sampling times allowing statistical evaluation of the results. These are called Benchmark samples. The samples were taken at 0-15, 15-30 and 30-60 cm depths to correspond with the other samplings. Weather data during the sampling period were obtained from Vancouver, Abbotsford and Chilliwack airports which are close to Delta, Abbotsford/Sumas and Chilliwack sites, respectively.

Specific but different attributes were desired for the selection of fields sampled in this project for Phase A versus Phase B. Fields that represented major soil types having had contrasting historic amounts of nutrient applications were desired for Phase A whereas soils representing the distribution of fields of the major crops grown in five Census regions were desired for Phase B. Since all fields sampled were volunteered by the owners, a bias in the results (especially for Phase B) cannot be ignored. In general, there was good cooperation for sampling fields. Field management and nutrient application histories were collected for the sampled fields from the operators by a personal interview questionnaire.

The samples were kept cool by use of coolers and refrigerators after sampling until they were stabilized by air drying. After they were air dried, aggregates were broken with a wooden rolling pin and screened through a 2 mm screen. Particles greater than 2 mm were discarded. The water content in the air dry samples was determined by oven drying at 110 °C, and the content was used to convert nutrient analyses conducted on air dry samples to an oven dry basis.

The chemical analyses conducted on the samples included water (1:10 soil:solution for 1 hour), Kelowna and Mehlich-3 soil test extractions, and the determination of the amount of phosphorus and potassium that was not bound by the soil during equilibration with a potassium phosphate solution of approximately 50 mg P kg<sup>-1</sup> soil solution (1:10 soil:solution for 1 hour). The concentration of potassium in the solution was 63 mg K kg<sup>-1</sup> soil. The equilibration was conducted on an air dry weight of sample and the precise concentration was calculated to an oven dry basis. In all cases, several drops of toluene were added to the soil-solution mixtures to limit changes that could occur by microbial activity during the extractions or equilibrations. Unbound phosphorus and potassium in the equilibration treatment was calculated as the percentage of the quantity of each of the respective elements measured in the equilibration solution less the quantity of each element measured in the water extract relative to the amount of the treatment, on a unit oven dry soil weight basis.

Inorganic phosphate phosphorus was measured in the water extracts and the equilibration solutions by ion chromatography and potassium by inductively coupled argon plasma atomic emission spectrophotometry (ICP). Potassium and total phosphorus were measured in the Kelowna and Mehlich-3 extracts by ICP. Both element quantification methods are capable of measuring other elements simultaneously. Ion chromatography was able to measure anion forms of various elements, whereas ICP was able to measure various elements in the elemental form. These and other element measurements were used for further interpretation of the P and K results where possible. Mehlich-3 phosphorus saturation ratio was calculated as phosphorus concentration divided by the aluminum concentration measured by ICP in Mehlich-3 extract solutions (Pellerin et al. 2006). Similar calculations were made for Kelowna extraction. Nitrate

and ammonium were determined by flow injection analysis on 2 M KCl extractions with nitrate determined by colorimetry after nitrate was reduced to nitrite by a cadmium-zinc column and ammonium by colorimetry on a pH indicator after diffusion of ammonium through a Teflon membrane.

Total carbon, nitrogen and sulphur contents were measured on the third sampling time (first sampling time when replicates were kept separate) in the four Benchmark sites using dry ash instrumentation (Kowalenko 2001).

A variety of quality control and assurance procedures were applied during the analyses including incorporating a reference sample periodically throughout the period of analyses to monitor consistency, periodic duplicate analyses of selected study samples (analyses on duplicate extractions and duplicate analyses on extract solutions) and extract/reagent blanks in addition to instrument blank, calibration and standard chemical solutions. An internal standard (beryllium) was included to monitor and adjust for ICP instrument drift over time. Re-analyses of samples that appeared to be suspicious from comparisons of replicates were also conducted.

The results presented in this report are limited to water, Kelowna and Mehlich-3 extract analyses, and equilibration solution analyses on Phase A depth samples, 2 M KCl nitrogen analyses on Benchmark and Phase B samples, and Kelowna and Mehlich-3 analyses on Phase B samples. Nitrate and ammonium were considered as a single value for the entire 60 cm sampling depth by transforming the analyses values ( $\text{mg N kg}^{-1}$ ) to a soil profile volume basis ( $\text{kg ha}^{-1}$ ) assuming a common bulk density ( $1.1 \text{ Mg m}^{-3}$ ) for all depth samples for all fields. The conversion then, was  $\text{mg kg}^{-1} \times 1.65$  for each 15 cm depth of the profile. Statistical analyses included analysis of variance, Least Significant Difference and regressions with  $P < 0.05$  considered significant.

Samples collected for Phase A focused on ensuring that all the important soil parent material types that occur in coastal British Columbia with each soil type including contrasting intensity of nutrient application histories, and were used for evaluation of analytical methodology especially for phosphorus and potassium. Phase B samples, collected from selected regions within the Valley that have been considered to have contrasting histories of nutrient application intensities by budget calculations, were used for survey purposes. Using Phase B samples ensured that the environmental risk status of all three nutrients (nitrogen, phosphorus and potassium) was examined on the same sample set. Comparison of values between Phase A and Phase B need to be considered with caution until the effect of time (growing season for Phase A and post-harvest for Phase B) is determined on phosphorus and potassium. Further, the “replicates” in Phase A were three individual pits in a field, whereas in Phase B, each replicate was a composite of numerous cores from the entire field.



## 9 RESULTS AND DISCUSSION

### 9.1 *Residual inorganic nitrogen (nitrate and extractable ammonium)*

#### 9.1.1 **Selection of measurement methods to evaluation the environmental risk of nitrogen**

The complex and dynamic nature of nitrogen transformations and transport in soils has limited the development of soil analysis methods for both agronomic and environmental purposes (Kowalenko 2000). Development of soil test methods has been limited to measurement of nitrate, but the method has limitations. The largest pool of nitrogen in the soil is associated with organic matter, which is relatively immobile and not available for crops unless it is mineralized. Although a measurement that could predict the amount of organic nitrogen that is mineralized over a defined period of time (mineralizable nitrogen) would provide useful information for both environmental and agronomic purposes, a widely accepted method has not yet been developed (Kowalenko 2000). Hence, an assessment of the environmental pollution risk is limited to measurement of nitrate in soils, and specifically measurement of residual (i.e., post-harvest) nitrate. Measurement of KCl extractable ammonium was included for assessment since it is the other primary inorganic nitrogen form in soils.

#### 9.1.2 **Effect of sampling time and selected physical and chemical factors on residual measurements**

There was no evidence that nitrate had leached below 60 cm at the Delta and Abbotsford Benchmark site areas, whereas, there was apparent deep leaching at Sumas and Chilliwack sites between at least October 22 and 31 (Table 1). The addition of manure to Sumas and Chilliwack sites in mid September complicated the interpretation of the measurements, but it appeared that there was an apparent increase in residual nitrate at Chilliwack site as a result of manure addition. The calculation of median depth provides evidence of the progression of leaching during the sampling period, but the value will be influenced by the addition of nitrogen as manure within the sampling period. The difference in the accumulated amount of precipitation at the sites in relation to the sampling times and the texture of the soil (as shown by the air dry water content of the soils at the four sites) probably contributed to the rate of leaching. Air dry water contents at the four sites differed, which suggests that soil physical attributes could have influenced nitrate leaching. Water contents of air dry soils are known to reflect both the texture and organic matter contents resulting in differences in water retention. Sumas site was a coarse textured soil and thus prone to relatively fast leaching.

Although it could not be confirmed statistically because of combining replicate samples into one, nitrate concentrations were quite dynamic at Delta and Chilliwack sites early (September 15 – 23) during the Phase B sampling period (Table 1). At Delta site it appeared that nitrate increased from the initial sampling, possibly due to mineralization. At Chilliwack site, nitrate during the

early part of Phase B sampling period was relatively large and decreased substantially by the end of September. The decrease would likely not have been due to leaching since only 10 mm precipitation had occurred, but may have been due to immobilization (conversion of nitrate to organic N) from a flush of microbial activity. It is evident that the dynamic nature of N transformations in soils complicates the interpretation and use of “residual” soil nitrate measurements.

Total nitrogen and C:N ratio may indicate why the amount of residual nitrate at the four sites varied. Delta site had the greatest amount of residual nitrate which corresponded with a large total nitrogen content. The relatively large amount of residual nitrate at Sumas site, where total nitrogen was the smallest of the four sites may have been due to the low C:N ratio. A soil with low C:N ratio would be expected to mineralize organic nitrogen to a greater extent than one with a larger ratio. Although nutrient amendments during the season of the sampling will also influence residual nitrate, total nitrogen and carbon measurements would probably reflect the cumulative influence of historic nitrogen amendments.

