Okanagan Agricultural Soil Study

2007

An Agronomic and Environmental Survey of Soil Chemical and Physical Properties

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A Survey of the Chemical and Physical Properties of Agricultural Soils of the Okanagan and Similkameen Valleys in Relation to Agronomic and Environmental Concerns

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The success of the project must largely be attributed to the 100 agricultural producers and growers in the region, who volunteered their fields to be sampled. The agricultural community participated enthusiastically in the study as farmers frequently accompanied field crews to share information and learn more about their own soils.

Regular members of the project steering committee members included:

- BC Ministry of Agriculture and Lands (MAL) – Orlando Schmidt (project coordinator), Kevin Murphy, Geoff Hughes-Games, and David Poon
- Agriculture and Agri-Food Canada (AAFC) – Grant Kowalenko, Denise Neilsen, Gerry Neilsen, Scott Smith, Elizabeth Kenney, and Eryne Croquet
- BC Agriculture Council (BCAC)
    - Lorne Hunter – Dairy, North Okanagan
    - Brian Mennell – Organics and Tree Fruit, Keremeos
    - Joe Sardinha – Tree Fruit, Summerland
    - Christine Dendy – Cherries, Kelowna

In addition to the steering committee, a number of other employees and contractors carried out the specific tasks required to complete the study. **Angela Taylor** (MAL) did an outstanding job of recruiting producers and growers to volunteer sampling sites. She also coordinated the daily schedules of work crews. In Phase A, the primary field crew consisted of **Elizabeth Kenney** and **Eryne Croquet** (pedologists), **David Gregory** (Guelph Permeameter), **Erica Milligan** (pedology and sample collection), and **Dave Stathers** (sample collection and hole filling). The Phase B crew sampling crew was **Erica Milligan** (leader), **Dave Stathers**, and **Richard Gilbert**. Benchmark sampling was done by **Orlando Schmidt**, **Geoff Hughes-Games** and **David Poon**. Soil processing and lab analysis was done by **Grant Kowalenko** (lead scientist, chemistry), **Denise Neilsen** (lead scientist, physical properties), **Erica Milligan**, **Suzanne Macht**, **Dean Babuin**, **Con Van Laerhoven**, **Pamela Babuin**, and **Janilee Olson**.

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Part A

Condensed Report

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1 Disclaimer

Caution should be used in interpreting the results. For a complete interpretation of results, read the full scientific reports, *Agronomic and Environmental Status of Extractable Nutrients and Other Elements in Commercial Agricultural Fields in the Okanagan-Similkameen Valleys in 2007* and *Pedology, Soil Survey and Soil Physical Properties of the Okanagan-Similkameen Valleys*.

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, participation in this study was strictly voluntary and some bias in site selection was possible.

2 Context and purpose of the study

An improved understanding of the soils in the Okanagan-Similkameen Valleys is critical to ensure they are managed properly long into the future. Following a similar study of agricultural soils of the Lower Fraser Valley in 2005, scientists and agricultural producers launched the Okanagan Agricultural Soil Study (OASS) in 2007.

The OASS was designed with four key goals:

1. Develop and verify improved soil testing techniques that can be used by producers and their advisors to improve soil management for agronomic and environmental purposes.
2. Obtain baseline data on the soil nutrient status of the Okanagan-Similkameen region, for future monitoring of the effectiveness of government and industry-led programs designed to improve nutrient management practices.
3. Use standard soil classification methods on approximately 60 sites to verify existing soil maps and improve the quality of information on soil maps.
4. Collect data on soil physical properties that can be used to provide producers with information for improving the precision of water management.

3 Assessment of soil chemical properties

The study area extended from Osoyoos and Keremeos in the south to Grindrod and Mara in the north as shown in Figure A-1. For purposes of analysis, the entire region was broken down into six subregions described as Similkameen, Oliver, Summerland, Kelowna, Vernon, and Armstrong.

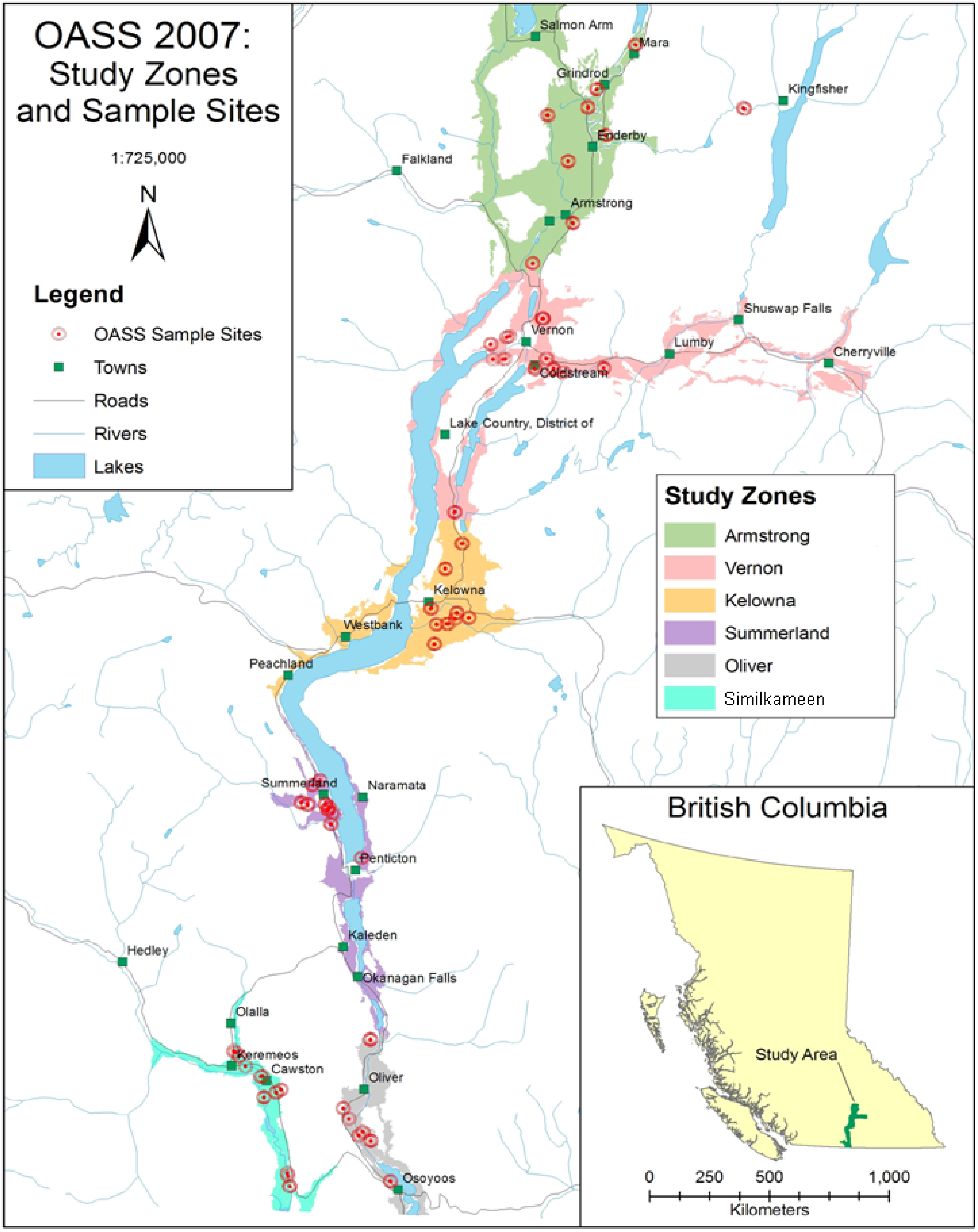

Figure A-1. Map of study area for Okanagan Agricultural Soil Study.

3.1 Methodology

3.1.1 Soil sampling and descriptions

The field component of the study was broken into three phases. To facilitate statistical analysis of the data, all sampling was done in three replications.

Phase A sampling occurred between June 5 and September 6, 2007 to develop soil test methods and their interpretations. Phase A involved excavation of soil pits at least one meter deep to allow for detailed soil descriptions and collection of different sets of samples at multiple depths for soil chemical and physical properties. Samples were collected from 56 fields that were selected to include the predominant soil types in the entire study area.

Phase B sampling was conducted between September 17 and November 26, 2007 to assess soil nutrient status at the end of the growing season. The Phase B sampling was done with a conventional soil probe and composite core samples were collected from 3 depths (0-15 cm, 15-30 cm, and 30-60 cm) from 180 fields. Fields were selected to obtain soil samples from a proportionate representation of the major crop types in each of the six subregions.

The Phase B sampling was complemented with repeated sampling from four benchmark sites within the study area, to assess the fate of soil nitrogen measured during the Phase B period and subsequent winter. This 'Benchmark' sampling occurred between September 18 and November 29, 2007 and also included one round of post-winter sampling on May 1, 2008.

3.1.2 Laboratory analysis

All soil samples that were collected for chemical analysis were air-dried and crushed to pass through a 2 mm sieve. A range of chemical analyses were used to both provide data on the agronomic nutrient status of the soil and to develop new testing procedures capable of assessing potential environmental risk associated with nutrient concentrations.

Examining elements in addition to nitrogen, phosphorus and potassium was beneficial in assessing broad agronomic and environmental issues.

3.2 Results and discussion

Nitrogen

The Benchmark sampling supported the assumption that very little soil nitrate present after harvest would be lost to leaching over the winter in the Okanagan. However, the variable results suggest interpretation of post-harvest soil nitrate concentrations should be done with caution.

Seven of the 180 Phase B fields could not be sampled to the 60 cm depth due to stoniness. Eighty percent of the 173 fields analyzed in Phase B had post-harvest soil nitrate contents in the low to medium rating categories (Table A-1). Of the 11 fields (6% of all) rated in the very high category, six were located in the Armstrong sampling region.

Total nitrogen contents ranged considerably across the sampled area with a tendency for increased amounts from south to north, which would reflect the change from hot and dry to cool and moist weather. Extrapolation of these measurements suggested that 86% of all fields were considered to have a low ability to potentially release inorganic nitrogen by mineralization. Only six fields showed high nitrogen mineralization potential, and all were located in the north corresponding to organic matter accumulations.

Table A-1. Post-harvest soil nitrate contents by subregion.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
(kg N ha^{-1})	*number of fields*						
Low (0-49)	27	19	21	5	10	14	96 (56%)
Medium (50-99)	11	10	2	5	5	8	41 (24%)
High (100-199)	12	5	3	2	2	1	25 (14%)
Very High (200+)	6	1	2	1	0	1	11 (6%)
	kg N ha^{-1} (0 to 60 cm depth)						
Average	106	57	65	78	47	61	75

Cereal, grass and forage corn fields had the highest average residual nitrate contents. Other tree fruit and vegetable fields had intermediate average residual nitrate contents, while apple, cherry, grape and alfalfa had the lowest average contents. There were no apparent differences among conventional, organic and transitional management systems. There were a few cases where substantial ammonium contents were found. The potential environmental impact of high nitrate and ammonium nitrogen contents is difficult to fully assess because of the generally dry climate where leaching would be limited. Those fields that had low nitrate could have indicated deficiency and limited crop production.

Phosphorus

A large majority of fields were in the high to very high environmental risk categories for water extractable phosphorus, but only about half were in those categories for Kelowna extractable phosphorus. The proportion of phosphorus in the Kelowna extraction that was extracted by water was about 15% compared to 6% in the Lower Fraser Valley, suggesting Okanagan-Similkameen soils have a lower P-binding ability than Lower Fraser Valley soils. The low ability of Okanagan-Similkameen soils to bind phosphorus contributed to classifying them as having greater environmental risk relative to agronomic classification. Based on agronomic interpretations, most agricultural fields in the study had high to very high soil phosphorus concentrations (Table A-2). Based on proposed environmental interpretations, which consider the ability of the soils to bind phosphorus, almost all (96%) fields surveyed had potentially high to very high environmental risk. Extra focus is required on management practices to prevent the potential for P transport from fields to surface waters.

Kelowna and Mehlich-3 phosphorus extraction results were highly correlated, but the nature of the relationship was different than observed for Lower Fraser Valley soils. This will need to be taken into consideration if Mehlich-3 is to be used as an alternative to Kelowna on a province-wide basis.

Table A-2. Soil phosphorus status of Okanagan soils according to agronomic criteria for crops with moderate to high phosphorus requirement.

Agronomic Rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
(mg kg^{-1} Kelowna P)	*number of fields*						
Low (0-20)	5	1	0	1	0	6	13 (7%)
Medium (21-50)	3	7	3	1	6	12	32 (18%)
High (51-100)	20	11	8	7	4	6	56 (31%)
Very High (100+)	28	18	17	4	7	5	79 (44%)
	mg kg^{-1} Kelowna P (0 to 15 cm depth)						
Average	149	111	117	80	91	58	111

Potassium and Other Elements

Measurements were made for potassium and a number of elements. For some elements, there are agronomic interpretations while for others, they are only of environmental interest.

- Potassium (K) – although 70 to 80% of Phase A fields had high to very high extractable K contents, farm survey data showed significant rates of application suggesting that current recommendations or management practices need attention. Similar to phosphorus, the correlation of Kelowna and Mehlich-3 extractions of potassium was strongly correlated but the relationship differed from that for Lower Fraser Valley soils.
- Magnesium (Mg) – 95 to 100% of Phase A fields ranked high to very high for Mg fertility. Increased attention is required to ensure there are no crop growth problems associated with high extractable Mg.
- Sulphur (S) – Results were highly variable with 74% of Phase B fields ranked very low and 16% ranked very high. Implications of both deficient and excessive S contents need to be determined.
- pH – Most (84%) of Phase A fields had pH greater than 6.5 and pH tended to increase from north to south. This reflected the difference that climatic conditions have on soils from north to south.
- Boron (B), Copper (Cu), and Zinc (Zn) – Mehlich-3 extraction showed promise as a replacement for hot water extraction for B and DPTA for Cu and Zn, which would provide a convenient and broad multiple element soil test. Extrapolation of the Mehlich-

3 information suggests most (92%) Phase A fields had low to medium B fertility contents while most soils had Cu or Zn that appeared to be adequate for crops.

- Measurements of other elements found high concentrations of lead and arsenic in a small number of fields. Further work is required to determine the environmental and agronomic consequences, and if this was from natural occurrences or amendments.

4 Assessment of soil physical properties

Phase A of the OASS included pedon descriptions that can be used to link pedons to existing soil surveys, maps, databases, and soil management manuals. The descriptions also are included in the National Pedon Database. Fifty-six fields were selected from within 6 study zones and three pits were excavated per field for a total of 168 excavation pits. Forty-eight pits were given comprehensive pedon descriptions while 120 were given simplified descriptions.

In addition to describing the pedons, samples were collected for determination of bulk density (D_b), available water storage capacity (AWSC), and saturated hydraulic conductivity (K_{sat}).

Bulk density is the ratio of the mass of dry solids to the bulk volume of oven-dry soil and is expressed in units of g cm^{-3}. Bulk density was determined by one of two methods – core sampling or excavation. Core sampling is the preferred method but cannot be done with soils having high coarse fragment contents.

Typically, soils that are loose or well structured, finer textured and those rich in organic matter have lower bulk densities. Sandy soils such as Osoyoos tend to have higher bulk densities. Average bulk density information was presented for the 1st, 2nd and 3rd horizons for various soil series in the study. In general, bulk density tended to increase with depth.

AWSC is the portion of water that can be readily absorbed by plant roots and is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point. In this study, there were some difficulties in the laboratory assessment of AWSC for fine-textured soils. In these cases (e.g. with clays and silty clays), default values from the BC Trickle Irrigation Manual were used.

The range of AWSC is shown in Table A-3. The majority of soil samples (61%), which are considered to be representative of the major cropped agricultural soils in the study area, had a weighted average AWSC of 13.3%. Precise management of these soils is required to prevent water stress and, because of the rapid drainage, nutrient leaching from fertilizer applications. Soils with the lowest AWSC were most prevalent in the Oliver-Osoyoos (AWSC = 12.2%) and Kelowna (AWSC = 13.5%) regions.

Table A-3. Range of available water storage capacity (AWSC) for Okanagan soils.

Soil Texture	AWSC (%)
Coarse Textured	10.7
Medium Textured	17.5
Fine Textured	20.3

Saturated hydraulic conductivity (K_{sat}) is a measure of the ability of a soil to transmit water. In this study, K_{sat} was measured by two methods: using the constant head method in the laboratory with core samples, and in the field using the two-head procedure with the Guelph Borehole Permeameter. K_{sat} is measured in cm hr^{-1} and results were classified into classes ranging from Low 1 (< 0.05 cm hr^{-1}) to High 2 (> 50 cm hr^{-1}).

With both measurement methods, coarser textured soils fell within the higher K_{sat} classes whereas finer textured soils were in the lower classes. Of 213 sample points where K_{sat} was determined by both methods, only 14% were in the same class, 32% were one class off, and the remainder were two classes or more off. This was not unexpected as the Guelph Permeameter measures field saturated hydraulic conductivity and air bubbles are often entrapped in the soil, resulting in lower values than at true saturation. The Guelph Permeameter tended to underestimate K_{sat}.

5 Conclusions and recommendations

The OASS generated important baseline information on the chemical and physical properties of Okanagan-Similkameen Valley soils. There remains a significant opportunity for both federal and provincial agencies in partnership with industry leaders to interpret findings from this study into meaningful information that can be used by producers to manage their soils as sustainably as possible.

Key conclusions and recommendations from this study are as follows:

5.1 Soil testing methods and interpretation

Results from the Mehlich-3 extraction method were closely correlated with the Kelowna extraction method for various elements, including phosphorus. However, the relationships between the two extractions were different than in the Lower Fraser Valley. The results suggest Mehlich-3 has value as a multi-element extraction method but regional differences need consideration in developing interpretation guidelines.

5.2 Nitrogen

Most soils had low to medium post-harvest nitrate contents. Some low testing fields could have been deficient, potentially limiting production. For fields that tested high to very high, nutrient management planning methods are strongly encouraged, including annual post-harvest soil nitrate testing and careful selection of nutrient application rates.

5.3 Phosphorus

Most soils had high to very high phosphorus contents and Okanagan-Similkameen soils have limited phosphorus binding capacity relative to Lower Fraser Valley soils. Attention is required for appropriate application rates of phosphorus amendments and management practices that minimize the potential for phosphorus transport to surface water.

5.4 Other elements

Whether from natural occurrences or amendments, a small number of fields had high concentrations of certain elements such as sulphur, lead, and arsenic. Further research is suggested to identify the sources of these elements and investigate both agronomic and environmental implications.

5.5 Soil physical properties

Available water storage capacity and saturated hydraulic conductivity values were assigned to all the major soils of the Okanagan-Similkameen area included in the study. Further work is required to incorporate this information into existing irrigation recommendations, allowing further refinement of beneficial management practices for irrigation.

Part B

Agronomic and Environmental Status of Extractable Nutrients and Other Elements in Commercial Agricultural Fields in the Okanagan-Similkameen Valleys in 2007

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6 Introduction

A study was conducted in 2005 to examine the agronomic and environmental status of commercial agricultural fields of the Lower Fraser Valley (Kowalenko et al. 2007). Regional nutrient budget calculations had shown that nutrient (nitrogen, phosphorus and potassium) applications are being applied to fields in excess to the removal as harvested crops (Schreier et al. 2003), but there were no direct soil measurements to evaluate the validity of the calculations nor the agronomic and environmental implications. The results of the soil nutrient survey showed that there were significant numbers of fields where these three nutrients had accumulated to contents where there is potential to adversely affect crop production and quality, and to pollute the environment. Nutrient management is an important concern for Environmental Farm Plans (EFP) especially in areas of intensive agricultural production, and the survey was important to provide a quantitative measure of the status of nutrients in commercial agriculture fields at the initiation of the EFP program in British Columbia, as a basis for assessing the impact of the program on the environment.

The accumulation of nutrients in soils of the Lower Fraser Valley has resulted largely from the intensive management required for economic crop production on high value land. The Okanagan-Similkameen area is another intensively farmed region of the province. In contrast to the diverse range of crops, concentration of dairy and poultry, and humid climate in the Lower Fraser Valley, agriculture in the Okanagan-Similkameen area is predominated by tree fruit and grape production that requires irrigation due to the arid climate. The Okanagan-Similkameen area also has substantial livestock production which is largely concentrated in the North Okanagan and scattered in the Similkameen Valley.

Since there is limited information about the nutrient status of soils in the Okanagan-Similkameen area, a survey of soils in commercial agricultural fields was conducted in 2007. The study was similar to what was done in 2005 in the Lower Fraser Valley, in that a significant component was included to evaluate methodology and develop interpretations for environmental purposes. For the methods and interpretation evaluation component, soil samples were collected from pits dug in the field to coordinate the samples with site-specific soil classifications. In addition to the pit sampling, four fields distributed across the geographic region of the sampling were sampled approximately every two weeks in the autumn and again the following spring to monitor nitrogen movement. This information was necessary to determine the implications of sampling time on interpretation of residual (post-harvest) soil nitrate measurements. The core of the project was sampling numerous fields with a probe (as for standard soil testing) during as uniform a time as possible in the autumn after crop harvest but before winter freeze-up. The advantage of the pit sampling was the direct coordination of the sample with soil survey information. The disadvantages were extensive time and resources required for each sample, the sample was specific to a single location in the field, and the sampling caused significant disturbance in the field. The advantages of the probe sampling were the lower amount of time and resources required for each sample and ability to obtain better representation of the field from numerous probes through the field. The probe method allowed sampling of numerous fields within a relatively short time interval to minimize the influence of time on interpretations. The disadvantage was classification of the soil in the field was limited to broad survey maps.

Elements in addition to nitrogen, phosphorus and potassium were measured simultaneously to examine broad agronomic and environmental issues. The objective of Part B of this report was to obtain a measure of the status of elements in the soil in relation to crop production and potential for environmental pollution in the Okanagan-Similkameen area by sampling sufficient commercial fields that would represent the range of crop, soil and management combinations that occurs in the region. Triplicates were obtained for all three types of samples to consider the implications of random and other variability, and each site was sampled to at least three depths to consider vertical movement of the nutrients.

7 Materials and methods

7.1 Sampling procedures and site characteristics

The three types of sampling in this project have been designated Phase A, Phase B and Benchmark. Phase A sampling involved excavating three pits in a field, characterizing the soil in the pit using visual and other data according to soil survey protocol and obtaining an uniform volume from the face of the profile at specified depths. Samples at 0 – 15, 15 – 30 and 30 – 60 cm depths were obtained from all pits, and samples from horizons were taken from selected pits. The three pre-specified depths were selected to be consistent with usual agronomic soil testing, and with Phase B and Benchmark sampling. Each of the three pits was considered to be a replicate for each field, with the mean of these measurements providing a value for the field. Phase B sampling was conducted with a probe (approximately 2 cm diameter) usually used for soil testing, with samples at 0 – 15, 15 – 30 and 30 – 60 cm increments. Three samples were obtained from each field, and each sample was composed of 15 to 20 probes taken randomly from the field with the objective that each of the three replicates represented the entire field. For tree fruit and grape fields, the samples were taken from the plant row (usually kept free of vegetation with herbicide) rather than between the rows. In a few fields, only the surface one or two depths were possible using the probes due to the presence of stones. Samples were transported in coolers to refrigerators until they were air dried as soon as possible.

Phase A fields were sampled from June 5 through September 6 (Table 1). Phase B fields were sampled between September 17 and November 26, with the northern regions being done earlier to coincide with the earlier harvest in those regions. The two northern Benchmark sites (Armstrong and Vernon) were sampled from September 18 to November 13, and the two southern sites (Summerland and Similkameen) from September 18 to November 29. This provided the monitoring of nitrate in the soil through the period when Phase B sampling was done. All four sites were sampled again 1 May 2008 to provide an assessment of nitrate changes over the winter. Management practices for all fields were derived by a standardized questionnaire conducted by site visits in the autumn after sampling was completed, supplemented with recorded observations during sampling.

Phase A sampling was limited to 56 fields (and therefore 168 pits) selected in six geographic regions to primarily represent the predominant soil types that occur over the entire area, with the type of crop as the secondary factor. In most cases, the three pits were within a field of the same crop and of uniform management, but in a few cases, an adjacent field with a different crop was sampled to ensure that certain soil types were included. In these cases, they were considered one field, but differences of field histories were recorded for detailed interpretations. The distribution of fields differed in their geological, soil and crop composition (Table 2). For example, fluvial deposits predominated in Oliver and Similkameen regions, whereas glacial lacustrine materials predominated in Summerland region. Numerous soil series were identified in the various pits excavated and grouped according to soil management (Gough et al. 1994) to simplify interpretations. These groups were prepared to provide information for crop production recommendations and mainly reflected parent material characteristics. Many of these factors are inter-related. For example, the northern region (Armstrong) of the area did not include any chernozemic soils due to the moister and cooler climate and these regions are more suitable for forage crop production, whereas grapes were predominant in the Oliver area where it is drier and warmer. This complex and inter-related array of the distribution of field characteristics in the regions makes it difficult to distinguish factors that would influence nutrient contents and inter-relationships.

The water contents of the samples after air drying were determined on all the samples in order to correct weight measurements to a constant (oven dry) value, and were examined for their potential to show differences in organic matter contents and texture (which were not included in this study). It was assumed that as the air dry water content increases the organic matter and fine particle content increases, and these will increase the water and nutrient holding capacity. Air dry contents differed among fields, geography (region), geology (type of deposit), soil taxonomy, soil management group and crop (Table 3), showing that soils differed in their textures and organic matter contents. Armstrong region had fields where the air dry water content was substantially greater than in the other regions and reflects the predominance of non-chernozemic and organic soils. The greater air dry water content of fields on glacio-lacustrine fields probably reflects the finer texture of this material. The miscellaneous group included organic deposits. The predominance of forage crops and presence of organic deposits in the Armstrong region probably contributes to grass and grass/alfalfa fields having the higher air dry water content (Table 4).

The depth of the surface soil horizon (mostly an Ap horizon, but there were a few cases of Ah horizons in undisturbed fields) in the 168 pits where measurements were made averaged 21 cm and ranged from 6 to 49 cm (Table 5). These depths varied with soil series. This shows that the surface depth (15 cm) that was sampled variably included not only all of the Ap/Ah horizon but a portion of the Ap/Ah horizon plus some of the subsurface, and should be considered for detailed interpretations particularly when evaluating nutrient movement down the profile and exploration for nutrients and water by plant roots. Analyses were not conducted on the samples that represented the whole of a genetic horizon in this part of the study, but samples are available from selected pits. The depth to which roots could visibly be identified ranged from 32 to 160 cm, and averaged close to a meter (Table 5). The depth to which the roots reached was apparently restricted by a specific layer of soil in 12 of the 168 pits examined and ranged from 68 to 120 cm (Table 6), suggesting that most soils provide an adequate depth for reasonable crop growth.

The selection of fields for sampling during the post-harvest period (Phase B) for the assessment of the nutrient status of the area was based on the relative distribution of crops within six regions to a total of 180 fields (Table 7). The greatest proportion of fields sampled was in the northern (Armstrong) region where there are large fields of forage crops to support livestock production. Horticultural crop production is limited in this region. Fields of tree fruits were sampled in the other five regions, and grapes were largely sampled in Kelowna and Oliver regions. There were small numbers of vegetable fields in almost all of the regions. There was no attempt to sample fields according to the proportion of conventional versus organic management, and most were conventional. Most of the soils in the sampled fields were distributed in 10 named management groups according to soil map information and each of these groups included from 7 to 26 fields. Twelve of the fields were grouped as “other” to accommodate statistical comparisons since there were only 1 to 4 fields in several named management groups; these included Guisachan with four fields, Similkameen with three fields, Postill with two fields and Greata, Roy Creek and Susap with one field each. Eight fields had soils that were classified as "miscellaneous" management group, and five of these fields were sampled in an area where suitable soil map information was not available.

Benchmark sampling was conducted by probe in three small adjacent areas (replicates) of four commercial fields in Armstrong (forage corn field near Enderby), Vernon (forage corn field near Coldstream), Summerland (apple field) and Similkameen (apple field near Cawston) regions. The Armstrong site was on fluvial fan over a floodplain deposit, Vernon site was on fluvial fan, Summerland on glacial lacustrine, and Cawston on fluvial/colluvial material. Air dry water content of the soil in the Armstrong region was the highest and it was lowest in Similkameen (Table 8). This suggests that the organic matter content was greater and the texture finer in the north part of the area than in the south. All fields had irrigation, but sampling was during a period (autumn) when limited water was applied. The sampling was initiated in the corn fields before harvest was conducted and continued after the crop was removed (around the second to third sampling). At the Vernon site, the sampling areas had to be moved slightly from the original for the third (Oct. 23) and subsequent samplings due to harvest traffic compaction. In the corn fields, 12 probe samples were taken midpoint between two plant rows in each of the three replicate areas at each sampling time. Sampling was done similarly in the apple fields, but with all probe samples collected within the normal tree radius. A probe thermometer was used to measure soil and air temperatures during October 23, November 13, November 29 samplings, and May 1 the subsequent spring. On Nov. 29, the soil was frozen and prevented sampling at Armstrong and Vernon sites. General weather measurements were obtained from weather stations near each of the sites. The soil samples were transported in coolers to Agassiz within one or two days of sampling, where field moisture contents were determined as soon as possible, and the remainder of the samples air dried for chemical analyses.