These measurements show that soil samples taken late in October and especially in the eastern end of the sampling area and in soils that are of coarse texture will probably underestimate residual nitrate of fields, and data and location will need to be considered for detailed interpretation of the results. Although sampling to 60 cm depth was useful to monitor residual nitrate in September and October under the precipitation conditions that occurred during the sampling year, deeper sampling would possibly have been better. However, a deeper sampling may not have compensated for evidence of nitrate loss if the water table rose closer to the surface and resulted in denitrification (Zebarth and Paul 1997).

### **9.1.3 Selection of environmental risk classes**

Kowalenko (2000) has shown that the greatest risk of nitrate pollution of groundwater in coastal British Columbia occurs at the end of the growing season, when evaporation and transpiration of water becomes very low and coincides with the time the majority of yearly precipitation occurs. It is assumed that essentially all residual nitrate in the soil in the autumn can potentially be completely lost from leaching and denitrification. However, categorizing the amount of nitrate in the soil at the end of the growing season according to environmental risk has not been well defined for this area.

Sullivan and Cogger (2003) have proposed report-card or feedback guidelines for nutrient applications with 10 to 25 % reductions in nitrogen amendments recommended when post harvest soil nitrate to 12 inches (30 cm) reached approximately 55 lb N acre<sup>-1</sup> (62 kg N ha<sup>-1</sup>) for grass and 70 lb N acre<sup>-1</sup> (78 kg N ha<sup>-1</sup>) for forage corn for weather conditions that occur west of the Cascades. The authors recognized that timing of post-harvest nitrate testing is very important and proposed dates before which the sampling must be completed for different areas according to autumn rainfall probabilities, based on the average date when precipitation after 1 September reaches five inches (12.5 cm). Since this guideline is based on average precipitation, it may not be suitable for years of extreme autumn precipitation.

For raspberries, the B.C. Ministry of Agriculture and Lands (2005) suggests that nitrate-N concentrations greater than 55 ppm (approximately 182 kg nitrate-N ha<sup>-1</sup>) presents a significant risk of nitrate leaching. This value takes into consideration the likely enhanced nitrate-N content of the soil when samples are collected from the location of the fertilizer band.

Drury et al. (2005) have proposed much more stringent values for residual soil nitrogen for National Agri-Environmental Indicators, with contents of 30 kg N ha<sup>-1</sup> classed as high risk. Residual soil nitrogen was calculated based on a nitrogen budget model, and the depth to which nitrogen was considered was not specified. De Jong et al. (2005) proposed that the risk for nitrate for water pollution should be modified according to the amount of precipitation involved but did not document specific soil nitrate-based concentrations for risk considerations. These values were designed for nation-wide comparative calculations, and direct association with actual field measurements was not discussed.

Zebarth et al. (1995) suggested the approximately 1000 mm of water that would flow through soil from typical coastal British Columbia precipitation in excess of transpiration and evaporation would dilute 100 kg N ha<sup>-1</sup> residual soil nitrate to the 10 mg N L<sup>-1</sup> Canadian Drinking Water Guideline for groundwater nitrate. One hundred kg N ha<sup>-1</sup> residual soil nitrate is similar to a preliminary environmental limit of 90 kg N ha<sup>-1</sup> proposed for Belgium (Neuens and Rehuel 2003, Geypens et al. 2005).

Considering the above, high risk for environmental pollution of groundwater in the humid weather conditions of coastal British Columbia would occur when residual soil nitrate is 100 kg N ha<sup>-1</sup> to 60 cm sampling depth (Table 2). Although ammonium does not normally leach in the soil, the same classes were applied to residual KCl extractable ammonium for simplicity since ammonium can potentially be readily converted to nitrate in most soils.

#### **9.1.4 Distribution in regions and among crops (Phase B samples)**

Thirty-one percent of the 172 fields that were sampled had residual soil nitrate contents that were greater than 99 kg N ha<sup>-1</sup> such that they would be in the high and very high environmental risk classes selected for this study, while almost one-half (46%) were in the low risk category (Table 3). If the much more stringent national Agri-Environment Residual Soil Nitrogen risk classes were used, 71% of the fields would have more than 30 kg N ha<sup>-1</sup> to be classed as high to very high risk, and only 17% of the fields would be low risk. Mean nitrate contents were relatively large (97 to 149 kg N ha<sup>-1</sup>) in West Delta, West Matsqui, South Matsqui and West Sumas regions with 41 to 43 % of the fields in the high to very high environmental risk (Table 3). Several individual fields had particularly large nitrate contents (greater than 600 kg N ha<sup>-1</sup>). Mean nitrate contents were substantially smaller in Sumas and East Chilliwack regions, with only 11 to 17 % of the fields in high to very high risk classes and individual fields having less than 285 kg N ha<sup>-1</sup>. Although nitrate contents were possibly underestimated since these fields were generally sampled late during the sampling period, this would not entirely account for the generally low quantities. The various regions had different crop distributions and grass fields tended to contain the lowest nitrate contents of all the crops within each region. This is consistent with the

conclusion of Sullivan and Cogger (2003) and measurements by Kowalenko and Bittman (2000) of usually low nitrate contents in grass fields.

Ammonium contents in the soils were generally low, with regions having means from 20 to 51 kg N ha<sup>-1</sup> (Table 4.). The three regions that had the greatest mean ammonium contents (West Delta, West Matsqui and South Matsqui) had individual fields with relatively large ammonium contents, but over all regions, these constituted only 2 % (4 of 172) of all the fields sampled that were within the high and very high environmental risk classes. Three of the four fields that had substantial ammonium contents also contained relatively large nitrate contents (158 to 663 kg N ha<sup>-1</sup>). The fourth field, which had 105 kg ammonium-N ha<sup>-1</sup>, had 41 kg nitrate-N ha<sup>-1</sup>.

In general, raspberry and blueberry fields had greatest mean nitrate contents, while annual and perennial horticultural crops and forage corn had intermediate contents (Table 5). Grass fields had the least mean nitrate even though one field had more than 390 kg N ha<sup>-1</sup>. Grass fields, which constituted almost one-half of all fields sampled, had the lowest percentage (14%) of fields that were in the high to very high environmental risk classes. This compares to 32% for annual horticultural crops, 50% for forage corn and blueberry, 58% for raspberry and 60% for perennial horticultural crops. The relatively high nitrate contents in raspberry and blueberry crops were probably enhanced by the sampling protocol where focus was on the area that would likely have had amendments placed in bands (Zebarth et al. 2002). Some fertilizers are applied as bands on other crops such as corn (Zebarth et al. 1999), however, the influence on residual nitrogen content measurements would probably be much smaller since the sampling was random throughout the field.

Coastal Fraser Valley soils tend to contain a constant but variable background quantity of KCl extractable ammonium, probably associated with soil characteristics such as clay fixation and management practices (Kowalenko and Yu 1996). Fields where KCl extractable ammonium contents were in the high to very high environmental risk classes were largely cropped to blueberry, with one field being grass (Table 5). The possible reason for the large quantities of ammonium in blueberry fields may be from large nitrogen applications, particularly when concentrated by band placement, and low soil pH that is often desired for the crop. Low pH can limit the rate of nitrification and result in high ammonium contents. The grass field having high ammonium content may have resulted, at least in part, from application of dairy manure just prior to sampling.

Mean variability of nitrate (CV = 36%, Table 3) and extractable ammonium (CV = 35%, Table 4) in the fields was somewhat greater than previously reported (Kowalenko 1991), which probably reflects the variety of crops, management practices and soil types involved in the study fields.

An evaluation of the influence of management practices and nutrient applications on the residual nitrogen measurements was not possible because information from field operation managers was inadequate and inconsistent for quantitative (statistical) analysis.

### 9.1.5 Comments

Although the numeric values of residual nitrogen in the 172 fields reported in this study suggest a great deal of precision, variability of the measurements due to field characteristics, sampling factors (time and depth) and sample analyses must be considered. Further, the value that is reported is for the entire 60 cm profile calculated from measurements of three depth increments on a soil weight basis ( $\text{mg kg}^{-1}$ ) and transformed to a soil volume ( $\text{kg ha}^{-1}$ ) basis assuming a common bulk density for each depth in all fields. However, the sampling and sample analyses were consistent such that the values should be suitable for comparative purposes, but subject to the influence of specific factors such as sampling protocols for blueberries and raspberries.