7.2 Laboratory and statistical analyses

The chemical analyses conducted on the soil samples were similar to those done on the samples for the 2005 Lower Fraser Valley Soil Nutrient Study (Kowalenko et al. 2007). The extraction solutions were Kelowna-original and Mehlich-3 (1:10 soil-weight:solution-volume for 5 minutes) and water (1:10 soil-weight:water-volume for 1 hour). A 4 g air dry soil sample was used for the extractions. In addition to the water extraction, an equilibration was conducted with a 1:10 ratio of water to a solution of potassium phosphate which would provide a 50 mg kg^{-1} treatment of P and K based on the use of the air dry soil (Kowalenko 2008). The final result was also corrected to an oven dry basis. The equilibration measurement was used to determine the relative ability of the soil sample to bind P and K. A few drops of toluene were added prior to the soil:solution extraction, and again to the filtered extract to minimize microbial action. Multiple elements were measured in the water extracts and equilibration solutions by ion chromatography and inductively coupled argon plasma emission spectrophotometry (ICP). The ion chromatograph measures elements in their anion or cation form (i.e., a specific molecular form), whereas the ICP measures the elements independent of its molecular form (i.e., total amount of the element present). The ion chromatograph measurements were limited to anions, and chloride, nitrate, phosphate, carbonate and sulphate were given special consideration. Ion chromatographically measured P is considered to be phosphate- (PO_4-) P, and S to be sulphate- (SO_4-) S. Phosphorus and S measured by ICP is considered to be total or elemental P and S. Numerous elements were measured by ICP, but the instrument cannot normally measure chloride and nitrogen. The pH of the samples was measured on a 1:10 soil:water mixture by electrode meter after equilibration for 30 minutes as has been done for soil testing for many years (Neufeld 1980). Nitrate and ammonium were extracted by 2 M KCl (1:10 air-dry-soil:solution-volume for 1 hour) and measured by flow injection analyzer where nitrate was measured colorimetrically as nitrite after nitrate was reduced on a cadmium column and ammonium by colorimetry of a pH indicator after the extract solution was treated with a sodium hydroxide solution and ammonium diffused through a Teflon membrane (Kowalenko and Yu 1996a, b). Total carbon (C), N and sulphur (S) were measured by dry combustion using a LECO CNS-2000 instrument (Kowalenko 2001). Water, Kelowna and Mehlich-3 extraction, P-K equilibration and pH measurements were conducted on all Phase A samples. Kelowna, Mehlich-3 and KCl extractions, and pH were conducted on all Phase B samples, plus total C, N, and S measurements were made on the 0 – 15 cm depth samples. Only nitrate and ammonium in the KCl extraction were measured on the Benchmark samples. All element values were examined on a soil weight concentration basis (mg kg^{-1}). Nitrate and ammonium were calculated and reported on a volume basis (kg ha^{-1}) by assuming the bulk density of the soil was 1.1 Mg m^3 in all three depths. Converting inorganic N to a volume basis from the measured concentration on weight basis provided the opportunity to calculate the amount to various depths, and the value to 60 cm using the three depth measurements and incorporating the depth of the sampling interval for the interpretations.

Extensive quality control and assessment procedures were incorporated in all of the chemical analyses on the samples, including instrument calibration standards made up in corresponding solution matrices, periodic measurements of a reference sample and random measurements of duplicate samples. This allowed monitoring consistency of the measurements using quality control statistics on the reference sample and linear regression on the random duplicates of samples to assess reproducibility. Consistency and variations among the three replicate samples and different elements within each extraction were also examined. Repeat analyses were conducted on suspicious values.

Since all sampling was conducted in triplicate, various analysis of variance statistical tests were conducted, and these assessments were supplemented with Least Significant Difference multiple range tests where appropriate when differences among fields, regions, soil types, etc. were examined. Relationships between corresponding measurements, e.g., Kelowna versus Mehlich-3 extracted P, were examined by standard linear regressions, and were also evaluated by visual examination of plotted data for potential curvilinearity, grouping of values, and other characteristics. Statistically significant differences were accepted when P was < 0.05.

Note that all of the extractions for this study were conducted on a weight of soil to volume of extract solution basis with an adjustment to an oven dry equivalent (i.e., mg kg^{-1} oven dry sample). In contrast, the former provincial Soil Test Laboratory conducted their analyses with a standard volume (scoop) of soil and the final content expressed as mg cm^{-3} of soil (Gough 1991). In this report, it was assumed that the provincial Soil Test Laboratory interpretations expressed on a volume (mg cm^{-3}) basis are the same for values expressed on a weight (mg kg^{-1}) basis.

8 Development of interpretations for chemical analyses

8.1 Nitrogen

Since there is a limited amount of data on extractable N for the Okanagan-Similkameen area of British Columbia (Kowalenko 2000), the agronomic/environmental interpretations that were used for the 2005 Lower Fraser Valley study were used for this study. The Lower Fraser Valley N categories for nitrate were based on an assumption that all residual N in the soil could potentially be leached into groundwater and when 100 kg N ha^{-1} was present the leached water would directly contribute 10 mg nitrate-N mL^{-1} to the ground water. Ten mg nitrate N kg^{-1} or more is considered to pose a health risk in Canadian drinking water guidelines. The categories for nitrate were also used for extractable ammonium, since it was assumed that ammonium could be converted to nitrate and thus cause a health risk. Although total soil N measurements were added to explore whether they could be used to further evaluate the N status, no interpretations were available. Preliminary interpretations were derived mathematically. The basis for the calculation involved the assumption that 1% of the total N in the surface depth of soil would be mineralized during one growing season. Since the interpretation value for low to very high residual N is based on a volume of soil (kg ha^{-1}) rather than a weight concentration, the 1% N mineralized from total N in the surface depth on a weight basis was adjusted to a volume basis to determine total N concentration categories (Table 9). The implications of the use of the N pollution risk categories for the Lower Fraser Valley (with a humid climate) for the Okanagan-Similkameen Valleys (with an arid climate) may need further consideration.

The sequential (Benchmark) sampling of fields in four regions showed different results at each of the locations (Table 10). There was no evidence of nitrate movement at the site in Armstrong region during the autumn, but there was an accumulation of nitrate the following spring. Liquid dairy manure had been applied 2 November, but apparently did not affect soil nitrate by 13 November. Any visible manure on the soil was not included in the sample of the soil taken. The increased nitrate on 1 May was likely due to the applied manure. Soil temperatures at all four sites were quite warm on 1 May. Almost all of the increased nitrate in the soil on 1 May was in the surface depth, which suggests that mineralization and/or nitrification of manure N had proceeded between 13 November and 1 May, but had not leached very significantly. Soil temperatures had gradually decreased in all fields as autumn progressed, but more quickly in the Armstrong and Vernon regions. Sampling was not done in the two northern regions 29 November due to the soil being frozen. There was an apparent loss of nitrate from the 60 cm sampling depth between 3 and 23 of October, and no further movement or loss from 23 October through 1 May in the field in the Vernon region. The loss of nitrate in early to mid October appears to have been due to a loss of the relatively large amount of nitrate that had been present toward the bottom (30 – 60 cm) of the profile. There was a similar loss of nitrate in mid October in the field in the Summerland region, although the data is not as definitive as in the Vernon region site. The field in the Similkameen region had negligible nitrate in the entire autumn sampling period, so no information can be derived about leaching through the entire sampling period. There was no evidence of nitrate accumulating from the mineralization of organic N. Ammonium was extracted from the soils at all four sites with the most being present in the Armstrong region field, an intermediate and similar amount in the Vernon and Summerland region fields and least in the Similkameen region field (Table 11). Although the amount of ammonium was relatively stable throughout the sampling period, there was a relatively consistent but small decrease of ammonium from the first to second sampling and then ammonium remained constant. The manure application in the Armstrong region field did not influence the ammonium content of the soil. Although the weather conditions had similar patterns among the four regions, there were differences in detail, especially precipitation (Table 12). Armstrong region tended to be wetter earlier in the autumn than in Vernon and Summerland. The relatively large amount of precipitation in Vernon and Summerland between 19 September and 23 October coincided with the period where nitrate was apparently leached. The relatively large amount of precipitation in Armstrong region between 19 September and 4 October did not result in apparent nitrate leaching. The content of nitrate in Armstrong site was initially much lower than what was present in the fields in the Vernon and Summerland regions. Soil water contents (Table 13) responded to precipitation (Table 12) as expected, but the magnitude of the changes were small. All four fields were already quite moist when the autumn sampling began, which reduced the ability for the water content measurements to show the response to precipitation. The soils being moist early in the autumn and significant nitrate depth in the profile (Table 10) probably contributed to the leaching that was observed in the Vernon and Summerland region fields. The water contents of the fields at the time of sampling were greatest in Armstrong, lower and similar for Vernon and Summerland, and lowest in Similkameen region (Table 13). This corresponded to air dry water contents (Table 8) which relates to the variable water holding capacities of the soils.

These results show that autumn extractable soil inorganic nitrogen, especially nitrate, measurements must be interpreted cautiously regarding residual effects. It would be best to sample as soon after harvest as possible, especially in the northern cooler and wetter areas if the field is already moist late in the growing season. The water content of cultivated fields in the Okanagan late in the season will be influenced by irrigation as well as precipitation. Fortunately, Phase B sampling was sampled earlier in the north than the south (Table 1).

8.2 Phosphorus

The four 2005 Lower Fraser Valley environmental risk ratings for water extractable PO_4-P and Kelowna extractable P (Kowalenko et al. 2007) were used as a preliminary environmental assessment for the Okanagan study (Table 14). An examination of the values for these four P ratings on the surface depth of the Phase A Okanagan samples showed a majority (89%) of fields had high to very high environmental P risk for the water extractable P, but only about half (54%) were in those categories using Kelowna extractable P (Table 15). The assessment of the potential environmental risk for applied P according to the equilibrium measurement showed that all fields were very high risk, whereas the index value for this same type of risk using the proportion of P to Al in the Mehlich-3 measurement showed much fewer samples at high risk with 25% at medium to low risk. The equilibration measurement shows that Okanagan soils do not bind very much of any P applied to it and all soils are close to P saturation. The P saturation index determined by the P and Al extracted by Mehlich-3, however, suggests that the soils are not particularly saturated. The regression between the Mehlich-3 P saturation index and the saturation based on the equilibration measurement was not significant (r^2 = 0.02 for the 504 Phase A samples that included all three depths). The Mehlich-3-based P saturation index has been criticized for not being able to assess P saturation for alkaline soils, since the original method was proposed for acidic soils and assumes that Al predominates P adsorption (Ige et al. 2008). The relatively large coefficients of variation for the extraction measurements are assumed to reflect a large amount of variation among the samples taken from three specific locations within a field using the pit approach.

There was a large difference in the number of fields classified as high and very high environmental risk by water and Kelowna extraction measurements in the Phase A samples of the Okanagan study (Table 15). This difference shows that agronomic interpretations for the Kelowna extraction cannot be used for the Okanagan as for the Lower Fraser Valley. It is apparent that this was the result of the Okanagan soils not binding as great a proportion of P as in the Lower Fraser Valley. The correlation coefficient between water extractable PO_4-P and Kelowna extractable P was significant for all three depths but differed among the depths (Table 16). Although the relationship of water with Kelowna extractable P was significant, the regression coefficients were moderate (r^2 = 0.52 to 0.86), and was influenced by depth of sampling, and soil factors such as taxonomy. The proportion of P in the Kelowna extraction that was extracted by water as phosphate was about 15%, whereas in the Lower Fraser Valley it was about 6% (Kowalenko et al. 2007). For the Lower Fraser Valley study, the agronomic interpretations were based on those for crops groups 2 – 5 since those were the predominant crops grown in the area. Crop group 1 is specifically for tree fruits (Gough 1991). Recommendations for these types of plants apparently assume that tree fruits do not require very much applied P since it is stated that “ a phosphorus recommendation is made only for orchards that are about to be planted” and a rate of application is provided up to a Kelowna extraction value up to 25 mg cm^{-3}. Using this information, new environmental risk categories using crop group 1 agronomic interpretations are proposed for the Okanagan-Similkameen area (Table 17). If it is assumed that water extractable PO_4-P provides the best basis for environmental risk, alternate environmental risk categories can be calculated for Kelowna extractable P by considering the variable proportion that Kelowna extraction would be water extractable. Using the 6 and 15 percentages of water to Kelowna extractable P that were noted for Lower Fraser Valley and Okanagan soils, respectively, two alternate environmental risk interpretations are proposed (Table 17). It is interesting that the categories for risk using the 6% water to Kelowna relationship is very similar to the agronomic categories for crop group 2 – 5. The categories based on crop group 1 agronomic interpretations have generally lower Kelowna values than for crop group 2 – 5, and those using the 15% water to Kelowna P extraction relationship are even lower than for crop group 1. These low Kelowna extraction values for the risk categories result from the low binding capability of Okanagan soils.

A majority (89%) of fields sampled in Phase A would be considered to be high to very high environmental risk when water extractable PO_4-P is considered, and as expected, the proportion (91%) is similar when using the risk categories based on Kelowna extraction when 15% water extractable P is assumed (Table 18). A slightly lower proportion (81%) was classified as high to very high risk when the crop-group-1 criterion was used. However, a substantially lower proportion of fields would be classified as high to very high risk when crop-group-2 – 5 and 6% water-extractable P criteria are used (54 and 64%, respectively). It is concluded that different criteria are needed for environmental assessment of Kelowna extractable P than for agronomic assessment for the Okanagan-Similkameen area, in contrast to what was proposed for the Lower Fraser Valley because of the much lower P binding ability of Okanagan-Similkameen soils. The values for extractable P content (water and Kelowna) and degree of P saturation (determined by equilibration and P/Al methods) generally differed by depth in Phase A fields (Table 19). These differences with depth varied from field to field (significant field x depth interaction) for all but the equilibrium measurement. The values for all the measurements were greater at the surface. This suggests that P has accumulated at the surface by the application of amendments, translocation from the subsurface by plants or simply changes to inherent P that would make it more soluble. More detailed examination of individual fields will be needed to determine whether the content of P in the soil is due to the inherent P in the soil or to application of amendments. Other factors (geography/region, geology, soil characteristics or management due to growth of specific crop types) also influenced the extraction and binding potential of P in the fields (Tables 19 – 22). The dark gray chernozem soil had substantially more water and Kelowna extractable P than the other types of soils (Table 20); however, this is based on samples from only one pit. The samples from the organic soil had increasing extractable P with increased depth of sampling in contrast to all the other types. The amount of PO_4-P extracted by water was significantly but poorly correlated with the air dry water content (regression $r^2 = 0.45$, n = 504 with all three depths considered), but Kelowna extractable P, and equilibration and Mehlich-3 P/Al estimates of P binding were not well correlated ($r^2 = 0.06$, 0.00 and 0.29, respectively). Air dry water content is assumed to integrate the effect of texture and organic matter in the soil.

The Kelowna and Mehlich-3 extractions of P were highly correlated ($r^2 = 0.97$ with all three depths considered), and the nature of the relationship varied somewhat with depth (Table 23). Mehlich-3 extracted 20 to 30% more P than Kelowna method. For similar analyses of Lower Fraser Valley soils, extraction of P by these two methods was also highly correlated ($r^2 = 0.97$ with three depths included; Kowalenko et al. 2007), but the regression relationship was different with Mehlich-3 extracting approximately 42% more than Kelowna. Although the regression coefficient between the two extractions for Okanagan samples was high, the differences between the methods varied with soil and/or management factors as occurred with the depth of the sampling.

The regression of estimating P saturation potential with Kelowna instead of Mehlich-3 extractable P and Al was relatively high ($r^2 = 0.79$ including 504 samples from all three depths), and was affected by depth of sampling and also various soil and management factors (Table 24). This relationship, however, was not as high as the relationship of the extraction of P by these two extract solutions ($r^2 = 0.97$, Table 23). The lower correlation of saturation estimates compared to P extraction by these two extract solutions was probably due to the lower correlation of the extraction of aluminum (Al) by Kelowna versus Mehlich-3 and influence of factors such as depth, soil characteristics and management practices (Table 25).

A comparison of estimates of the degree of saturation of soils with P by the equilibration and P/Al ratio methods showed that they were not correlated ($r^2 = 0.02$ including all three depths). It is assumed that the equilibration measurement is a better measure of relative saturation than the P/Al ratio since it is a direct measure rather than an estimate. Part of the reason for the lack of a relationship between the equilibration measurement and the P/Al ratio was the lack of a correlation between the equilibration measurement and Al extracted by Mehlich-3 ($r^2 = 0.00$) and

Kelowna ($r^2 = 0.02$) solutions. Ige et al. (2008) have proposed that Mg should be used instead of Al for calcareous soils for calculating the degree of P saturation, assuming that the binding of P is largely due to Mg rather than Al. The regression of the equilibration measurement of P binding for the Okanagan samples was certainly better with Kelowna extractable Mg ($r^2 = 0.28$) than with extraction of Al, but the relationship was quite weak. The relationship between unbound P by equilibration method and Kelowna extraction of Mg was influenced by depth, soil and management factors (Table 26). It is concluded that with available data and lack of knowledge of P binding mechanisms in Okanagan soils that an estimate of P saturation cannot be made using a ratio of P with another element extracted by Mehlich-3 or Kelowna solutions, and only the equilibration method is suitable at this time. Since the equilibration method was not conducted on Phase B samples of this study because of time and cost limitations, a measurement of P saturation is not available for these assessment samples. However, the equilibration measurements on Phase A samples had shown that 100% of the fields would be classed as very high environmental risk (Table 15). This high risk is due to Okanagan soils having very limited potential to bind applied P.

8.3 Potassium

The K status of 2005 Lower Fraser Valley soils were based on agronomic interpretations (Kowalenko et al. 2007). Agronomic interpretations for K as for P vary with crop type as well as geographic region (Gough 1991), and the interpretations for two crop groups are proposed for this study of Okanagan soils (Table 27). Only crop groups 1 and 2 have been selected as they differ substantially, whereas there are much smaller differences among crop groups 2 through 5. Similar to P, crop group 1 for K is for tree fruits. The low K threshold soil extraction values for application recommendations suggest that these plants are generally considered to not respond significantly to K applications. Similar to the 2005 Lower Fraser Valley study, measurements of the amount of K extracted by water, the proportion of added K that was not bound during equilibrium and the ratio of K to Mg in addition to extraction by Kelowna and Mehlich-3 solutions were used to assess the status of K in the Okanagan-Similkameen fields. There were differences among these five measurements on Phase A samples as expected, and the values differed by depth (Table 28). The differences among depths varied with fields (field x depth interaction) for all measurements except water extraction. For all five measurements, values decreased with depth of sampling. General variations of all measurements were relatively high and assumed to reflect the variation of the samples from specific locations in the pits within each field. The negative value for the measurement of K binding suggests that the method needs further evaluation. A majority (70 to 80%) of Phase A fields had high to very high contents of Kelowna extractable K in the surface depth (Table 29). The proportion of water extractable K of that extracted by Kelowna solution was relatively well correlated ($r^2 = 0.76$ with samples of all depths included), and the relationship was influenced by depth, soil and management factors (Table 30). The influence of depth was limited as the effect was on the intercept of the regression only. Unbound K during equilibration could not be predicted by the K extraction as the correlations were not significant for comparison with both water ($r^2 = 0.10$) and Kelowna ($r^2 = 0.08$) extract values. Although the relationship of K to Mg extraction with Kelowna solution was not significant ($r^2 = 0.08$), visual inspection of plots suggest that there may be cases of distinctly different groups of samples beyond the depth, geography, geology taxonomy, soil management groups and crop type factors examined. More detailed examination of the relationship of water with Kelowna extraction of Mg may be scientifically and practically useful. Similar to that observed for P, the extraction of K by Kelowna and Mehlich-3 extracts was significantly correlated ($r^2 = 0.98$), but unlike P, the relationship was consistent with depth (Table 31). The relationship was, however, influenced by soil and crop factors. The amount of K extracted by Kelowna and Mehlich-3 was also highly correlated for Lower Fraser Valley soils ($r^2 = 0.98$), but the nature of the relationship was different from that for Okanagan soils. Mehlich-3 extracted more K than Kelowna extract, with a smaller proportion in Okanagan (27%) than Lower Fraser Valley soils (41%).

8.4 Other measurements with provincially developed agronomic interpretations

A number of soil test measurements other than N, P and K have published agronomic interpretations and can provide a basis for assessing their status (Neufeld 1980; Gough 1991). These include magnesium (Mg) and sulphur (S) for Kelowna extraction, boron (B) in hot water extraction and pH where values can be ranked into a range of categories (such as low, medium, high and very high), and zinc and copper in DTPA extraction where a single value distinguishes deficient from sufficient concentrations.

Two classifications are given for Mg: Group A for crops with low recommended applications and Group B for crops with higher recommendations (Table 32). For both classifications, a majority (95 to 100%) of the Phase A Okanagan fields rank high to very high for Mg fertility. The mean concentration of Mg extracted with Kelowna solution was greater than 200 mg kg^{-1} from all three depths and apparently was consistent with depth for all the fields (Table 33). Water extracted an average of 29 mg Mg kg^{-1} and the concentration was similar for the next two depths. Mehlich-3 extracted an average of more than 350 mg Mg kg^{-1} from the surface two depths and significantly more from the deepest depth. Overall variability was relatively high as was noted for P and K. Magnesium extracted with Kelowna and water was weakly correlated, and the relationship was observed to be in three groups. The regression for this relationship for all the data and all three depths was:

Water-Mg = 3.54 + 0.103 Kelowna-Mg with $r^2 = 0.34$ and n = 504.

When the pairs of values were confined to a ratio of water to Kelowna values less than 0.09, the regression was:

Water-Mg = 6.85 + 0.038 Kelowna-Mg with $r^2 = 0.67$ and n = 250.

When the pairs of values were confined to a ratio of water to Kelowna values between 0.10 and 0.20, the regression was:

Water-Mg = -6.67 + 0.158 Kelowna-Mg with $r^2 = 0.91$ and n = 211.

When the pairs of values were confined to a ratio of water to Kelowna values more than 0.20, the regression was:

$$\text{Water-Mg} = -32.53 + 0.393 \text{ Kelowna-Mg with } r^2 = 0.90 \text{ and } n = 43.$$

It is apparent soils in the Okanagan can contain Mg that has quite different solubilities. This difference of the type of Mg in the soils probably contributed to the relatively weak correlations between Kelowna and Mehlich-3 extraction which may not be directly related to the soil factors considered in this study (Table 34). This weak relationship precludes making interpretations for water extractable Mg for Okanagan soils using Kelowna (and Mehlich-3) values without detailed and additional data.

A majority (74%) of the Phase B fields were ranked very low S fertility using the criteria for Kelowna extraction values, but 16% were ranked very high (Table 35). The range of Kelowna extractable S of the surface depth was very wide (2 to 3923 mg S kg^{-1}), which resulted in very different mean (56 mg S kg^{-1}) and median (11 mg S kg^{-1}) values. This extremely wide range of values probably contributed to the very high coefficient of variation (564%). Analysis of variance of these values showed that only fields were significantly different, with no apparent differences among depths, either generally (depth main effect) or from field to field (field x depth interaction). Conducting the same analysis of variance, however, when the field with the extremely high S content was not included considerably reduced variability (coefficient of variation = 227%), and field x depth interaction was significant in addition to field. The value for the field with the second highest Kelowna extractable S was 381 mg S kg^{-1}. Water extractable inorganic (sulphate) S also showed a very wide range with the maximum field value being greater than Kelowna extractable total S. This suggests that there were possibly solubility differences of soil S in the extracting solutions, and problems in the chemical analyses of the very wide range of S concentration. The measurement for the very wide range of concentrations certainly stretched the analysis capability of both instruments (ion chromatograph and ICP), but checks by diluting the extract solutions showed that they performed quite well, suggesting that at least a part of the problem was in the extraction rather than just the chemical quantification. Similar to that found for Kelowna extraction values, not including the one field with the highest S concentration for the analysis of variance resulted in a significant field x depth effect in addition to a depth effect, and the coefficient of variation was reduced substantially for the water and Mehlich-3 extraction measurements. Mehlich-3 tended to extract more S than Kelowna, and had a higher value than water sulphate-S for the field with the highest concentration. The large variability for the S measurements may not be a major issue for commercial soil testing if the variability associated with the measurements of very high concentrations is not included since the recommendation will probably not change. For example, fields are considered to have very high S contents when Kelowna values are greater than 35 mg S kg^{-1}; thus even 300 mg S kg^{-1} is exceedingly high.

Since the field with the maximum concentration of S had water extractable sulphate-S that was as large as or larger than total S extracted by Kelowna and Mehlich-3 (Table 36), it is concluded that the large amount of S is from an inorganic S pool in the soil. The correlation between Kelowna extractable total-S and water extractable sulphate-S was very high (r^2 = 0.98), although depth and other factors influenced the relationship (Table 37). The slope of the regression equation (1.36 for all three depths combined) suggests that Kelowna extraction includes substantial organic S which is consistent with observations for Lower Fraser Valley soils (Kowalenko 2008). There was also a close relationship between Kelowna and Mehlich-3 extractions of total-S ($r^2 = 0.98$) and Mehlich-3 apparently extracted about 60% more than Kelowna (Table 38).

It should be noted that the plots of the relationship show the majority of the values grouped at very low and very high concentrations (Table 35), and a more detailed examination of relationships among the different extractions or other elements is warranted. For example, other elements that could be considered are Mg and calcium (Ca), since the large concentrations of sulphate may be associated with gypsum (calcium sulphate) or Epsom salts (magnesium sulphate). The regression of water extracted sulphate-S with water extracted Mg was quite good ($r^2 = 0.62$) when all data from all three depths were considered. However, when only water extracted sulphate-S concentrations greater than 25 mg S kg^{-1} were considered, the regression coefficient increased to 0.80 while the coefficient was low ($r^2 = 0.10$) for sulphate values less than 25 mg S kg^{-1}. The regression of water extracted sulphate-S with water extracted Ca was also very good ($r^2 = 0.95$), and the coefficient was also higher for sulphate-S greater than 25 mg S kg^{-1} ($r^2 = 0.97$) than when it was less than that concentration ($r^2 = 0.11$). This suggests that soils with very high concentrations of extractable S contain substantial amounts of calcium and magnesium sulphates.

Soil pH measurements are usually used for determining the acidity of the soil for consideration for the application of lime. With the adoption of buffer pH measurements, lime requirements are derived by formulas and matrix tables (Ziadi and Tran 2008) rather than by classifying them as low, medium and high. Previously, limestone recommendations were made according to actual pH measurements for specific soil types (Neufeld 1980). For this report, soils were considered to have low pH when significant limestone applications would be recommended, medium when low rates would be recommended and high when little or no lime would have been recommended for pH tables. Acidification (e.g., application of elemental sulphur) of very high pH soils may be considered for certain crops. Most (84%) of the fields in the Phase A samples had pH >6.5, with a small percentage (2%) <5.5 when the surface depth of sampling was considered (Table 39). In general, pH increased with depth of sampling. However, this trend varied with field as shown by the significant field x depth interaction effect (Table 40). This trend of increasing pH with depth of sampling and the deepest sample averaging 7.61 is consistent with the assumption that Okanagan soils are calcareous, but many of the soils have been weathered considerably.

Using the agronomic interpretation ranges for hot water extraction of B, most (92%) Phase A fields would be considered low to medium fertility for water measurements, less than half (36%) for Kelowna measurements and half (50%) using Mehlich-3 measurements. This resulted from the lower amount of water extracted B from surface samples than extracted by Kelowna and Mehlich-3 (Table 42). All three solutions extracted progressively less with progressively deeper sampling. The regression of Kelowna to Mehlich-3 extraction was quite good with the regression equation being:

Kelowna-B = -0.114 + 1.78 Mehlich-3-B ($r^2 = 0.990$, n = 504 including all three depths).

The regression equation shows that Kelowna solution extracted about 78% more B than Mehlich-3. The regressions of these two extractions with water extraction were not as good:

> Water-B = -0.021 + 0.326 Kelowna-3-B (r^2 = 0.600, n = 504 including all three depths), and

> Water-B = -0.066 + 0.593 Mehlich-3-B (r^2 = 0.622, n = 504 including all three depths).

It is assumed that hot water will extract more B than room temperature water, but the actual relationships among room temperature water, Kelowna and Mehlich-3 extraction values will require direct comparisons with hot water extraction measurements. The nature of the relationships will influence interpretations.

Applying the DTPA extraction concentration value (<1.0 mg kg^{-1}) that is used to distinguish Zn deficient from sufficient fields to water, Kelowna and Mehlich-3 extractions would classify Phase A fields to have 99, 14 and 0% deficient, respectively (Table 43). Each of the three solutions extracted quite different amounts of Zn with Mehlich-3 > Kelowna > water (Table 44). Both Kelowna and Mehlich-3 solutions extracted proportionately more Zn than by water as the sampling was deeper. This difference shows that a greater proportion of subsurface Kelowna and Mehlich-3 extracted zinc would be more water soluble. The regression of Kelowna to Mehlich-3 extraction of Zn was quite good with the equation:

> Kelowna-Zn = -0.063 +0.274 Mehlich-3-Zn (r^2 = 0.915, n = 504 including all three depths).

The regression equation shows that Kelowna solution extracted only about one-quarter the Zn extracted Mehlich-3 solution. The regressions of Kelowna and Mehlich-3 extract values with water extract values were not significant (r^2 = 0.098 and 0.111, respectively). A comparison of water, Kelowna and Mehlich-3 extract values with DTPA extract values will require actual measurements, but it is assumed that Mehlich-3 extraction would be similar to DTPA extraction as they both contain a chelate in their solutions. Similar to B, the nature of the relationships among the extractions will determine interpretations.

Water and Kelowna extracts classified a majority (88 and 75%, respectively) of Phase A fields to be Cu deficient according to the concentration (0.30 mg Cu kg^{-1}) used for DTPA interpretation, whereas Mehlich-3 would classify all fields as sufficient (Table 45). This occurred because water and Kelowna extracted similar and small amounts from the surface 15 cm samples of Phase A fields, and Mehlich-3 extracted considerable Cu (Table 46). Water extracted a similar amount of Cu from all three depths, and Kelowna tended to extract slightly more as sampling depth increased, whereas Mehlich-3 extracted less with increasing depth. Water-extracted Cu was not correlated with Kelowna- (r^2 = 0.09) nor Mehlich-3- (r^2 = 0.17) extracted Cu, and Kelowna and Mehlich-3 Cu values were also not correlated (r^2 = 0.23). It is apparent that these three solutions extract Cu from very different pools that are present in the soil, and that values from each cannot be interpreted the same way or proportionally. Similar to Zn, it is assumed that Mehlich-3 solution would extract Cu from a similar pool as DTPA because of the chelate in both extract solutions.

8.5 Other measurements without agronomic interpretations

Calcium (Ca) and sodium (Na) are important essential nutrients, but are usually not applied intentionally as fertilizers, since they are usually present in most soils in adequate amounts for plant growth. Calcium is added as a liming agent to adjust soil pH, and recommendations for limestone application rates are usually determined by pH measurements. Sodium (Na) is quite ubiquitous and is not usually considered for amendment, but it can be a problem for plant growth when soils are saline.

Water extracted small quantities of Ca compared to extraction with Kelowna and Mehlich-3 solutions (Table 47). In general, more Ca was extracted in the subsurface horizon, which corresponds to previous observations of pH (Table 40). Regression coefficients of water extraction with Kelowna ($r^2 = 0.26$) and Mehlich-3 ($r^2 = 0.37$) were low, but several distinct groups of measurements were noted in the plots that would suggest there could be a series of different Ca pools in the fields that have different solubilities. Although the regression coefficient between Kelowna and Mehlich-3 extracted Ca was high ($r^2 = 0.97$), visual inspection of the plots suggest that there might be groups of soil that have a different relationship and there was evidence of curvilinearity such that detailed consideration may determine useful information about Ca in soils regarding implications for plant growth and soil reaction (pH).