By using the proposed  $100 \text{ kg N ha}^{-1}$  high risk value, about one-third of the fields had excessive quantities of residual nitrate. Assuming that the fields that were sampled represented nutrient applications from slightly deficient to excessive, it is concluded that the proposed risk criteria are operationally attainable to result in low to moderate risk. The classes proposed for National Agri-Environmental Indicators appear to be very stringent and would be very difficult to attain, especially crops other than grass, without major changes to nutrient management practices and yield expectations. However, it is apparent that changes to nutrient applications are required for environmental purposes, and initial focus should be on fields that are managed to result in nitrate greater than  $99 \text{ kg N ha}^{-1}$ . More detailed study should be conducted, especially on those fields with large contents of residual nitrate and ammonium, to determine how amendment applications should be changed. The analyses (residual inorganic N) conducted could not distinguish the proportion of current year applications from historic applications that result in the large amounts of residual nitrogen in specific fields. Additional measurements, such as total organic nitrogen quantity and quality (as shown in the discussion on the Benchmark sampling) may be needed. This kind of information will be necessary to refine nutrient recommendations that achieve economic yields while limiting environmental pollution. Factors such as the balance of nitrogen to other nutrients and the ability of the soil to store nitrogen in association with texture or soil classification attributes would be useful. Consideration should also be given to the concentrations assigned to the risk classes (i.e.,  $100 \text{ kg N ha}^{-1}$  of nitrate as high risk may not be sufficiently stringent), the involvement of high ammonium for environmental risk and the impact of amendment placement (e.g., banding) on data interpretation.

More focus is required on crops other than grass, however, those fields of grass with large contents of nitrate and ammonium were surprising and need special attention. The reason that nitrate is usually limited in grass fields is that the nitrogen is immobilized in soil biota and organic matter, thus there will be an accumulation of total nitrogen stored in the soil. The implications to soil nitrate should be considered when organic nitrogen mineralization is promoted such as when grass fields are cultivated for renovation or crop rotation.

The measurement of nitrate in the soil after the crop has been harvested in the autumn can indicate whether or not the N inherent in the soil and that added as an amendment was excessive for crop requirement. To obtain this assessment, sampling should be done as soon as possible after crop maturity or harvest. However, mineralization of soil or amendment N will not cease at this time and additional nitrate could be produced if the soil remains warm and moist. Delaying sampling after harvest will include a measurement of this post-harvest mineralization.

Sampling deeper than 60 cm may be required in years when precipitation is abundant early during the autumn to account for leaching. Certainly, it was important to have sampled to at least 60 cm to get a full accounting of residual nitrate within the sampling period. Deep sampling would not compensate for measuring residual nitrate where denitrification may occur such as when the water table rises close to the surface.

## 9.2 Phosphorus

### 9.2.1 Proposed environmental status measurement methods and associated risk classes

Limited research has been conducted on British Columbia soils to establish methods of analyses and their interpretation for determining the environmental risk of increasing phosphorus contents. Yuan and Lavkulich (1994, 1995) used traditional equilibration methods to examine adsorption and estimation of saturation of phosphorus in British Columbia soils. However, Kowalenko (2005) showed that many coastal British Columbia soils do not adsorb phosphorus according to traditional theory and alternate analysis methods are needed to quantify binding mechanisms. The methods selected for this study to quantify environmental implications of increasing phosphorus in soils were extraction with water and equilibration of the soil with a standard quantity of inorganic phosphorus. Water extractable phosphorus is assumed to quantify the immediate risk of phosphorus being available for transfer to waters (especially surface waters) by runoff from fields. The equilibration measurement is assumed to quantify potential future risk of phosphorus being transferred into waters when phosphorus is applied to the field, as it determines how much of the applied phosphorus is not bound by the soil and adds to the water extractable pool. Recently, Kowalenko and Babuin (2007) have shown that the most frequently used colorimetric method (Murphy and Riley 1962) for measuring phosphorus in this type of situation is subject to interference from many elements and compounds in soil extracts and appropriate methods (e.g., ion chromatography) for measuring inorganic phosphorus (i.e., phosphate anion) are essential for accurate measurement.

Phosphorus soil tests that have been developed for agronomic purposes (i.e., determining how much phosphorus amendment is required for optimum crop growth) have not been evaluated for their potential for determining environmental risk, however, it is assumed that as soil test phosphorus increases beyond contents where fertilizer is recommended it will indicate greater environmental risk but the relationship between soil test values and environmental risk has not been evaluated for British Columbia soils. The Mehlich-3 soil test extraction solution in association with the use of the measurement of aluminum to estimate degree of phosphorus saturation has been proposed as a method to determine environmental risk (Pellerin et al. 2006), but this extraction method has only received limited research attention for British Columbia soils. Most of the recent data for soil phosphorus testing has been done by Kelowna extract. These soil tests, including measurements of aluminum, were examined for their potential for use in determining the environmental risk of large phosphorus contents in coastal British Columbia soils. The evaluation of these methods was largely based on the water extraction and binding

potential measurements, since these measurements were assumed to be directly related to the potential for phosphorus in the soils to be transferred to surface waters.

The quantities of water extractable phosphorus that would constitute environmental risk have not been defined for coastal British Columbia soils. Giroux and Tran (1996) had proposed that 2.5 to 6 mg P kg<sup>-1</sup> of water extractable phosphorus would be high risk and greater than 6 mg P kg<sup>-1</sup> would be very high risk for Quebec soils. Measurements by Kowalenko (2005) on a limited number of coastal soils showed that water extractable phosphorus ranged from 0 to 16 mg P kg<sup>-1</sup> (Table 6). Samples where Kelowna values were >100 mg P kg<sup>-1</sup> contained 5 mg kg<sup>-1</sup> or more water extracted phosphorus whereas those with <100 mg kg<sup>-1</sup> Kelowna extractable phosphorus contained 2 mg kg<sup>-1</sup> or less water extracted phosphorus. Currently, when Kelowna extracted phosphorus is >100 mg P kg<sup>-1</sup>, the soil is considered to have sufficient phosphorus for crop growth and no amendment is recommended. This suggests that the environmental criteria proposed by Giroux and Tran (1996) should be applicable to coastal British Columbia soils. Measurements of the amount of phosphorus that is not bound by coastal soils when equilibrated with 50 mg P kg<sup>-1</sup> ranged from 0 (all applied phosphorus was bound) to 71%, and similar to water extracted phosphorus, the value tended to increase as Kelowna extracted phosphorus increased. Since the unbound P measurement is a new proposal for evaluating coastal British Columbia soils, there are no guidelines for interpreting them for environmental risk. However, if it is assumed that the guidelines for water extracted phosphorus are valid, they could be used to calculate guidelines for unbound phosphorus measurements. Thus, when it has been determined by the equilibrium measurement that a soil binds all but 5% of a 50 mg P kg<sup>-1</sup> treatment, it would result in 2.5 mg P kg<sup>-1</sup> in the soil solution, and would be classed as high risk according to the water extractable classes.

The risk classes that were selected for phosphorus are shown in Table 7. In addition to water extraction and unbound treatment phosphorus measurements, a combined potential pollution index is proposed. This index is an attempt to obtain one risk value by combining water extracted values for both the surface 15 cm and the immediate subsurface 15 cm plus the unbound value. It is assumed that water extracted phosphorus tends to decrease with depth of soil, and as the surface depth increases in water extracted phosphorus it will leach to the subsurface, providing evidence that the environmental risk of that soil has increased from the accumulation of excess phosphorus applications. The risk classes for Kelowna extractable phosphorus assumed that risk increases as the recommendation for amendment application rates decrease, thus very high risk occurs when no amendment is recommended. Risk classes involving an estimation of phosphorus saturation based on Mehlich-3 phosphorus and aluminum measurements are included as proposed by Giroux and Tran (1996).

### **9.2.2 Examination of specific environmental assessment methods and association to soil test analyses on Phase A samples**

Since only Kelowna, but not water and Mehlich-3, extraction was conducted on Phase B samples, assessment of the environmental status on the post-harvest sample set is limited to Kelowna extractable phosphorus and aluminum. The focus of this section is to examine the effectiveness of Kelowna extraction to evaluate risk of environmental pollution potential by comparisons to

water extracted phosphorus, phosphorus binding potential measurements and Kelowna and Mehlich-3 degree of saturation measurements on Phase A samples.

Measurements of phosphorus in water extracts by ICP analytical method were generally greater than measurement by ion chromatography with an overall greater (12%) value by ICP for all depths of all fields in the Phase A samples. The difference between the two methods of measurement varied to a small extent with depth of sampling, but management practices (crop type and intensity of nutrient applications) as well as soil characteristics (parent matter origin) had a significant effect. Measurements by ICP were up to 28% greater than measurements by ion chromatography. The ICP instrument measures total phosphorus whereas ion chromatography measures inorganic phosphate, thus it is assumed the difference between the two measurements is probably largely organic phosphorus. This shows again that it is critical that the interpretation of results and comparison of values with other studies must consider analytical methodology. The environmental pollution risk of inorganic phosphate relative to organic phosphorus is not known, but it is assumed that inorganic phosphate will have a more immediate and direct effect on surface waters than organic phosphorus. Thus, this study will focus on inorganic phosphate (i.e., measurement by ion chromatography) rather than total phosphorus in the water extract.