Extraction values for Na were quite similar among the three solutions, which shows that a similar pool of Na is being affected (Table 47). This resulted in an apparent close relationship among the extracts as shown by the regression coefficients between water and Kelowna ($r^2 = 0.81$), water and Mehlich-3 ($r^2 = 0.76$) and Kelowna and Mehlich-3 ($r^2 = 0.91$). However, similar to the observation for Ca, the plots show that there are several groups of samples where the relationship is different. More detailed examination may provide useful soil process and practical agronomic information.

Aluminum (Al), iron (Fe), manganese (Mn) and silicon (Si) are of agronomic interest because of their direct and indirect effects on plant growth. Fertility interpretations for these elements have not been established for British Columbia. Iron and manganese are sometimes applied as micronutrient fertilizers, but soil test criteria are not available for British Columbia. Their indirect effects are often associated with P and S (Kowalenko 2008).

Kelowna and Mehlich-3 solutions extracted similar amounts of aluminum (Al), and significantly more than by water (Table 48). Regression coefficients between Kelowna and Mehlich-3 with water extract were low ($r^2 = 0.27$ and 0.19, respectively), but the plots suggested curvilinearity and several groups of different relationships. The regression of Kelowna and Mehlich-3 extraction values was high ($r^2 = 0.84$). The relationships of water with Kelowna and Mehlich-3 extracts were also low for Mn and Si (r^2 from 0.00 to 0.23) although the magnitude of each element extracted differed with element. The regression between Kelowna and Mehlich-3 was high for Si ($r^2 = 0.81$), but very poor for Mn ($r^2 = 0.17$). There appeared to be a problem with the measurement of Fe by Kelowna, as shown by negative average values for the surface two depths. This may have been related to the nature of the Kelowna extract chemical composition and ICP measurement. This needs to be evaluated further. The regression of water to Mehlich-3 extracted Fe was very low ($r^2 = 0.04$).

There is a very wide array of elements in the earth's crust. Some are present in very small quantities but may have important plant or environmental implications. Others may be present in significant quantities with little significance to plant growth or for pollution concerns, but may provide information about soil forming processes. In some cases, elements could potentially provide a "fingerprint" function for identification purposes. A number of non-nutrient elements were simultaneously measured in the various extracts to take advantage of the capability of the ICP instrument used in the study and the values are briefly explored for their potential use for plant, soil and methodology evaluations and considerations. Although there is knowledge about the total content of these elements in earth materials, little information is available about their extractability especially with soil test solutions and especially for British Columbia soils.

Strontium (Sr), barium (Ba), lithium (Li) and rubidium (Rb) were considered in relation to their potential to examine the behaviour of cations in the soil (Table 49). The Kelowna solution extracted quantities of Sr similar to water, and Mehlich-3 extracted substantially more probably due to the presence of a chelate. The similar extraction of Sr with water and Kelowna suggests that Sr is quite soluble in the soil. Concentrations of Mehlich-3 extractable Sr were similar for all three depths. Kelowna solution extracted more Ba than water, but less than extracted with Mehlich-3 solution. Mehlich-3 extracted Ba increased with depth of sampling. Only small and similar quantities of Li and Rb were extracted by the three solutions, and differences among depths were small.

Very small amounts of beryllium (Be) were extracted by all three solutions (Table 50). Slightly more scandium (Sc), vanadium (V), yttrium (Y), and cerium (Ce) were extracted. Mehlich-3 solution tended to extract more of these elements than Kelowna, and Kelowna tended to extract more than water, and concentrations tended to be similar with depth. Water tended to extract more titanium (Ti) than Kelowna solution, and Kelowna more than Mehlich-3 solution. There was increased Ti extracted by Mehlich-3 with increased depth. Mehlich-3 extracted more zirconium (Zr) than Kelowna, and Kelowna extracted more than water. Mehlich-3 extracted similar amounts of Zr from the three depths. The different amounts of these seven elements extracted by the three solutions, and the differences with depth show a potential opportunity to study soil processes, but the results need detailed examination and comparisons with soils from other areas. This type of information is also important for evaluating the use of "exotic" elements as internal standards. Codling (2008) used Sc as an internal standard in a USA study. In order for an element to be useful as an internal standard, inherent quantities of that element must be negligible in the study matrix.

Lead, (Pb), arsenic (As), nickel (Ni), cadmium (Cd), cobalt (Co), chromium (Cr) and tungsten (W) can be important industrial elements, but can also be significant pollutants in the environment. Variable quantities of these elements were extracted by the three "soil test" solutions from the Phase A soil samples, and in a number of cases, they were at or below the detection limit considering the combined effect of the extraction and the measurement (ICP) of the elements (Table 51). Mehlich-3 tended to extract the most of these elements, and the relatively large amounts of Pb and As encourage further investigation. Mehlich-3 extracted substantially more Pb than Kelowna and water, and quantities decreased substantially with depth. The presence of large quantities of Mehlich-3 extracted Pb at the surface suggests that it was due to an amendment to the field. Kelowna solution tended to extract more As than water, and quantities similar to Mehlich-3. Maximum quantities of As extracted by Kelowna and Mehlich-3 solutions were significant, and Mehlich-3-extracted As tended to increase with depth. This suggests that the relatively high extractable As is influenced by the make-up of the soil.

9 Assessment of the agronomic and environmental status of nutrient and element contents

9.1 Nitrogen

Over one-half (56%) of the 173 fields assessed in the Okanagan-Similkameen Valleys were classed as having low residual nitrate and about one-quarter (24%) were classed as medium (Table 52). Seven of the 180 fields (4% of all fields) in the study had sufficient stones that prevented sampling the entire 60 cm depth that was necessary for the assessment, with two of the fields not included being in Vernon region and the other five in Similkameen region. Of the eleven fields that were classed as having very high residual nitrate, six were in the Armstrong region. Armstrong region had the field with the highest residual nitrate (712 kg N ha^{-1} to 60 cm), thus contributing to that region having the highest average residual nitrate. The remaining fields of very high nitrate were in Vernon, Kelowna and Summerland regions. Only three fields (1% of all 173) contained very high residual ammonium, and these were in the Armstrong region (Table 53). The three fields were growing grass or alfalfa. The maximum content of ammonium was 328 kg N ha^{-1} to 60 cm. Most of the fields (95%) contained low ammonium contents.

A large proportion of the fields (86%) were considered to have a low ability to potentially release inorganic N by mineralization using the total N content of the surface depth sample (Table 54). All six of the fields that showed very high potential for mineralizing total N according to total N content were in the Armstrong region where the highest residual nitrate contents were found (Table 52), but the correlation between residual nitrate and total N was low ($r^2 = 0.31$). The regression plot showed that there were several distinct groups of data. More detailed examination may provide insight into the reason for the grouping of the data. Part of the reason for the grouping may be due to differences in the quality of organic N in these soils. Total C in the surface depth of these fields ranged from 0.4 to 38.6% (average of 3.5%), and total C and N concentrations were highly correlated with the following regression equation:

$$Total\_N = 0.021 + 0.069\ Total\_C \text{ with } r^2 = 0.99\ (n = 540).$$

This relationship resulted in an average C/N ratio of 13.2 and range from 10.2 to 25.6. It should be noted that the C/N ratios were calculated with total and not organic C and N measurements. Some of the C in these soils may have been inorganic from the presence of carbonate. Although the extractable nitrate and ammonium (i.e., inorganic N) contents of these can be subtracted to calculate organic N, there are no measurements on the potential for clay-fixed ammonium being present in Okanagan soils as has been observed in the Lower Fraser Valley (Kowalenko and Yu 1996b).

Cereal, grass and forage corn fields had the highest average residual nitrate contents, other tree fruit and vegetable fields had an intermediate average content, while apple, cherry, grape and alfalfa had the lowest average content (Table 55). There were no apparent differences among conventional, organic and transitional management types. The variability of soil total N in fields grouped according to the crop grown was too large to distinguish differences by Least Significant Difference test. Although the average amount of N reported to have been applied to the soil in 2007 tended to correspond to the nitrate content, there was no correlation (r^2 = 0.00) between these factors. The range of N applied to the soil was from zero to 539 kg N ha^{-1}. Foliar applied N was not considered in this comparison.

The survey shows that a majority of Okanagan-Similkameen fields contained low contents of N and may have been deficient for crop growth. Much of the low N content is probably due to low inherent organic matter contents. There were a few cases where nitrate and ammonium contents were sufficiently large to cause potential for pollution. The potential environmental impact of high mineral N contents is difficult to fully assess because of the generally dry climate where leaching would be limited. More data on N leaching from natural precipitation and irrigation, both during the growing season and after crop harvest to freeze-up, are required to determine the full impact for nitrate pollution of water.

9.2 Phosphorus

According to agronomic interpretations, whether considering crops that are anticipated to respond readily to P applications or not, most (75 to 91%) Okanagan-Similkameen Valley agricultural fields had high to very high P contents (Table 56). When an environmental interpretation based on the predicted proportion of Kelowna P to be water extractable, almost all of the fields (96%) were considered to pose a potentially high to very high pollution risk, with 75% ranked very high and none ranked low. The number of fields distributed in the crop 2-5 agronomic categories was fairly uniform over the sampled area, although Similkameen region tended to have more fields ranked low to medium (Table 57). Armstrong region had the highest average residual P content (149 mg P kg^{-1}) and Similkameen region had the lowest average (58 mg P kg^{-1}). The field with the highest P concentration was in Armstrong region. Fields cropped to forage corn and cereal had the highest average residual P, while fields of alfalfa-grass/barley mixture and grass alone had the lowest average concentration (Table 58). The concentration of residual P did not differ among conventional, organic and other management practices. There was no correlation (r^2 = 0.00) of extracted P with reported soil P applications, as there was a wide range of rates applied.

Since the high residual P content and the limited P binding capability makes Okanagan-Similkameen agricultural fields high risk for water pollution, soil P amendment rates need re-evaluation and management practices to minimizing transport of soil P via erosion and runoff are necessary. The naturally low precipitation in the area will help to minimize pollution of water, but attention will be needed on irrigation practices and application rates of P amendments.

9.3 Potassium

From 59 to 84% of the fields sampled in the Okanagan-Similkameen area were classed as having high to very high extractable K depending on the agronomic classification (Table 59). There were no fields in Vernon, Kelowna, Summerland and Oliver regions which were classed as low according to crop group 1 agronomic classification, and also no medium fields in Kelowna and Summerland regions (Table 60). The highest average Kelowna extractable K was in Vernon, where the field with the highest extraction value occurred (Table 61). The lowest average concentration was in Similkameen region. Fields cropped to forage corn and cereal had the highest average concentration and low concentrations in fields of other tree fruits, grapes and alfalfa alone or mixed with grass or cereal. Similar to N and P, there was no correlation (r^2 = 0.00) of soil K with K applied to the soil in 2007 since there was a wide range of application rates. This suggests that rates of K applied to Okanagan-Similkameen agricultural fields need examination, with encouragement to use soil tests.

9.4 pH

There were only a few (4) fields in the study where the pH of the soil was low, and all of these were in the Armstrong region (Table 62). A significant number of fields (38 representing 21%) had soils that were very high, with most in Similkameen region. This probably reflects the more highly weathered soils in the northern part of the study area, and the calcareous nature in the south. Although there were differences in average pH among the regions, the differences were relatively small (Table 63), likely due to the measurement being on a logarithmic scale. A detailed evaluation is needed to fully determine the agronomic implications of the pH measurements.

9.5 Magnesium

Almost all (95%) of the fields in the study had high to very high Kelowna-extractable Mg (Table 64). The rest of the samples (5%) were considered to be medium, such that no samples were considered low. Maximum Mg values in each of the regions were very much (from about 10 to over 30 times) greater than the 35 mg kg^{-1} considered to be very high. With the very wide range of values, differences among crop types could not be calculated by Least Significant Difference test, although organic fields were significantly lower than other fields (Table 65). The generally high Mg concentrations meant that the mean K/Mg ratio was 1.1, with a range of 0.1 to 4.6. Fifteen per cent of the fields had K/Mg ratios greater than 1.75, and the other 85% were equal to or less than 1.75. A ratio of 1.75 was considered optimum from a consideration of K and Mg values for soils classed as medium for each of the nutrients (Kowalenko et al. 2007). This data shows that deficiencies of Mg would be rare, but attention is needed to determine if there will be crop growth problems in soils with very high Kelowna-extractable Mg.

9.6 Sulphur

Although 75% of the fields in the study area had Kelowna extractable S values that were considered to be agronomically low, 16% were classed as very high (Table 66). The fields with low extractable S were distributed in all regions, and all but three of the 28 fields of very high S were in Armstrong, Vernon and Similkameen regions. Similkameen region had a field with an exceedingly high concentration (2152 mg S kg^{-1}). The second highest concentration was in a field in Vernon (1455 mg S kg^{-1}). The field with the maximum extractable S in Armstrong had 621 mg S kg^{-1}. The highest S concentration in Summerland region, where the three other fields of very high concentrations occurred, was only 56 mg S kg^{-1}. The exceedingly wide range in S values in the fields did not allow the use of Least Significance Test to statistically distinguish concentrations in fields of different crops, although average values for grass and alfalfa mixed with either grass or cereal were much higher than for other crops (Table 67). It is apparent that the agronomic and environmental implications of both deficient and excessive S contents of fields need to be determined. The fields with very high S may be those that have natural deposits of gypsum (calcium sulphate) or Epsom (magnesium sulphate) salts.

9.7 Boron, zinc and copper

Mehlich-3 extractable residual B in the study fields ranged from below the detection limit of 0.2 to maximum of 3.66 mg B kg^{-1} (Table 68). Summerland and Similkameen regions had the highest average concentrations. Classifying the concentrations according to agronomic ratings for hot water extraction shows the fields distributed fairly uniformly from low to very high. The large variability of the data limited the examination of differences among crops and management types. The ability of Mehlich-3 solution to extract significant quantities of B and distinguish differences among regions shows that this extraction could be explored as an alternative to hot water extraction. Field response trials will be needed in addition to comparing extraction values of Mehlich-3 with hot water to enable the adoption of Mehlich-3 method. Mehlich-3 extraction would be preferable because of its simultaneous use for several other nutrients.

Similar to B, Mehlich-3 extracted significant quantities of Zn and Cu (Table 69), and with differences measured among regions, management practices and, to a certain extent, crop groups. Mehlich-3 extracted more Zn and Cu from all fields in the study than the thresholds that are considered for deficient soils using a DTPA extraction method (1.0 and 0.3 mg kg^{-1}, respectively). Comparisons of Mehlich-3 with DTPA extraction values for these soils are needed to determine which solution extracts more of these nutrients, and crop response trials are needed to determine agronomic interpretations. Again, Mehlich-3 extraction would be preferable to DTPA extraction because of its multiple nutrient extraction capability.

9.8 Lead and arsenic

Mehlich-3 extracted a very wide range of Pb (from below the detection limit of 1.3 up to 102 mg kg^{-1}) from the study fields (Table 70). There was a range of average Pb extracted from the various regions, but high concentrations tended to be in apple and cherry fields. Fourteen of the fields had greater than 50 mg Pb kg^{-1}, 18 had 10 – 50 mg Pb kg^{-1} and the other 148 had less than 10 mg Pb kg^{-1}. More detailed work is needed to determine whether the high concentrations in some fields are due to amendments or the contents are natural. The concentration of high values in two crop groups would suggest that the source was due to amendments. Detailed examination and more measurements are needed to determine environmental implications

Six of the fields in the study had Mehlich-3 extracted As concentrations that were two times the detection limit (4.2 mg kg^{-1}) of the extraction procedure (Table 71). Eighty eight per cent (158 fields) were below the detection limit. The concentration of As tended to decrease with depth of sampling and may suggest an amendment source. All six fields were in Similkameen region, and included five different soil series (Nighthawk, Susap, Cawston, Snehumpton and Iltcoola) and three crop groups (alfalfa, grass and vegetables) with three being managed conventionally, two organically, and one of unknown management. Further work is needed on this element as well to determine the environmental implications of these measurements.

10 Summary and conclusions

This study involved three types of sampling, two (in open pits and sequentially in plots) for the development of interpretations of chemical measurements, and one (by probe after harvest) for determining the agronomic and environmental status of representative agricultural fields in six regions in the Okanagan and Similkameen Valleys. A wide range of nutrients and elements were considered. Interpretations for N, P and K previously used for a similar Fraser Valley study were modified for Okanagan-Similkameen soil conditions, and agronomic interpretations were adapted to include environmental considerations for other nutrients and elements. These interpretations were then used to assess the agronomic and environmental status of commercial agricultural fields representing the distribution of crops in the area by the measurements of elements after crop harvest (i.e., residual to crop utilization).

Most of the fields contained low to medium contents of N, but there were a few cases where contents were very high and could potentially pollute water. Both the phosphorus contents of the soils and the relatively high degree of saturation showed that management practices are needed to prevent the potential to pollute surface waters. Attention will have to be on the application rate of P amendments and management practices to limit P transport from fields to surface waters. Potassium and Mg contents were generally high, probably due to inherent quantities in the soil. Fields with very high contents of these nutrients, especially Mg, need to be examined further to determine agronomic and environmental implications. The S content of the fields included many that were potentially deficient, but there also were some fields that had extremely high contents. The S in the fields with very high contents may be natural from calcium (gypsum) and magnesium (Epsom salts) sulphate deposits. The agronomic and environmental implications of the very high S contents need examination. The pH of the soils tended to be medium to high, but there were a few that were acidic. Fields with low and very high values warrant further investigation. The evaluation of the status of B, Zn and Cu for field crop production needs attention to methods used and their interpretations. Field response data would be needed. The measurements of other elements showed that they have potential for studying soil processes, and for assisting in soil test interpretations. Very high contents of Pb and As in Mehlich-3 extracts of a number of the fields are of potential health and environmental concern.

The extraction of most nutrients by Kelowna and Mehlich-3 extracts were generally closely correlated with Mehlich-3 tending to extract more than Kelowna. Depth of sampling and soil characteristics had small but significant effects on the nature of the relationships. The relationships appeared to differ considerably more in soils from the Lower Fraser Valley versus the Okanagan-Similkameen area. This shows that the relationship between these two extractions is not universal. Although different relationships between Kelowna and Mehlich-3 extractions could possibly be developed for interpretations using soil survey or geographic information, measurements of elements that are naturally in the soil but are not nutrients may provide a chemical measurement that could distinguish these differences.

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Part C

Pedology, Soil Survey and Soil Physical Properties of the Okanagan-Similkameen Valleys

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12 Introduction

Pedology is the science of soil formation and classification. It is the root of soil survey because soils are classified according to characteristics that arise because of soil formation. In Canada, soils are classified according to pedon descriptions. Pedons are excavations, approximately 1 m^3 in size, that are thought to represent the smallest unit of soil that contains all the characteristics of the soil.

Pedology was an important part of this study for two reasons. First, pedon descriptions are used to determine soil series, which can be used to link the pedons to existing soil surveys, maps, databases and soil management manuals. Second, the pedon descriptions can be included in the National Pedon Database.

13 Methodology

13.1 Study area

The study area includes the Similkameen Valley and the Okanagan Valley as shown in Figure 1. This area is covered by three soil surveys: Soils of the Okanagan and Similkameen Valleys (Wittneben 1986), Soils of the North Okanagan Area (Wittneben 1986), and Soils of the North Okanagan Valley (Sprout et al. 1960).

There are over 160 soil series in the study area. These soils belong to seventeen soil management groups, a group of miscellaneous soils and a group of miscellaneous land types. A soil management group contains soils that have similar limitations to agriculture and management requirements for crop production, in addition to forming on similar parent materials (Gough et al. 1994).

13.2 Site selection

The study area was divided into 6 study zones. Each zone represents a unique combination of geographic area, soil parent material, and soil management group (Figure 1). Sites were evenly distributed amongst the study zones. Sites were also selected to sample all the major soil management groups, parent materials and soil series. Based on those criteria, 56 fields were selected from among those farmers volunteering to take part in the study. At each site, three soil pits were excavated with a mini-excavator.

13.3 Site and soil description

Soils were described at two levels of detail. Pedons were given comprehensive descriptions, using the standards in the Second Edition of Describing Ecosystems in the Field (Luttmerding et al. 1990). Verification pits were given a brief soil description. All pits were given a complete site description. Site description details include slope and terrain (parent material) data, among other characteristics.

For pedons, complete information on morphological characteristics was recorded on the form shown in Figure 2. Soil samples were collected by soil horizon. Forty-eight of the 168 pits were described as pedons.

For 120 of the 168 pits, verification pits were described with a simplified set of soil properties because there was not sufficient time or resources for complete descriptions. The simplified descriptions contained enough detail to allow for later correlation work.

13.4 Measurement of soil physical properties

At each pedon, samples for bulk density (D_b), saturated hydraulic conductivity (K_{sat}), and available water storage capacity (AWSC) were taken for each horizon. Bulk soil samples were also collected for routine soil characterization, including particle size distribution (texture), pH (0.1M $CaCl_2$), organic matter percent, salinity, calcium carbonate equivalents, and cation exchange capacity. The soil samples for chemical analysis were air-dried in a greenhouse at the Pacific Agri-Food Research Centre, Summerland and crushed or sieved (2 mm), then stored in preparation for laboratory analysis.

Bulk density was not determined at the verification pits. However, AWSC, K_{sat} and Field K_{sat} were measured at 7.5 cm, 22.5 cm and 45 cm depths.

13.4.1 Bulk density

Bulk density is the ratio of the mass of dry solids to the bulk volume of oven-dry soil. Bulk density is required for converting measurements from a weight basis to volume basis (Culley 1993).

Bulk density was determined by one of two methods – core sampling or excavation. Both of these methods determined whole-soil bulk density and were not corrected for coarse fragment content. Core sampling was the preferred method; however, soils with high coarse fragment contents could not be sampled with a core.

The core was 5 cm in diameter and 2 cm in height. It was driven into the soil with a slide hammer. The cores were cleaned and the soil from within was carefully collected for bulk density determination. An occasional coarse fragment in a core sample does not affect the measurement (Vincent and Chadwick 2008).

For the excavation method (Blake and Hartge 1986), soil and coarse fragments from a small excavation are carefully collected into a sample bag. The volume of the excavation is then measured. First, the excavation is lined with a thin plastic bag. Next, it is filled with glass beads. Finally, the volume of beads is recorded.

The soil is taken to a lab, where it is oven dried at 105°C for a minimum of 24 hours. That value is the mass of soil occupying the known volume. Equation 1 shows how bulk density is determined.

$$D_b = \text{oven-dry weight (g) /core volume (cm}^3\text{)} \qquad (1)$$

13.4.2 Saturated hydraulic conductivity (K_{sat})

Saturated hydraulic conductivity is an important soil parameter that measures the ability of a soil to transmit water. Core samples for K_{sat} were collected from soils with none or few coarse fragments. The cores had a diameter of 5.45 cm and length of 6.0 cm. These were considered disturbed cores and run in the laboratory using a constant head method as described by Klute and Dirksen (1986). In total, 413 soil cores were analyzed.

Measurement of field saturated hydraulic conductivity (Field K_{sat}) was determined using the Guelph Borehole Permeameter, following the two-head procedure as outlined by Reynolds (2008). Field K_{sat} was measured at three depths: 15, 30 and 45 cm. The diameter of the Guelph Permeameter borehole is 6 cm.

13.4.3 Available water storage capacity (AWSC)

AWSC is the portion of water that can be readily absorbed by plant roots and is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point. Both field capacity and permanent wilting point are dependent on soil characteristics, plant type and the weather-driven evaporative demand of the atmosphere (Hillel 2004) and thus can vary at a given site from day to day. However, to aid irrigation management, certain definitions of field capacity and permanent wilting point have been adopted. Field capacity is the water content of the soil where all free water has been drained from the soil through gravity, and has been approximated at -33 kPa. For coarser-textured soils, field capacity may be as high as -5 kPa (Topp et al. 1993). Permanent wilting point is the soil moisture content at which the plant will wilt and die because water is held tightly to soil particles, or because water movement to plant roots is limited at low water content (Hillel 2004). The lowest value for permanent wilting point is approximately -1500 kPa, but may be as high as -200 kPa (Topp et al. 1993).

AWSC was sampled using a 5x2 cm core and a slide hammer. Where there were coarse fragments, the core was filled with the sieved soil. Water retention is determined in the laboratory on the cores following the procedures of Klute (1986). Water retention was measured at -10, -33 and -1500 kPa. Field capacity for soil textures finer than loam was usually determined at -33 kPa. For all other textures, field capacity was usually determined at -10 kPa. In all, 544 cores were analyzed.

14 Results and discussion

14.1 Sampling

Table 72 lists the number of verification pits and pedons for each soil management group sampled.

14.2 Bulk density

Table 73 presents whole-soil bulk density values for selected horizons for some of the soil series sampled. Excavated bulk density values greater than 2.6 were excluded from the table.

Of the 189 bulk density measurements made, 161 used the core technique and 28 used the excavation method. The core method provides samples with consistent known volumes.

The excavation method is problematic because volume is measured in the field. (Brye et al. 2004; Vincent and Chadwick 1994). Following the guidelines of Byre et al. (2004), bulk density values greater than 2.65 were excluded from the data set as they exceed the assumed particle density of the coarse fragments. Bulk density values that exceeded the theoretical maximum are likely the result of an underestimation of the total volume of the excavation. Vincent and Chadwick (1994) indicate that sample volumes for soils with high coarse fragment content should be at least 5 litres or more. Brye et al. (2004) indicate that sampling volumes are dictated by horizon thickness and in their study, volumes ranged from 676 to 2375 cm^3 and averaged 1294 cm^3. Sauer and Logsdon (2002) used volumes of 884 cm^3 for their bulk density by excavation determinations. The volumes used in this study ranged from 75 to 2550 cm^3 and averaged 730 cm^3. Table 73 illustrates the variation that occurs in soil bulk density. Soil texture, organic matter content, soil structure, coarse fragment content, soil mineralogy as well as porosity (air space:pore space) influence bulk density. Bulk densities for mineral soils generally range from 1.0 g cm^{-3} to 2.0 g cm^{-3}, whereas bulk densities for organic soils typically are 0.5 g cm^{-3} or less. The Waby soil in Table 73 is an organic soil. Typically, soils that are loose or well structured, finer textured and those rich in organic matter have lower bulk densities. The Boucherie soil is such a soil. Sandy soils such as Osoyoos tend to have higher bulk densities. Bulk densities greater than 1.6 g cm^{-3} tend to limit root penetration (Cooperative Soil Survey 2007). As density increases, pore space decreases and the amount of air and water held in the soil also decreases (Brady 1974; Cooperative Soil Survey 2007).

As illustrated in Table 73, bulk density also tends to increase with soil depth. Subsoils tend to have less organic matter, less roots and less aggregation relative to the surface horizons. In addition, the weight of the overlying horizons may contribute to compaction in the subsoil (Brady 1974; Cooperative Soil Survey 2007).

14.3 Saturated hydraulic conductivity (K_{sat})

There were 413 cores analyzed for K_{sat} and 220 determinations for Field K_{sat}. Using hand texture data, the soils were classified into soil texture groups according to Luttmerding et al. (1990). Table 74 lists the number and texture grouping for each type of K_{sat} sample.

The K_{sat} results were assigned to K_{sat} classes according to McKeague et al. (1986). The data are presented in Table 75.

Figures 3 and 4 compare texture classes and K_{sat} classes for both methods. The texture class for organic soils is the state of decomposition of the organic matter.

Although 6% of the medium textured cores fell within highest K_{sat} class, the majority (58%) were in the three moderate classes. The fine textured core samples tended to have lower K_{sat} values than the coarse textured soils. The Guelph Permeameter values show a similar trend. The coarser textures soils tend to fall within the higher K_{sat} classes whereas the finer textured soils are in the lower classes.

There were 213 sample points that had K_{sat} determined by both methods. Thirty (14%) of the sample points had the same K_{sat} class, sixty-eight (32%) were one class off, and the remainder were two or more classes off. This result is not unexpected. The Guelph Permeameter measures field-saturated hydraulic conductivity. As water flows into the soil from the Guelph Permeameter, air bubbles are often entrapped in the soil, resulting in lower values than those obtained at true saturation. Depending on the amount of air entrapment field K_{sat} can be a factor of two or more below the truly saturated hydraulic conductivity (Reynolds 2008).

The Guelph Permeameter also measured a number of samples in the lower K_{sat} classes (See Figures 3 and 4). This is true for the medium and fine textured soils. There were no L Classes determined by the core method. If compaction or smearing occurs during the preparation of the borehole, then the measured Field K_{sat} value can be reduced by an order of magnitude or more. Siltation in the measurement zone can also reduce the Field K_{sat} measurement (Reynolds 2008).

The organic soil samples from cores and Guelph Permeameter had similar results. The fibric sample, which is the least decomposed and has greater pore space, had the highest K_{sat}. The mesic or medium decomposed materials fell within the moderate and H1 classes.

Figure 5 compares texture class and K_{sat} class for Guelph Permeameter data from the Southern Okanagan, provided by J. Liggett (personal communication 2008).

Comparing Figure 5 with Figure 4 shows similar trends. The data set from J. Liggett is primarily coarse textured. There were one fine and two medium and fifty-one coarse textured samples.

Hydraulic conductivity is influenced by both texture and soil structure. Guidelines for estimating vertical K_{sat} from soil properties for mineral soils were developed by McKeague et al. (1986). These guidelines were used to predict K_{sat} for the pedon samples where a core sample or Guelph

Permeameter reading was taken and predicted values were compared to both measured sets. The default values used in the National Soils Database for K_{sat} for organic soils were used to predict K_{sat} for the organic horizons sampled in this study.

The core method was used to predict K_{sat} for 154 soil horizons and 89 of these soil horizons also had Guelph Permeameter readings. The results are summarized in Figures 6 and 7.

The predicted K_{sat} value was a better match to the K_{sat} determined by core method than by the Guelph Permeameter method. The predicted and measured values match 100% for the organic horizons. The predicted value was the same as the measured value for 40% of the mineral horizons and within 1 class for 27%. Thirty-three percent of the predicted values were two or more classes off the measured values. There was no match between the Guelph Permeameter reading and predicted values. Only 29% of the measured values were the same as the predicted values and 44% of the Guelph Permeameter readings were two or more classes different from the prediction. The Guelph Permeameter reading tended to underestimate K_{sat} compared to the predicted values. Better correlations between the measured Guelph Permeameter reading and predicted K_{sat} values are reported in the literature (McKeague et al. 1982; Coen and Wang 1989).