The amount of phosphate extracted by water was generally about 6% of the phosphorus extracted by Kelowna solution extraction ( $r^2 = 0.75$ ,  $n = 486$ ; considering all samples from all fields and three depths). This relationship varied with crop, parent material origin and soil classification order, but not by depth or relative intensity of historic nutrient applications. The relationship of water extracted phosphate with Mehlich-3 extracted phosphorus was similar except that water phosphate was about 5% of Mehlich-3 extracted phosphorus. Part of the difference in the relationship of water extraction to soil test solution extraction may be related to organic phosphorus since two different quantification methods used for analyses in the two extracts measure specific forms of phosphorus. Inorganic phosphate was measured in the water extraction and total phosphorus in the soil test extractions. Sims et al. (2002) reported that water soluble phosphorus was about 4% of Mehlich-3 extracted phosphorus ( $r^2 = 0.68$ ), but they apparently used ICP to measure phosphorus in both extracts. This shows that water extractable/soluble phosphate is only crudely proportional to the phosphorus extracted by the two soil test extract solutions. The relationship of water extracted phosphate to the two soil test extractions were similar since the amount of phosphorus in the two extracts was consistently similar ( $r^2 = 0.97$ ,  $n = 486$ ), with Mehlich-3 extracting about 42% more than Kelowna. Although the correlation between the two extractions was very close, there was evidence that the relationship was influenced by sample depth, soil characteristics (parent material origin and soil classification order) and field management (crop type). For example, the regression equations for the three depths are:

$$\begin{aligned} \text{Mehlich-3} &= -0.34 + 1.40 \text{ Kelowna for 0-15 cm} \\ \text{Mehlich-3} &= -4.18 + 1.47 \text{ Kelowna for 15-30 cm} \\ \text{Mehlich-3} &= -0.82 + 1.38 \text{ Kelowna for 30-60 cm depths} \end{aligned}$$

The close association of Kelowna and Mehlich-3 soil test solution to extract similar quantities of phosphorus is not unexpected since they contain many of the same chemicals in the solutions

that were developed to extract phosphorus specifically (e.g., Bray-P1). The make-up of the extract solutions are:

$$\begin{aligned} \text{Kelowna} &= 0.25 \text{ M acetic acid} + 0.015 \text{ M ammonium fluoride} \\ \text{Mehlich-3} &= 0.2 \text{ M acetic acid} + 0.015 \text{ M ammonium fluoride} + \\ &0.25 \text{ M ammonium nitrate} + 0.001 \text{ EDTA (a chelate)} \end{aligned}$$

The make-up of Bray-P1 solution is:

$$\text{Bray-P1} = 0.03 \text{ M ammonium fluoride} + 0.025 \text{ M hydrochloric acid.}$$

The estimations for degree of phosphorus saturation by the Mehlich-3 soil test method involves the measurement of aluminum in the extract along with phosphorus. The amount of aluminum extracted by Kelowna and Mehlich-3 extractions were highly correlated ( $r^2 = 0.95$ ,  $n=486$ ), similar to that found for phosphorus. The regression equation was:

$$\text{Mehlich-3} = -163 + 1.36 \text{ Kelowna}$$

This relationship was also influenced by depth of sampling, soil characteristics and field management conditions. With the close association of extraction of phosphorus and aluminum by the two soil test methods, it is not surprising that the estimated degree of phosphorus saturation using the corresponding elements for the calculation in each of the two extracts was highly correlated ( $r^2 = 0.94$ ,  $n = 486$ ). The two calculated values were within about 10% as the regression equation by the two methods as follows:

$$\text{Mehlich-3 degree of sat.} = 0.57 + 1.10 \text{ Kelowna degree of sat.}$$

This relationship was also affected by soil characteristics and field management, but was apparently consistent with depth of the sampling.

Binding of phosphorus in acidic soils has been associated with aluminum, iron, manganese and silicon (Pellerin et al. 2006), and with calcium and magnesium in calcareous soils (Ige et al. 2005). The quantities of aluminum, iron, manganese, calcium, magnesium and silicon in water extracts were not correlated with phosphate ( $r^2 = 0.00$  to  $0.19$ ,  $n=486$ ). This shows that if any of these elements is influencing phosphate binding, it is not directly associated with their proportions in soil water. Aluminum was found to be very closely related to iron ( $r^2 = 0.89$ ,  $n=486$ ) and silicon ( $r^2 = 0.99$ ,  $n=486$ ), but not with manganese ( $r^2 = 0.16$ ,  $n=486$ ). This suggests iron and silicon instead of aluminum could be used to calculate the degree of saturation for coastal British Columbia soils. Manganese contents in water extracts are much less than aluminum, iron and silicon, and would not predominate any binding that would occur. Although there was a close linear relationship between aluminum and iron in water extracts, the relationship in Kelowna soil test extraction was not very close ( $r^2 = 0.53$ ,  $n = 486$ ), with evidence that the relationship was non-linear with iron becoming negligible at about  $1000 \text{ mg Al kg}^{-1}$ . The linear correlation of aluminum extracted with water with that extracted by Kelowna extraction solution was negligible ( $r^2 = 0.01$ ), however, it was interesting that aluminum extracted with water was less than  $100 \text{ mg kg}^{-1}$  when Kelowna aluminum was either less than about  $600 \text{ mg kg}^{-1}$  or greater than  $1500 \text{ mg kg}^{-1}$ . When Kelowna aluminum ranged from  $600$  to  $1500 \text{ mg kg}^{-1}$ , water extractable aluminum ranged from less than  $100$  to about  $800 \text{ mg kg}^{-1}$ . Detailed examination on the relative water and Kelowna solution extractability of aluminum with

phosphorus may help to understand the mechanisms of phosphorus binding in coastal British Columbia soils.

The associations among the various environmental risk indicators that were selected varied considerably (Table 8), which shows that each indicator is relatively unique, and one cannot be used as an alternative for another. Although some of the indicators are closely related by including the same measurement, each considers a different aspect of potential pollution. For example, water extracted phosphate would be associated with immediate risk of surface water pollution, whereas unbound phosphate would consider future risk as phosphorus is added to the soil. The proposed potential-pollution-index attempts to blend immediate and future risk. The closest correlation of Kelowna extracted phosphorus was with water extracted phosphate, which indicates immediate pollution potential.

Applying the five risk indicators to the A-series sampled fields showed that water and Kelowna extractions classify similar and the largest proportion (78 and 80%, respectively) of the 54 fields as high or greater risk (Table 9). This is consistent with the correlation ( $r^2 = 0.73$ , Table 8) between water extracted phosphate and Kelowna extracted phosphorus. The pollution potential index and Mehlich-3 degree of saturation indices classified fewer soils in these two classes (48 to 53%) and the unbound phosphorus indicator resulted in the least (39%, Table 9). The similar proportion of fields classified as high and very high for pollution potential by Mehlich-3 degree of saturation indices is also consistent with the fairly close correlation ( $r^2 = 0.72$ , Table 8) found between these two measurements. These results show that using the agronomic recommendations for Kelowna extraction (Gough 1996) also provides a relatively stringent phosphorus pollution potential assessment of coastal British Columbia soils and should provide a reasonable method to evaluate the fields sampled after harvest (B-series) as used for nitrogen assessment.

### 9.2.3 Distribution of environmental risk potentials of Phase B fields

Using Kelowna extraction of the surface 15 cm of soil as the basis for the environmental assessment of fields in selected regions of the Lower Fraser Valley showed that a majority (80%) were classified as either high or very high in phosphorus pollution potential risk (Table 10). West Delta and Sumas regions had the largest proportion (91 and 89%, respectively) in high to very high risk and West Matsqui had the smallest proportion (55%). The other two regions had proportions ranging from 80 to 83 %. Several fields in South Matsqui and West Delta had very large contents of extractable phosphorus (617 and 526 mg P kg<sup>-1</sup>, respectively). The maxima ranged from 158 to 366 in the other four regions. Mean phosphorus contents (285 mg kg<sup>-1</sup>) were greatest in raspberry fields, all of which were in South Matsqui region. Mean contents ranged from 102 to 157 mg P kg<sup>-1</sup> for crops other than raspberry in the other five regions.