14.4 Available water storage capacity (AWSC)

There were some difficulties with the analysis of AWSC for fine textured soils. This was likely a consequence of too short of an equilibration time for core samples at 1500 kPa in the pressure plate systems used. As a result, default values were substituted for soils where measured AWSC was considered to be out of range and the average AWSC percentages contain both measured and default values (Table 76). These were derived from Table 3.1 in the BC Trickle Irrigation Manual (Van der Gulik 1999). For samples classified as loam and coarser, field capacity was defined as water in the soil equilibrated to 10 kPa pressure.

For silt and silt loam soils, AWSC was determined using 10 kPa or 33 kPa soil moisture retention values, depending on how similar the values were to the default value. This was because soils were hand-textured, which is subject to some errors, particularly for medium textured soils (Table 74). Nevertheless, the average of measured AWSC for most soil textures was quite similar to the default average values (Table 76).

On average, coarse textured soils had AWSC of around 10.7%, medium textured soils had AWSC of around 17.5% and fine textured soils (including clay loam) had AWSC around 20.3%. However, there was a considerable range of values in each texture class. The majority of soil samples (61%), which are considered to be representative of the major cropped agricultural soils in the two basins, have a loam texture or coarser and a weighted average AWSC of 13.3%. Consequently, precise water management of these soils is required to prevent crop water stress and, because of their rapid drainage, nutrient leaching from fertilizer applications.

Available water storage capacity values for each soil management group are given in Table 77. The Greata, Kelowna, Osoyoos, Shuswap and Skaha soil management groups all have limited water-holding capacity. Soils with low AWSC are most prevalent in the Oliver-Osoyoos

(AWSC = 12.2%) and Kelowna (AWSC = 13.5%) regions. The Summerland and Cawston-Keremeos regions have AWSC of approximately16% and the North Okanagan region has higher AWSC values (17-19%).

AWSC is determined not only by soil texture (Table 76) but also soil structure, which is why AWSC of soils of similar textures may differ. To use AWSC values for water management, a number of calculations are required that take into account crop characteristics such as rooting depth and efficiency. Crop rooting efficiency determines the maximum allowable depletion of the soil water reservoir and varies from 35 to 50%. A new term, the effective water storage capacity (EWSC), accounts for these factors. For example a high density apple planting on a loam soil (AWSC = 15%) might have a rooting depth of 40 cm with a maximum allowable depletion (MAD) of 40%. For irrigation calculations in mm per metre soil depth, multiply the AWSC values in this report by a factor of 10.

$$\text{EWSC} = \text{AWSC x rooting depth x MAD} \qquad (2)$$

$$\text{EWSC} = 150 \text{ mm m}^{-1} \text{ x } 0.4 \text{ m x } 0.4 = 24 \text{ mm} \qquad (3)$$

For a more detailed discussion of these calculations, see Van der Gulik (1989; 1999).

Irrigation scheduling and irrigation system design uses AWSC, as discussed for sprinkler systems in Van der Gulik (1989) and micro-irrigation systems in Van der Gulik (1999). Irrigation scheduling allows one to determine how much water to apply at one time and how long to wait between irrigations (Nyvall 2002). Under-application of irrigation results in plant stress and potential reductions in crop yield and quality, although for some crops like wine grapes, water deficits may increase desirable crop components. Over-application can be detrimental to crop growth if the root zone becomes waterlogged and can also result in excessive drainage and nutrient leaching to groundwater or runoff to surface water. To achieve precise water management, it is also necessary to estimate how much water the crop has used (evapotranspiration), based either on soil moisture measurements or climate information. Potential evapotranspiration data are available at http://www.farmwest.com and these can be modified by crop coefficients to determine actual water use. Practical information on scheduling irrigation for different irrigation systems, crops and soil types is available in Water Fact Sheets available in Van der Gulik (1989; 1999) and through the following link: (http://www.farmwest.com/index.cfm?method=pages.ShowPage&pageid=235).

15 Conclusions

Each sample pit was correlated to its correct soil series and these soils correlate well with existing knowledge of Okanagan soils. Therefore, existing management guides, such as the Soil Management Handbook for the Okanagan and Similkameen Valleys (Gough et al. 1994) are still relevant.

Soil physical properties (texture, bulk density, AWSC, and K_{sat}) evaluated from pedon samplings are the most valuable properties that explain water and nutrient (N, P, and K) retention in these soils.

Further evaluating K_{sat} measurements of the Guelph Permeameter, core, and texture/structure predictive methods would help determine which method generates the most reliable results.

Pedon data obtained are incorporated into the Canadian National Pedon Database to update the Okanagan agricultural soils with measured data.

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Tables and Figures

Table 1. Times of sampling of various phases of the 2007 Okanagan Agricultural Soil Study.

Region	Phase A (pit sampling)	Phase B (probe sampling)	Benchmark (sequential)
Armstrong	Aug. 13 – Sept. 6	Sept. 19 – Oct. 15	Sept 18. – Nov. 13 & May 1/08
Vernon	July 16 – Sept. 5	Sept. 17 – Oct. 26	Sept 18. – Nov. 13 & May 1/08
Kelowna	July 19 – Aug. 30	Oct. 17 – Nov. 19	n/a
Summerland	June 5 – July 13	Oct. 24 – Nov. 26	Sept 18. – Nov. 29 & May 1/08
Oliver	June 26 – July 5	Nov. 8 – Nov. 20	n/a
Similkameen	June 12 – June 26	Oct. 31 – Nov. 14	Sept 18. – Nov. 29 & May 1/08

Table 2. Geological, taxonomic, soil management grouping and cropping of sites in geographic regions for the Okanagan Agricultural Soil Study sampled by digging pits.

Field type	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similk-ameen	All
				number of pits			
Geology							
- fluvial	12	11	3	7	9	27	69
- fluv.glac.	0	10	19	8	9	0	46
- glac.lac.	12	11	5	18	0	0	46
- misc.	3	1	0	0	3	0	7
Taxonomy							
- br.chern.	0	9	6	19	0	11	45
- dk.br.chern.	0	12	4	10	6	9	41
- blk. chern.	0	10	0	1	3	1	15
- dk.gr.chern.	0	1	0	0	0	0	1
- brunisol	12	1	14	3	9	0	39
- luvisol	7	0	0	0	0	0	7
- gleysol	4	0	3	0	3	4	14
- regosol	1	0	0	0	0	2	3
- organic	3	0	0	0	0	0	3
Soil man. groups							
- Chopaka	9	1	0	0	3	4	17
- Gammil	0	7	9	4	3	0	23
- Glenmore	7	11	5	0	0	0	23
- Munson	3	0	0	18	0	0	21
- Osoyoos	2	2	7	0	9	0	20
- Similka-meen	0	10	0	0	0	4	14
- Stemwinder	2	0	0	7	6	14	29
- Misc.	4	2	6	4	0	5	21
Crop							
- apple	0	6	12	24	0	12	54
- cherry	0	0	6	3	0	3	12
- grape	0	0	0	0	12	3	15
- grass-nat.-barley[y]	9	6	0	3	0	3	21
- grass/alfalfa	15	3	0	0	0	3	21
- fallow	0	9	3	0	6	0	18
- misc.	3	3	0	0	0	3	9
- mixed[z]	0	6	6	3	3	0	18

[y] Includes fields of both domestic and natural grasses, and barley.
[z] Includes fields where there were different crops in at least one of the pits sampled.

Table 3. Variance of **air dry water content** of soils sampled in pits in representative fields of the Okanagan-Similkameen Valleys.

Source	Analysis of variance source factor *x* =					
	Field	Geography	Geology	Taxonomy	Soil man. group	Crop
	P value					
Pit	0.146	0.844	0.706	0.457	0.994	0.846
Depth	0.272	0.868	**0.000**	**0.000**	0.920	0.929
x (see column)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Depth x *x*	**0.000**	0.540	**0.000**	**0.000**	0.866	0.901
	%					
Coeff. of var.	52	176	74	24	173	177

Table 4. Air dry water contents of soils sampled in pits in representative fields of the Okanagan-Similkameen Valleys.

Geography	Mean	Geology	Mean	Taxonomy	Mean	Crop	Mean
	%		%		%		%
Armstrong	5.49 a[x]	Fluvial	1.64 c	Br.chern.	1.45 d	Apple	1.33 c
Vernon	1.90 b	Fluvioglac.	0.97 c	Dk.br.chern	1.26 d	Cherry	1.62 bc
Kelowna	1.47 b	Glacio-lacustrine	2.38 b	Blk. chern.	1.46 cd	Grape	0.68 c
Summerland	1.27 b	Misc.	12.27 a	Dk.gr.chern	1.50 cd	Grass-nat.-bar.[y]	5.88 a
Oliver	0.78 b			Brunisol	1.52 cd	Grass/alfalfa	2.77 b
Similkameen	1.51 b			Luvisol	4.94 b	Fallow	1.37 c
				Gleysol	1.95 c	Misc.	1.94 bc
				Regosol	2.27 c	Mixed[z]	1.36 c
				Organic	24.42 a		

[x] Values within columns followed by the same letter are not significantly different (P = 0.05) according to Least Significant Difference test.
[y] Includes fields of both domestic and natural grasses, and barley.
[z] Includes fields where there were different crops in at least one of the pits sampled.

Table 5. Depth of Ap or Ah horizon and of rooting observed in 168 pits sampled for the Okanagan Agricultural Soil Study.

Management group	Series (# of pits examined)	Ap/Ah depth (cm)			Rooting depth (cm)		
		Mean	Min	Max	Mean	Min	Max
Chopaka	Chopaka (7), Ida (2), Mara (1), Nisconlith (7)	19	11	32	101 (2)[z]	55	160
Gammil	Gammil (3), Nahun (7), Rutland (13)	20	9	40	88 (0)	59	124
Glenmore	Boucherie (2), Broadview (7), Glenmore (5), Spallumcheen (9)	21	7	42	97 (2)	32	125
Greata	Greata (1)	14	14	14	100 (0)	100	100
Guisachan	Guisachan (3)	26	22	31	82 (0)	76	89
Kelowna	Kelowna (1)	36	36	36	100 (0)	100	100
Keremeos	Cawston (2), Keremeos (5)	22	20	24	85 (5)	60	110
Munson	Enderby (3), Munson (1), Olhausen (3), Penticton (14)	20	9	33	104 (0)	50	130
Osoyoos	Grandview (2), Haynes (3), Osoyoos (6), Parkill (6), Shuswap (2), Trepanier (1)	21	7	43	91 (2)	48	135
Rumohr	Waby (3)	30	18	49	94 (0)	73	130
Similkameen	Kalamalka (10), Similkameen (5)	26	15	40	104 (0)	76	130
Skaha	Acland Creek (3), Agar Lake (1), Dartmouth (1), Paradise (2)	17	10	26	90 (1)	70	120
Stemwinder	Lumby (2), Ratnip (6), Stemwinder (17), Tomlin (3)	22	6	38	111 (0)	70	128
Susap	Monashee (1)	24	24	24	100 (0)	100	100
All 14	All 38	21	6	49	98 (12)	32	160

[z] Number of observations within each management group where a root restricting layer was identified by visual inspection. Depth to these layers given in Table 6.

Table 6. Depth to an apparent root restricting layer observed in pits sampled for the Okanagan Agricultural Soil Study.

Management group	Series	Depth (cm)
Chopaka	Chopaka	90
	Nisconlith	100
Glenmore	Glenmore	80
	Glenmore	104
Keremeos	Cawston	103
	Cawston	93
	Keremeos	90
	Keremeos	68
	Keremeos	120
Osoyoos	Haynes	98
	Haynes	74
Skaha	Acland Creek	98

Table 7. Distribution of crops, field management types and soil management groups of fields in geographic regions for the Okanagan Agricultural Soil Study by traditional post-harvest probe sampling.

Field type	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
				number of fields			
Crop group							
- apple	-	11	4	6	-	3	24
- cherry	-	2	5	3	1	2	13
- other tree fruit	-	1	7	-	3	3	14
- grape	-	2	10	-	9	1	22
- alfalfa	19	7	-	-	-	4	30
- alfalfa/other mix	7	4	1	3	-	9	24
- grass	11	6	1	-	1	5	24
- corn	7	1	-	-	-	-	8
- cereal	9	1	-	-	-	-	10
- vegetables	3	2	-	1	3	2	11
Subtotal	56	37	28	13	17	29	180
Management type							
- conventional	45	33	20	11	13	19	141
- organic	3	1	5	-	1	6	16
- transitional	6	-	2	1	2	-	11
- unknown/ misc.	2	3	1	1	1	4	12
Soil man. group							
- Glenmore	16	6	4	-	-	-	26
- Osoyoos	2	8	4	-	9	1	24
- Stemwinder	-	2	2	1	4	12	21
- Chopaka	13	1	-	4	-	-	18
- Gammil	3	5	5	1	2	-	16
- Munson	7	-	2	3	1	-	13
- Kelowna	2	7	2	1	-	-	12
- Keremeos	-	-	-	-	-	11	11
- Rumohr	7	-	-	-	-	-	7
- Skaha	-	-	5	2	-	-	7
- misc.	1	6	-	-	-	1	8
- other	2	2	3	-	1	4	12
- unknown	3	-	1	1	-	-	5

Table 8. Air dry water content of soils in the four Benchmark fields sampled in 2007 for the Okanagan Agricultural Soil Study.

Depth	Field 1 (Armstrong)	Field 2 (Vernon)	Field 3 (Summerland)	Field 4 (Similkameen)
(cm)	% water content			
0 – 15	3.2 a[z]	2.8 b	2.4 c	1.7 e
15 – 30	3.0 b	2.8 b	2.2 d	1.4 f
30 – 60	2.8 b	2.5 c	2.1 d	1.1 g
Mean	3.0 A	2.7 B	2.2 C	1.4 D

[z] Field x depth interaction values followed by the same lower case letter and field main effect values followed by the same upper case letter not significantly (P = 0.05) different according to Least Significant Different test.

Table 9. Proposed categories for soil nitrogen measurements for agronomic or environmental interpretations.

N contribution	Residual NO_3 or NH_4	Potentially mineralizable
	kg N ha^{-1} to 60 cm	% total N
L (low)	0 – 49	0.00 – 0.30
M (medium)	50 – 99	0.31 – 0.60
H (high)	100 – 199	0.61 – 1.21
VH (very high)	>199	>1.21

Table 10. Total amount and distribution of nitrate in fields sampled sequentially in autumn of 2007 and the next spring in four regions of the Okanagan-Similkameen Valley areas.