Mean Kelowna extractable phosphorus for all 172 fields was much smaller in 30-60 cm depth samples (31 mg P kg<sup>-1</sup>) than in the surface 15 cm (131 mg P kg<sup>-1</sup>), and suggests that the surface depth had accumulated considerable phosphorus (0-15 cm data in Table 10, 30-60 cm depth data not in tabular form). However, the poor correlation between the two depths ( $r^2 = 0.42$ ,  $n = 486$ ) suggests that some of the soils have had greater inherent phosphorus contents, or substantial

phosphorus had leached deep into the profile. Only 15% of the 30-60 cm depths of B-series samples were  $>50 \text{ mg P kg}^{-1}$  (high to very high risk), compared to 80% of the surface 15 cm of the same samples. Data will have to be examined in greater detail and additional types of chemical analyses (e.g., water extraction, total phosphorus, measurement of deeper samples such as available from horizon samples taken during A-series sampling) will be required to determine the precise reason (related to inherent soil characteristics or field management and nutrient application histories) for soils having environmentally high phosphorus contents in the surface depth.

Estimates of the degree of phosphorus saturation using the percentage of Kelowna extractable phosphorus to Kelowna extractable aluminum averaged 15% (coefficient of variation of variation = 12) for all B-series surface 15 cm samples (data not in tabular form). Applying the 0 – 15 cm regression equation relating Kelowna degree of saturation to Mehlich-3 degree of saturation (see Section 3.2.2 Examination of specific environmental assessment methods and association to soil test analyses on Phase A samples), the risk classes equivalent to the those for Mehlich-3 (Table 7) for Kelowna degree of saturation would be 0 to 3.9% for low, 4.0 to 8.3% for medium, 8.3 to 17.3 for high and more than 17.3% for very high. Using these criteria, the Kelowna degree of saturation classified 15%, 23%, 30% and 32% of the B-series fields sampled to 15 cm as low, medium, high and very high risk, respectively. The 62% of fields classified as high and very high is less than the proportion of samples in the same (high and very high) classifications (80%) using Kelowna extractable phosphorus (Table 10). Since Kelowna extractable phosphorus classified a greater proportion of samples as high to very high risk, use of Kelowna extractable phosphorus would provide environmental guidelines that are as or more stringent than use of degree of phosphorus saturation, and the recommendations for environmental purposes for Kelowna values would be the same as for agronomic recommendations.

#### 9.2.4 Comments

A large proportion (80%) of the post-harvest sampled fields in specific regions of coastal British Columbia had Kelowna soil test phosphorus contents that were  $>50 \text{ mg P kg}^{-1}$ , when little or no phosphorus amendments are recommended. The proportion of fields that would be classed as high to very high would probably be similar if water extracted phosphate was used as the criteria instead of Kelowna extractable phosphorus. These measurements have not been done on Phase B samples at this time. It is convenient that the Kelowna soil test extraction provides an assessment of both the agronomic and environmental status of coastal British Columbia soils, as it can provide guidelines for environmental and agronomic purposes simultaneously. However, recent field research has shown that corn responds to banded phosphorus applications even on soils that have relatively high soil test values (Bittman et al. 2006), and this issue will require consideration.

Theoretically, water extracted inorganic phosphate would provide the best environmental risk measurement for phosphorus especially in relation to runoff from fields, but the method requires instrumentation (ion chromatograph) that is not usual in most commercial soil test laboratories.

Although ICP instrumentation can measure phosphorus in water extracts, it includes all forms (organic and inorganic) of phosphorus and the amount of phosphorus by ICP measurement was shown to be generally greater than measurements by ion chromatography. The environmental impact of water soluble organic phosphorus is not known at this time. It probably would have an impact, but the organic phosphorus would have to be mineralized first, similar to that assumed for agricultural crops. Colorimetry to measure inorganic phosphate may be an option, but interference issues (Kowalenko and Babuin 2007) need to be resolved.

The close relationship between Kelowna and Mehlich-3 extractable phosphorus allows use of Mehlich-3 instead of Kelowna, however, the values for the classes will need to be adjusted for the greater amount of phosphorus that is extracted by Mehlich-3 solution. Using the regression equation, the Kelowna values for the risk category values would have to be multiplied by 1.4, such that Mehlich-3 measured values would be high risk between 70.1 and 140 and very high risk would be greater than 140. These values are within the range (75 to 200 mg P kg<sup>-1</sup>) many U.S.A. states have proposed as “critical P levels” for use of Mehlich-3 method for environmental purposes (D’Angelo et al. 2003).

The assessment of the phosphorus status of the different regions was based on the analyses of the post-harvest (B-series) samples. The influence of time of sampling has not yet been examined as was done for nitrate analyses in the Benchmark samples. It is assumed at this time that Kelowna soil test analyses will be stable through the sampling period since Kowalenko (1991) found negligible change from autumn to spring in six fields over three winters. He did, however, detect changes from year to year in the fields which would be expected from the amendments and crop growth during the growing season. This suggests that changes are probable from spring to post-harvest in fields, thus direct comparisons of measurements in A-series with B-series need to be examined with caution.

This study has examined the soil as a potential source of phosphorus to pollute surface waters. Phosphorus that is not bound to soil particles (i.e., water extractable) is assumed to be vulnerable to transport to surface waters by runoff. Phosphorus that is bound by soil particles can also contribute to water pollution when erosion occurs. Since Kelowna soil test extracts unbound and bound phosphorus in soils and the unbound is somewhat proportional to bound phosphorus, it provides an environmental measurement for potential pollution from runoff and erosion processes. However, soil, crop and landscape features are needed to fully assess the potential for agricultural fields to pollute surface water (Schendel et al. 2004).

## **9.3 Potassium**

### **9.3.1 Proposed classes for the potassium status of fields and relationship of water extraction and binding measurements with soil test values (A-series samples)**

Since potassium is not usually considered to be a serious environmental risk to surface and ground waters, environmental criteria for the concern of accumulating contents in the soil are not

available. For this study, soil test criteria are proposed for the assessment of potassium in coastal soils. Measurements of water extracted potassium and the amount of applied potassium in equilibration that is unbound, as was done for phosphorus, are considered to see if they could be used to determine relative potential saturation of the soils with potassium. The Kelowna extractable potassium classes that are proposed (Table 11) are based on fertilizer recommendations (Gough 1996).

The relationship of water to Kelowna extraction was fairly close ( $r^2 = 0.74$ ) for all A-series samples and the relationship varied with depth as follows:

$$\begin{aligned} \text{Water} &= -2.53 + 0.32 \text{ Kelowna for 0-15 cm depth} \\ \text{Water} &= 2.05 + 0.28 \text{ Kelowna for 15-30 cm depth} \\ \text{Water} &= 11.22 + 0.23 \text{ Kelowna for 30-60 cm depth} \end{aligned}$$

This shows that water extractable potassium is generally proportional to and accounts for about 1/3 of that by Kelowna solution extraction.

The proportion of potassium applied that is not bound by the soil samples was not correlated with water ( $r^2 = 0.08$ ,  $n = 486$ ) or Kelowna ( $r^2 = 0.13$ ,  $n = 486$ ) extraction. The mean proportion of applied potassium not being bound was 23% (range from 6 to 57%) for 0-15 cm depth and 20% (from less than 1% to more than 55%) for 15-30 and 30-60 cm depths. The proportion was influenced by the type of crop being grown, intensity of nutrient application histories and soil characteristics (classification order and parent material origin).

Since the environmental implications of potassium are not defined at this time, evaluation of the status of potassium in relation to accumulations can only be examined by evaluation of Kelowna soil test values. In the A-series samples, Kelowna solution extracted considerably more potassium from the surface 15 cm (mean of 54 fields was  $129 \text{ mg K kg}^{-1}$ ) than in the subsurface (30-60 cm) depth ( $57 \text{ mg K kg}^{-1}$ ), which suggests that there has been an accumulation of available potassium at the surface. The greatest proportion of surface depth Kelowna extracted potassium from the A-series fields was classified as medium (41%), followed by low (33%), high (15%) and very high (11%). The maximum amount extracted was  $351 \text{ mg K kg}^{-1}$ . In the subsurface (30-60 cm) depth, 80% of the fields would have been classified as being low and the remainder (20%) as medium, with a maximum of  $145 \text{ mg K kg}^{-1}$ .

### 9.3.2 Comparison of measurements by Mehlich-3 and Kelowna solutions (A-series samples)

The amount of potassium by Mehlich-3 extract was very closely correlated with that by Kelowna extract ( $r^2 = 0.98$ ,  $n = 486$ ). The following regression equation shows that Mehlich-3 extracted about 41% more potassium than Kelowna extraction:

$$\text{Mehlich-3} = -2.03 + 1.41 \text{ Kelowna}$$

This relationship was consistent with depth, varied somewhat with crop and nutrient application histories, but more with classification order and parent material origin. This shows that with proper adjustment, Mehlich-3 can be used as a good alternative to Kelowna method.

### 9.3.3 Evaluation of K/Mg ratios (A-series samples)

The relative proportion of potassium to magnesium has been implicated as an important issue in animal feed (Rehm and Sorenson 1985) and plant growth (Miller 1999). Kelowna extractable magnesium in the surface (0-15 cm) A-series samples averaged 153 mg Mg kg<sup>-1</sup> for the 54 fields and ranged from 27 to 480 mg Mg kg<sup>-1</sup> (tabular data not provided). This compares to a subsurface (30-60 cm) depth mean of 147 mg Mg kg<sup>-1</sup>, which suggests little accumulation of extractable Mg at the surface from agricultural activity. According to soil test criteria, 4% of the surface depth of the 54 fields would be low (0-50 mg Mg kg<sup>-1</sup>), 26% medium (51-100 mg Mg kg<sup>-1</sup>), 28% high (101-150 mg Mg kg<sup>-1</sup>) and 42% very high (>150 mg Mg kg<sup>-1</sup>). There was no correlation among all A-series samples between Kelowna potassium and Kelowna magnesium ( $r^2 = 0.05$ ), which shows that the two nutrients vary independently. The ratio of Kelowna potassium to Kelowna magnesium averaged 1.2 with ratios of 1.1, 1.2 and 1.3 for 0 to 15, 14 to 30 and 30 to 60 cm depths, respectively. The range of the ratio for the surface 15 cm was from 0.2 to 4.6. The ratio of the maximum medium soil test category (Gough 1996) value for Kelowna potassium (175 mg K kg<sup>-1</sup>; see Table 11) to the maximum medium soil test category (Gough 1996) value for Kelowna magnesium (100 mg Mg kg<sup>-1</sup>) would be 1.75. If this ratio is assumed to indicate the optimum in the soil, 17% of the A-series fields have a ratio >1.75, which shows either high potassium or low magnesium. This suggests that at least some coastal soils may have accumulations of potassium relative to magnesium that may result in poor crop performance or quality.

### 9.3.4 Distribution according to agronomic classes (B-series samples)

A substantial proportion (47%) of the 172 fields sampled after harvest had high to very high Kelowna extractable potassium (Table 12). Most (87%) fields were high to very high in Delta region, 51 to 59% were high to very high in South Matsqui, West Sumas and East Chilliwack, and 14 to 26% were high to very high in Sumas and West Matsqui. Forage corn and raspberry fields tended to have generally large mean contents (237 to 239 mg K kg<sup>-1</sup>), annual horticulture and blueberry fields had moderate mean quantities (190 mg K kg<sup>-1</sup>), and grass and perennial horticulture fields had the smallest mean quantities (166 to 167 mg K kg<sup>-1</sup>). Similar to observations in the A-series samples, subsurface 30 to 60 cm depth had a considerably smaller mean content of Kelowna extractable potassium (89 mg K kg<sup>-1</sup>) than the surface 15 cm depth (187 mg K kg<sup>-1</sup>). The correlation of Kelowna extractable potassium in the surface 15 cm depth with that in the 30 to 60 cm subsurface depth was significant but not very strong ( $r^2 = 0.46$ ,  $n = 516$ ), and the relationship differed with crop and parent material origin. This suggests that the crop grown and its associated management practices influenced the accumulation of extractable potassium at the surface and the effect of the crop on accumulation varied with soil type.

Mean Kelowna extractable magnesium in the 172 fields was 140 mg Mg kg<sup>-1</sup> in the surface 15 cm, 123 mg Mg kg<sup>-1</sup> in the 15 to 30 cm depth and 119 mg Mg kg<sup>-1</sup> in the 30 to 60 cm depth (tabulated data not shown). Kelowna extractable magnesium was generally abundant in all the fields with 5% classed as low (0 to 50 mg Mg kg<sup>-1</sup>), 30% as medium (51 to 100 mg Mg kg<sup>-1</sup>), 26% as high (101 to 150 mg Mg kg<sup>-1</sup>) and 39% as very high (>150 mg Mg kg<sup>-1</sup>) in the surface 15 cm according to soil test guidelines (Gough 1996). The maximum mean content in a field

was 484 mg Mg kg<sup>-1</sup>. This suggests that management practices did not result in significant accumulation of extractable magnesium in the soils and that most soils have high natural contents. There was a smaller proportion of the fields that had potassium:magnesium ratios greater than 1.75 (3%) to that which was less than 1.75 (67%) in the surface 15 cm. The maximum ratio was substantial at 8.5, which could have resulted in an adverse effect to crop growth and quality. The data would need to be examined in greater detail to determine if the large ratios were due to an accumulation of potassium from nutrient amendments.

### 9.3.5 Comments

There were a substantial number of fields in coastal British Columbia where the potassium content is considerable and may be impacting crop growth and quality. The influence of management practices on increased extractable potassium relative to inherent potassium contents of soil is difficult to determine from the data because of the lack of precise information on the histories of nutrient amendments. However, the generally greater quantities in the surface compared to the subsurface depths suggests that the increase at the surface from management practices either directly from amendment applications or indirectly from enhanced weathering converting non-extractable to extractable forms. Ross et al. (1985) showed that large applications of liquid dairy manure caused the conversion of vermiculitic clays to mica after six years through the influence on clay fixation by applied potassium and ammonium. Coastal British Columbia soils contain significant quantities of clay fixed ammonium (Kowalenko and Yu 1996). More detailed examination of currently available data and additional measurements would be needed to sort out the reasons for the large extractable potassium contents; however, adjustments to further amendments need to be considered for many fields.

## 9.4 Comparison of nitrogen, phosphorus and potassium environmental rankings in selected regions

Five regions of contrasting calculated surpluses of nitrogen, phosphorus and potassium applications were selected for the assessment of the status of nutrients in soils for potential environmental pollution risk in this study. During the sampling, the Abbotsford region was subdivided into West Sumas and Sumas areas. Table 13 shows that the relative order of calculated surpluses do not coincide very well with the proportions soils of the samples fields ranked to have high to very high environmental risk. Many factors (such as bias in the selection of fields, soils having different initial quantities of nutrients, etc.) can probably account for some of the differences, but, the comparison illustrates that it is difficult to directly extrapolate calculations to actual measurements. It is also difficult to distinguish the influence of single season from historic nutrient applications, and management from inherent influences with simple chemical measurements. However, the budget calculations and soil measurements show that the intensive nature of agricultural operations in coastal British Columbia where substantial nutrients are imported by fertilizer and feed for livestock are resulting in nutrient accumulations in the soils.



## 10 PRACTICAL IMPLICATIONS

Chemical analyses have shown that a significant proportion of coastal British Columbia soils have relatively large quantities of nitrogen, phosphorus and potassium, most likely due to histories of applications of nutrients as fertilizer and various organic amendments which pose environmental and agronomic concerns. Although the analytical methods that were applied and their interpretations may need further refinement, they are based on theoretical and historic information, and should provide direct information of the relative environmental status of agricultural fields in coastal British Columbia.

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## 12 TABLES

### List of Tables

Table 1.	Effect of date on residual nitrate in soil profiles at four sites during post-harvest B series Benchmark sampling for 2005 nutrient status evaluation study, and relationship to precipitation, total nitrogen, C:N ration and air dry water content.....	34
Table 2.	Comparison of classes proposed to assess the environmental risk of residual nitrate and extractable ammonium in survey samples in coastal British Columbia with national Residual Soil Nitrogen Indicator.....	35
Table 3.	Distribution of residual (B-series soil sampling) nitrate in proposed environmental risk classes in fields of selected regions of the Lower Fraser Valley sampled in 2005.....	36
Table 4.	Distribution of residual (B-series soil sampling) KCl extractable ammonium in proposed environmental risk classes in fields of selected regions of the Lower Fraser Valley sampled in 2005.....	37
Table 5.	Distribution of residual (B-series soil sampling) nitrate and KCl extractable ammonium in proposed environmental risk classes in fields of different crops in selected regions of the Lower Fraser Valley sampled in 2005.....	38
Table 6.	Percentage phosphate not bound by selected Lower Fraser Valley soil samples during a 50 mg P kg <sup>-1</sup> solution equilibration, and amount of phosphate extracted by water and Kelowna soil test solution from untreated soil (from Kowalenko 2005).....	39
Table 7.	Proposed environment risk classes for phosphorus in coastal British Columbia soils.....	40
Table 8.	Correlations among phosphorus environmental risk indicators in soils representing major soil types in south coastal British Columbia (A-series samples).....	41
Table 9.	Distribution of 54 fields of representative coastal British Columbia fields (A-series sampling) in proposed environment risk classes for phosphorus.....	42
Table 10.	Distribution of residual (B-series soil samples) Kelowna extractable phosphorus in proposed environmental risk classes surface 0-15 cm depth in fields of selected regions of the Lower Fraser Valley in 2005.....	43
Table 11.	Proposed environmental risk classes for Kelowna extractable soil potassium and relationship to amendment recommendations.....	44
Table 12.	Distribution of residual (B-series soil samples) Kelowna extractable potassium in proposed environmental/agronomic risk classes of surface 0-15 cm depth in fields of selected regions of the Lower Fraser Valley in 2005.....	45
Table 13.	Comparison of surplus calculated by budget model using 2001 census data with proportion of B-series sampled fields ranked to have high to very high environmental pollution risk by nitrogen, phosphorus and potassium measured by soil test analyses of 2005 post-harvest soil samples in selected regions.....	46

<b>Table 1. Effect of date on residual nitrate in soil profiles at four sites during post-harvest B series Benchmark sampling for 2005 nutrient status evaluation study, and relationship to precipitation, total nitrogen, C:N ration and air dry water content</b>				
Date/depth	Delta (potato)	Abbotsford (raspberry)	Sumas (corn)	Chilliwack (corn)
Amount of nitrate to 60 cm (kg N ha <sup>-1</sup> )				
(Sept. 15) <sup>1</sup>	(247)	(95)	(170)	(140)
(Sept. 22-23)	(287)	(91)	(184)	(160)
Sept. 28-30	357 a <sup>2</sup>	87 a	185 a <sup>3</sup>	89 c <sup>4</sup>
Oct. 6-7	403 a	98 a	218 a	109 b
Oct. 13	364 a	83 a	179 a	127 a
Oct. 22	349 a	83 a	119 a	92 c
Oct. 31	316 a	91 a	66 c	72 d
Median depth of nitrate in 60 cm profile (cm)				
(Sept. 15)	(20)	(23)	(15)	(20)
(Sept. 22-23)	(19)	(22)	(14)	(20)
Sept. 28-30	14 c	24 b	15 d	19 d
Oct. 6-7	14 c	23 b	30 c	29 c
Oct. 13	15 c	30 ab	33 b	26 c
Oct. 22	20 b	30 ab	39 a	33 b
Oct. 31	24 a	37 a	40 a	38 a
Cumulative precipitation from Sept. 15 (mm)				
(Sept. 15)	(0)	(0)	(0)	(0)
(Sept. 22-23)	(5)	(8)	(8)	(10)
Sept. 28-30	53	85	12	19
Oct. 6-7	80	115	116	128
Oct. 13	103	140	140	145
Oct. 22	168	229	229	199
Oct. 31	208	289	289	264
Air dry sample water content (%)				
0-15 cm	3.1	4.8	1.5	2.7
15-30 cm	2.8	4.8	1.5	2.6
30-60 cm	2.7	4.5	0.9	2.1
Total nitrogen (% on oven dry weight) <sup>5</sup>				
0-15 cm	0.29	0.29	0.17 <sup>5</sup>	0.19
C:N ratio				
0-15 cm	11.5	14.7	10.1	10.4

<sup>1</sup> Values in brackets are single analyses on samples where three plot replicates were bulked into one and could not be evaluated statistically.

<sup>2</sup> Values within columns of individual measurements followed by the same letter are not significantly (P=0.05) different according to Least Significant Difference statistical test.

<sup>3</sup> Manure applied Sept. 23

<sup>4</sup> Manure applied Sept. 29

<sup>5</sup> Analyses for Sept. 28-30 samplings and are assumed to represent each site over the entire sampling period.

**Table 2. Comparison of classes proposed to assess the environmental risk of residual nitrate and extractable ammonium in survey samples in coastal British Columbia with national Residual Soil Nitrogen Indicator.**

Risk classes	National Agri-Environmental Indicator for Residual Soil Nitrogen <sup>1</sup> kg N ha <sup>-1</sup>	Proposed Environmental Risk for residual nitrate and ammonium in coastal B.C. kg N ha <sup>-1</sup> to 60 cm
Low	0 - 20	0 - 49
Medium	20 - 30	50 - 99
High	30 - 40	100 - 199
Very high	>40	>199

<sup>1</sup> From Drury et al. (2005) Environmental Sustainability of Canadian Agriculture - Agri-Environmental Indicator Report Series Report #2, pp. 69-75.

**Table 3. Distribution of residual (B-series soil sampling) nitrate in proposed environmental risk classes in fields of selected regions of the Lower Fraser Valley sampled in 2005**

Measurement	W. Delta	W. Matsqui	S Matsqui	W. Sumas	Sumas	E. Chilliwack	All
Fields	23	27	30	17	28	47	172
Mean nitrate	128 AB <sup>1</sup>	97 B	149 A	104 B	57 C	56 C	93
Coeff. of variation	34	27	40	14	25	27	36
Environmental risk	% of fields in each category within each region [maximum kg N ha <sup>-1</sup> to 60 cm]						
Low (0-49)	44	37	20	41	50	68	46
Medium (50-99)	13	22	37	12	39	15	23
High (100-199)	26	33	20	35	11 [132]	13	21
Very high (200+)	17 [663]	8 [377]	23 [761]	12 [333]	0	4 [284]	10
Crops	kg N ha <sup>-1</sup> to 60 cm (number of fields in brackets)						
Grass	12 b (5)	83 b (17)	89 b (12)	85 a (10)	34 c (10)	27 b (30)	54 d (84)
Forage corn	N.A.	N.A.	N.A.	132 a (7)	98 a (3)	107 (12)	114 c (22)
Annual hort.	149 a (13)	N.A.	N.A.	N.A.	63 b (15)	N.A.	102 c (28)
Perennial hort.	N.A.	104 ab (5)	N.A.	N.A.	N.A.	106 a (5)	105 c (10)
Raspberries	N.A.	N.A.	219 a (12)	N.A.	N.A.	N.A.	219 a (12)
Blueberries	194 a (5)	140 a (5)	129 ab (6)	N.A.	N.A.	N.A.	153 b (16)

<sup>1</sup> Values within columns of individual measurements followed by the same capital letter within row and same lower case letter within each column are not significantly (P=0.05) different according to Least Significant Difference statistical test.

**Table 4. Distribution of residual (B-series soil sampling) KCl extractable ammonium in proposed environmental risk classes in fields of selected regions of the Lower Fraser Valley sampled in 2005**

Measurement	W. Delta	W. Matsqui	S. Matsqui	W. Sumas	Sumas	E. Chilliwack	All
Fields	23	27	30	17	28	47	172
Mean ammonium	51 A <sup>1</sup>	49 A	43 A	24 BC	20 C	30 B	36
Coeff. of variation	40	39	30	9	24	24	35
Environmental risk	% of fields in each category within each region [maximum kg N ha <sup>-1</sup> to 60 cm]						
Low (0-49)	83	63	77	100 [45]	96	94	85
Medium (50-99)	9	33	20	0	4 [51]	6 [94]	12
High (100-199)	4	0	3 [106]	0	0	0	1
Very high (200+)	4 [294]	4 [206]	0	0	0	0	1

<sup>1</sup> Values within columns of individual measurements followed by the same capital letter within row are not significantly different according to Least Significant Difference statistical test.

**Table 5. Distribution of residual (B-series soil sampling) nitrate and KCl extractable ammonium in proposed environmental risk classes in fields of different crops in selected regions of the Lower Fraser Valley sampled in 2005**

	Grass	Forage corn	Annual hort.	Perennial hort.	Blueberry	Raspberry
Fields	84	22	28	10	16	12
Nitrate to 60 cm	54 D	113 C	102 C	105 C	153 B	219 A
	%					
Coeff. of variation	34	14	31	30	29	37
Environmental risk	% of fields within each region [maximum kg N ha <sup>-1</sup> to 60 cm]					
Low (0-49)	71	18	32	20	25	0
Medium (50-99)	15	32	36	20	25	42
High (100-199)	10	41	21	50	31	16
Very high (200+)	4 [391]	9 [284]	11 [414]	10 [206]	19 [663]	42 [761]
	kg N ha <sup>-1</sup> to 60 cm					
Ammonium to 60 cm	34 C	24 D	26 D	51 B	65 A	40 BC
	%					
Coeff. of variation	35	13	19	30	38	38
Environmental risk	% of fields in each category within each region [maximum kg N ha <sup>-1</sup> to 60 cm]					
Low (0-49)	89	91	93	40	69	83
Medium (50-99)	10	9 [88]	7 [57]	60 [94]	12.5	17 [74]
High (100-199)	0	0	0	0	12.5	0
Very high (200+)	1 [206]	0	0	0	6 [294]	0

<sup>1</sup> Values within columns of individual measurements followed by the same capital letter within row are not significantly different according to Least Significant Difference statistical test. (P=0.05)

**Table 6. Percentage phosphate not bound by selected Lower Fraser Valley soil samples during a 50 mg P kg<sup>-1</sup> solution equilibration, and amount of phosphate extracted by water and Kelowna soil test solution from untreated soil (from Kowalenko 2005).**

Soil series (order)	Unbound by soil %	Water extract <sup>1</sup> mg P kg <sup>-1</sup>	Kelowna extract <sup>2</sup> mg P kg <sup>-1</sup>
Monroe (Brunisol)	0	0	14
Marble Hill (Brunisol)	3	0	44
Deas-a (Gleysol)	12	2	57
Vye (Luvisol)	14	1	58
Dixon (Gleysol)	34	1	31
Hatzic-a (Gleysol)	42	5	166
Hatzic-b (Gleysol)	67	9	149
Ladner (Gleysol)	46	5	143
Buckerfield (Gleysol)	54	8	124
Richmond (Gleysol)	71	16	189

<sup>1</sup> Quebec and Ontario guidelines for tributary water is < 0.03 mg P L<sup>-1</sup>.

<sup>2</sup> Kelowna extract values > 100 rated as high+ for growing corn and no phosphorus fertilizer recommended, including no starter applications.

<b>Table 7. Proposed environment risk classes for phosphorus in coastal British Columbia soils</b>						
Risk	Water extracted inorganic phosphate mg P kg <sup>-1</sup>	Unbound P during 50 mg P kg <sup>-1</sup> treatment %	Potential pollution index Index value <sup>1</sup>	Kelowna soil test solution extraction mg P kg <sup>-1</sup>	Mehlich-3 phosphorus saturation index <sup>2</sup> %	
Low	0 - 1	0 - 5	0 - 7	0 - 20	0 - 4.9	
Medium	1.1 - 2.5	5.1 - 10	7.1 - 20	20.1 - 50	5.0 - 9.8	
High	2.6 - 6.0	10.1 - 20	20.1 - 40	50.1 - 100	9.9 - 19.6	
Very high	>6.0	>20	>40	>100	>19.6	
<sup>1</sup> Index value = (water extracted P in 0-15 cm depth) + (water extracted P in 15-30 cm depth) + (percentage of P treatment unbound).						
<sup>2</sup> Index = (mg Mehlich-3 P kg <sup>-1</sup> )/(mg Mehlich-3 Al kg <sup>-1</sup> )x100 (according to Giroux and Tran 1996)						

**Table 8. Correlations among phosphorus environmental risk indicators in soils representing major soil types in south coastal British Columbia (A-series samples).**

Indicator	Kelowna extracted P	Water extracted P	Unbound P treated soils	Mehlich-3 degree of P saturation
	--- r <sup>2</sup> ---			
Water extracted phosphate	0.73			
Unbound phosphate in treated soils	0.07	0.32		
Mehlich-3 degree of saturation	0.56	0.78	0.48	
Potential pollution index	0.25	0.60	0.91	0.72

**Table 9. Distribution of 54 fields of representative coastal British Columbia fields (A-series sampling) in proposed environment risk classes<sup>1</sup> for phosphorus.**

Risk	Water extraction (mg P kg <sup>-1</sup> )	Unbound P during 50 mg P kg <sup>-1</sup> treatment (%)	Potential pollution index value	Kelowna soil test solution extraction (mg P kg <sup>-1</sup> )	Mehlich-3 phosphorus saturation index (%)
	% of fields (maximum value of respective risk indicator)				
Low	2	11	7	4	17
Medium	20	35	45	16	30
High	41	22	26	41	33
Very high	37 (31)	17 (66)	22 (109)	39 (436)	20 (63)

<sup>1</sup> See Table 7 for values classes for each risk indicator

**Table 10. Distribution of residual (B-series soil samples) Kelowna extractable phosphorus in proposed environmental risk classes surface 0-15 cm depth in fields of selected regions of the Lower Fraser Valley in 2005**

Measurement	W. Delta	W. Matsqui	S. Matsqui	W. Sumas	Sumas	E. Chilliwack	All
Fields	23	27	30	17	28	47	172
Mean phosphorus	158 AB <sup>1</sup>	66 E	184 A	120 CD	110 D	138 BC	131
Coeff. of variation	11	19	14	9	8	10	12
Environmental risk	% of fields in each category within each region [maximum mg P kg <sup>-1</sup> ]						
Low (0-20)	0	15	10	0	0	2	5
Medium (20.1-50)	9	30	10	18	11	15	15
High (50.1-100)	22	33	17	35	43	21	28
Very high (>100)	69 [526]	22 [158]	63 [617]	47 [261]	46 [366]	62 [375]	52
Crops	mg P kg <sup>-1</sup> (number of fields in brackets)						
Grass	90 b (5)	71 a (17)	103 b (12)	112 a (10)	94 a (10)	119 b (30)	102 d (84)
Forage corn	N.A.	N.A.	N.A.	132 a (7)	119 a (3)	175 a (12)	153 b (22)
Annual hort.	140 b (13)	N.A.	N.A.	N.A.	118 a (15)	N.A.	128 bc (28)
Perennial hort.	N.A.	56 a (5)	N.A.	N.A.	N.A.	167 a (5)	111 cd (10)
Raspberries	N.A.	N.A.	285 a (12)	N.A.	N.A.	N.A.	285 a (12)
Blueberries	273 a (5)	59 a (5)	142 b (6)	N.A.	N.A.	N.A.	157 b (16)

<sup>1</sup> Values within columns of individual measurements followed by the same capital letter within row and same lower case letter within each column are not significantly (P=0.05) different according to Least Significant Difference statistical test.

**Table 11. Proposed environmental risk classes for Kelowna extractable soil potassium and relationship to amendment recommendations**

Risk	Soil test value mg K kg <sup>-1</sup>	Application recommendation kg K <sub>2</sub> O ha <sup>-1</sup> (kg K ha <sup>-1</sup> )
Low	0 - 80	250 - 60 (210 - 50)
Medium	81 - 175	150 - 40 (125 - 35)
High	176 - 250	40 - 20 (35 - 15)
Very high	>250	0

**Table 12. Distribution of residual (B-series soil samples) Kelowna extractable potassium in proposed environmental/agronomic risk classes of surface 0-15 cm depth in fields of selected regions of the Lower Fraser Valley in 2005**

Measurement	W. Delta	W. Matsqui	S. Matsqui	W. Sumas	Sumas	E. Chilliwack	All
Fields	23	27	30	17	28	47	172
Mean potassium	253 A <sup>1</sup>	141 C	199 B	224 AB	126 C	197 B	187
Coeff. of variation	12	15	12	9	14	15	13
Content classes	% of fields in each category within each region [maximum mg K kg <sup>-1</sup> ]						
Low (0-80)	0	30	14	12	25	13	16
Medium (81-175)	13	44	30	29	61	36	37
High (176-250)	48	7	23	24	11	32	24
Very high (>250)	39 [432]	19 [361]	33 [404]	35 [502]	3 [267]	19 [715]	23
Crops	mg K kg <sup>-1</sup> (number of fields in brackets)						
Grass	218 b (5)	133 a (17)	190 b (12)	214 a (10)	109 b (10)	174 b (30)	167 c (84)
Forage corn	N.A.	N.A.	N.A.	242 a (7)	114 ab (3)	271 a (12)	239 a (22)
Annual hort.	249 b (13)	N.A.	N.A.	N.A.	139 a (15)	N.A.	190 c (28)
Perennial hort.	N.A.	170 a (5)	N.A.	N.A.	N.A.	162 b (5)	166 c (10)
Raspberries	N.A.	N.A.	237 a (12)	N.A.	N.A.	N.A.	237 ab (12)
Blueberries	300 a (5)	141 a (5)	141 b (6)	N.A.	N.A.	N.A.	190 bc (16)
<sup>1</sup> Values within columns of individual measurements followed by the same capital letter within row and same lower case letter within each column are not significantly (P=0.05) different according to Least Significant Difference statistical test.							

**Table 13. Comparison of surplus calculated by budget model using 2001 census data<sup>1</sup> with proportion of B-series sampled fields ranked to have high to very high environmental pollution risk by nitrogen, phosphorus and potassium measured by soil test analyses of 2005 post-harvest soil samples in selected regions.**

Region	Nitrogen		Phosphorus		Potassium	
	2001 calculated surplus kg N ha <sup>-1</sup>	2005 post-harvest sampled fields ranked high to very high risk % of all sampled	2001 calculated surplus kg P ha <sup>-1</sup>	2005 post-harvest sampled fields ranked high to very high risk % of all sampled	2001 calculated surplus kg K ha <sup>-1</sup>	2005 post-harvest sampled fields ranked high to very high risk % of all sampled
W. Delta	- 34	43	32	91	- 15	87
W. Matsqui	174	41	181	55	290	26
S. Matsqui	117	43	119	80	168	56
Abbotsford	139	N.A.	75	N.A.	162	N.A.
- W. Sumas	N.A.	47	N.A.	82	N.A.	59
- Sumas	N.A.	11	N.A.	89	N.A.	14
E. Chilliwack	132	17	65	83	166	51

<sup>1</sup> Schreier, H., Bestbier, R. and Derksen, G. (2003).