Region	Sampling date	0 – 15 cm	15 – 30 cm	30 – 60 cm	0 – 60 cm
		kg N ha^{-1} (soil temperature (°C) in brackets)			
Armstrong	18 Sept.	17 b[t]	4 b	10 a	31 b
(corn)	3 Oct.[u]	26 b	7 b	9 a	42 b
	23 Oct.	20 b (10)	7 b	13 a	40 b
	13 Nov.[v]	34 b (6.6)	5 b	8 a	47 b
	1 May	97 a (14.1)	16 a	10 a	123 a
	L.S.D.	17	6	9	26
Vernon	18 Sept.	46 b	46 a	91 a	183 a
(corn)	3 Oct.[w]	68 a	60 a	88 a	216 a
	23 Oct.[x]	38 bc (9)	27 b	33 b	99 b
	13 Nov.[y]	35 bc (6.6)	27 b	29 b	91 b
	1 May[z]	26 c (10.8)	23 b	29 b	78 b
	L.S.D.	18	15	27	37
Summerland	18 Sept.	21 b	18 a	131 ab	170 a
(apples)	3 Oct.	21 b	17 ab	102 ab	141 ab
	23 Oct.	20 b (9.5)	17 a	85 bc	123 bc
	13 Nov.	13 b (6.3)	12 b	64 c	89 c
	29 Nov.	21 b (1.4)	15 ab	90 bc	126 bc
	1 May	31 a (11.5)	20 a	61 c	111 bc
	L.S.D.	9	5	36	42
Similkameen	18 Sept.	1 c	0 b	0 a	1 c
(apples)	3 Oct.	1 bc	0 a	0 a	2 bc
	23 Oct.	1 bc (11.0)	0 a	0 a	2 bc
	13 Nov.	3 a (7.2)	1 a	0 a	3 a
	29 Nov.	2 ab (0.9)	0 a	0 a	3 ab
	1 May	1 bc (15.5)	0 a	0 a	2 bc
	L.S.D.	<1	0.4	0.01	1

[t] Values within each depth for each site followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[u] Corn harvested 3-5 October.
[v] Liquid dairy manure applied 2 November.
[w] Corn harvested 1-6 October.
[x] Sampling site moved approximately 10 m within the field to avoid effect of harvest traffic.
[y] Cover crop had been recently seeded, but plants not yet visible.
[z] Cover crop approximately 10 – 15 cm tall at time of sampling.

Table 11. Total amount and distribution of ammonium in fields sampled sequentially in the autumn of 2007 and the next spring in four regions of the Okanagan-Similkameen Valley areas.

Region	Sampling date	0 – 15 cm	15 – 30 cm	30 – 60 cm	0 – 60 cm
		kg N ha^{-1} (soil temperature (°C) in brackets)			
Armstrong	18 Sept.	17 a[t]	7 a	13 a	37 a
	3 Oct.[u]	12 b	6 b	12 ab	30 b
	23 Oct.	12 b (10)	6 b	10 b	28 b
	13 Nov.[v]	15 a (6.6)	5 b	10 b	39 b
	1 May	17 a (14.1)	6 b	10 b	32 b
	L.S.D.	2	1	2	5
Vernon	18 Sept.	11 a	7 a	15 a	33 a
	3 Oct.[w]	7 b	5 b	11 b	22 b
	23 Oct.[x]	6 bc (9)	5 b	9 c	19 c
	13 Nov.[y]	5 c (6.6)	5 ab	10 bc	21 bc
	1 May[z]	7 b (10.8)	6 ab	11 bc	23 b
	L.S.D.	1	2	2	3
Summerland	18 Sept.	11 a	11 a	18 a	40 a
	3 Oct.	10 abc	7 b	12 b	29 b
	23 Oct.	10 ab (9.5)	6 bc	11 bc	28 b
	13 Nov.	9 abc (6.3)	7 bc	11 bc	27 b
	29 Nov.	6 c (1.4)	5 c	9 d	20 c
	1 May	7 bc (11.5)	5 bc	10 cd	23 bc
	L.S.D.	3	2	2	6
Similkameen	18 Sept.	8 a	6 a	14 a	28 a
	3 Oct.	6 b	4 bc	8 b	17 b
	23 Oct.	6 b (11.0)	4 c	7 bcd	16 bc
	13 Nov.	5 b (7.2)	5 bc	8 bc	18 b
	29 Nov.	4 bc (0.9)	3 c	7 cd	14 cd
	1 May	3 c (5.5)	2 d	6 d	12 d
	L.S.D.	1	1	1	3

[t] Values within each depth for each site followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[u] Corn harvested 3-5 October.
[v] Liquid dairy manure applied 2 November.
[w] Corn harvested 1-6 October.
[x] Sampling site moved approximately 10 m within the field to avoid effect of harvest traffic.
[y] Cover crop had been recently seeded, but plants not yet visible.
[z] Cover crop approximately 10 – 15 cm tall at time of sampling.

Table 12. Weather conditions in the areas near the four fields where the soil was sampled sequentially in the autumn of 2007 and in the next spring.

Time interval	Mean air temperature (^{o}C)				Accumulated precipitation[z] (mm)		
	Arm-strong	Vernon	Summer-land	Similka-meen	Arm-strong	Vernon	Summer-land
August	14.7	19.0	19.9	21.6	16.3	0.4	4.8
September	13.0	16.6	17.6	20.1	3.8	2.4	8.4
19 Sept. – 4 Oct.	10.0	10.2	11.2	12.1	57.9	36.0	26.2
5 Oct. – 23 Oct.	9.0	8.6	9.0	9.1	8.6	27.6	26.8
24 Oct. – 5 Nov.	5.8	4.5	5.5	5.0	4.8	2.8	2.2
6 Nov. – 13 Nov.	7.6	5.5	5.9	5.6	7.2	12.4	7.6
March	6.1	4.6	4.4	5.1	32.6	12.6	5.2
April	8.5	7.3	7.7	9.1	18.7	3.0	4.4

[z] No precipitation data available at the Similkameen site. Precipitation that fell was converted to equivalent in rainfall.

Table 13. Soil water content of fields sampled sequentially in the autumn of 2007 and the next spring in four regions of the Okanagan-Similkameen Valley areas.

Region	**Sampling date**	**0 – 15 cm**	**15 – 30 cm**	**30 – 60 cm**	**Mean**
		% gravimetric water content			
Armstrong	18 Sept.	34.4[u]	23.0	24.7	27.4 B[v]
	3 Oct.	40.8	24.1	25.1	30.0 AB
	23 Oct.	39.8	27.8	35.0	34.2 A
	13 Nov.[w]	41.4	24.1	26.5	30.7 AB
	1 May	47.2	24.4	25.7	32.5 A
	Mean	40.7 A	24.7 B	27.4 B	
Vernon	18 Sept.	18.2	21.3	17.7	19.0 C
	3 Oct.	27.5	21.0	16.7	21.7 B
	23 Oct.[x]	29.2	24.2	21.6	25.0 A
	13 Nov.[y]	26.8	25.7	22.5	25.0 A
	1 May[z]	19.9	21.8	21.1	20.9 B
	Mean	24.3 A	22.8 A	19.9 B	
Summerland	18 Sept.	23.5	20.2	30.4	24.7 B
	3 Oct.	21.7	17.8	29.8	23.1 CD
	23 Oct.	26.1	20.1	33.3	26.5 A
	13 Nov.	22.8	19.3	30.0	24.0 BC
	29 Nov.	22.7	18.0	31.2	23.9 BC
	1 May	18.7	18.1	29.3	22.0 D
	Mean	22.6 B	18.9 C	30.7 A	
Similkameen	18 Sept.	10.3	9.7	7.8	9.3 C
	3 Oct.	12.7	10.4	8.3	10.5 C
	23 Oct.	19.5	15.7	13.5	16.2 A
	13 Nov.	16.5	14.7	12.4	14.5 B
	29 Nov.	18.3	14.5	11.3	14.7 B
	1 May	17.8	13.4	13.3	14.9 B
	Mean	15.9 A	13.1 B	11.1 C	

[u] Analysis of variance showed that depth and time main effects were significant at $P < 0.05$ for all four sites but depth x time interaction effect was significant for Vernon site only.
[v] Date or Depth main effect means for each site followed by the same upper case letter are not significantly ($P < 0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[w] Liquid dairy manure applied 2 November.
[x] Sampling site moved approximately 10 m within the field to avoid effect of harvest traffic.
[y] Cover crop had been recently seeded, but plants not yet visible.
[z] Cover crop approximately 10 – 15 cm tall at time of sampling.

Table 14. Environmental risk rating categories for soil **phosphorus** analyses used to assess soils sampled in 2005 in the Lower Fraser Valley.

Rating	Water extractable phosphate	Kelowna extractable P	Unbound when treated with 50 mg P kg^{-1}	P saturation as P/Al by Mehlich-3
	mg P kg^{-1}	mg P kg^{-1}	%	index
Low (L)	0 - 1	0 – 20	0 - 5	0 – 4.9
Medium (M)	1.1 – 2.5	21 – 50	5.1 – 10	5.0 – 9.8
High (H)	2.6 – 6.0	51 – 100	11 – 20	9.9 – 19.6
Very high (VH)	> 6.0	> 100	> 20	> 19.6

Table 15. Environmental risk ratings and measurement values of phosphorus in surface (0 – 15 cm depth) soil sampled in pits that represented commercial fields of the Okanagan-Similkameen Valleys.

Rating/value	Water extractable phosphate	Kelowna extractable P	Unbound when treated with 50 mg P kg^{-1}	P saturation as P/Al by Mehlich-3
% of fields sampled				
Low (L)	2	14	0	5
Medium (M)	9	32	0	20
High (H)	23	27	0	39
Very High (VH)	66	27	100	36
	mg P kg^{-1}	mg P kg^{-1}	%	index
Mean	14	83	59	26
Median	8	52	61	15
Maximum	112	561	91	395
Minimum	1	6	-3	1
%				
Coeff. of variation	119	111	28	147

Table 16. Factors that influenced the regression of the amount of phosphate-P extracted by water with amount of **phosphorus** extracted by Kelowna solution for Okanagan and Lower Fraser Valley studies.

Study location	Factor	Slope	Intercept
Okanagan-Similkameen		P value for regression	
	Depth	**0.000**	**0.020**
	Geography	**0.001**	**0.000**
	Geology	**0.000**	**0.000**
	Taxonomy	**0.000**	**0.000**
	Soil man. groups	**0.000**	**0.000**
	Crop	**0.000**	**0.000**
		Values for regression equation	
	Depth[y]		
	- 0 – 15 cm	0.147	1.47
	- 15 – 30 cm	0.181	0.13
	- 30 – 60 cm	0.434	-4.07
	Taxonomy		
	- br.chern.	0.134	1.09
	- dk.br.chern.	0.143	0.50
	- blk. chern.	0.131	0.16
	- dk.gr.chern.[z]	0.243	3.90
	- brunisol	0.183	-0.95
	- luvisol	0.256	-3.67
	- gleysol	0.138	0.35
	- regosol	0.066	1.07
	- organic	0.434	27.31
Lower Fraser Valley		P value for regression	
	Depth	0.402	0.318
		Values for regression equation	
	Depth		
	- 0 – 15 cm	0.067	-0.36
	- 15 – 30 cm	0.062	-0.19
	- 30 – 60 cm	0.056	0.19

[y] r^2 values = 0.690, 0.521 and 0.860 for 0 – 15, 15 – 30 and 30 – 60 cm depths, respectively.
[z] Note: there was only one pit with a soil of this type.

Table 17. Environmental risk categories for Kelowna extractable phosphorus when based on British Columbia agronomic criteria versus the percentage of Kelowna P that is extracted by water.

Rating	Water extractable phosphate	Kelowna P based on agronomic crop groups 2 - 5	Kelowna P based on agronomic crop group 1	Kelowna P if 6% is water extractable	Kelowna P if 15% is water extractable
	mg P kg^{-1}				
Low (L)	0 - 1	0 – 20	0 – 15	0 – 16.5	0 – 6.5
Medium (M)	1.1 – 2.5	21 – 50	16 – 25	16.6 – 41.5	6.6 – 16.5
High (H)	2.6 – 6.0	51 – 100	26 – 100	41.6 – 100	16.6 – 40
Very high (VH)	> 6.0	> 100	> 100	> 100	> 40

Table 18. Comparison percentages of fields in different phosphorus risk ratings for soil (0 – 15 cm depth) sampled in pits that represented commercial fields of the Okanagan-Similkameen Valleys when measured by Kelowna extraction.

Rating	Water extractable phosphate	Kelowna P based on agronomic crop groups 2 - 5	Kelowna P based on agronomic crop group 1	Kelowna P if 6% is water extractable	Kelowna P if 15% is water extractable
	% of all fields sampled				
Low (L)	2	14	7	9	0
Medium (M)	9	32	12	27	9
High (H)	23	27	54	37	27
Very high (VH)	66	27	27	27	64

Table 19. Influence of field and other factors on four proposed phosphorus environmental analyses on soils of fields sampled at three depths by pit method in the Okanagan-Similkameen Valleys.

	Water extractable phosphate P	**Kelowna extractable P**	**Unbound P when treated with 50 mg P kg^{-1}**	**P saturation index using Al/P ratio in Mehlich-3 extraction**
Anal. of var. source	P value			
- pit (replicate)	0.448	0.546	0.104	**0.015**
- field	**0.000**	**0.000**	**0.000**	**0.000**
- depth	**0.000**	**0.000**	**0.000**	**0.010**
- field x depth	**0.000**	**0.000**	0.344	**0.000**
Content	mg P kg^{-1}		%	ratio
- 0 – 15 cm	14 a[z]	83 a	59 a	26 a
- 15 – 30 cm	8 b	42 b	53 b	20 ab
- 30 – 60 cm	5 c	22 c	53 b	15 b
Factor	P value for factor x depth interaction			
- geography	0.872	**0.000**	0.959	0.720
- geology	**0.000**	**0.024**	**0.009**	**0.000**
- taxonomy	**0.000**	**0.003**	0.927	**0.000**
- soil man. groups	0.523	0.217	**0.047**	0.255
- crop	0.717	**0.020**	0.966	0.650

[z] Values within each column followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference Test.

Table 20. Influence of taxonomy, geology and crop on the distribution of water and Kelowna extractable phosphorus in three depths sampled in pits of representative Okanagan fields.

Factor	Water extractable phosphate P			Kelowna extractable P		
	0 – 15 cm	15 – 30 cm	30 – 60 cm	0 – 15 cm	15 – 30 cm	30 – 60 cm
	mg P kg^{-1}					
Taxonomy						
- br.chern.	10	5	3	65	32	16
- dk.br.chern.	11	5	3	65	31	18
- blk. chern.	14	6	3	98	51	20
- dk.gr.chern.[z]	61	52	25	243	179	92
- brunisol	16	10	5	102	60	23
- luvisol	25	11	4	127	50	23
- gleysol	15	4	2	109	30	5
- regosol	10	8	3	136	104	30
- organic	47	72	126	51	88	236
Geology						
- fluvial	15	7	3	101	48	19
- fluv.glac.	10	5	3	72	35	17
- glac.lac.	12	6	3	70	35	16
- misc.	30	38	58	73	72	123
Crop						
- apple	8	3	2	51	22	11
- cherry	9	4	2	58	27	15
- grape	12	6	4	56	29	19
- grass-nat.-barley	23	19	22	118	66	55
- grass/alfalfa	24	13	4	164	78	24
- fallow	14	8	4	115	58	25
- misc.	18	14	6	90	66	31
- mixed	3	4	3	50	25	14

[z] Note: there was only one pit with a soil of this type.

Table 21. Influence of geology on the proportion of a 50 mg kg^{-1} phosphorus treatment that is not bound in soils sampled at three depths in pits of representative Okanagan fields.

Geology	0 – 15 cm	15 – 30 cm	30 – 60 cm
		%	
Fluvial	57	51	50
Fluvioglacial	65	62	69
Glaciolacustrine	52	45	36
Misc.	79	77	76

Table 22. Influence of geology and taxonomy on an index of phosphorus saturation estimated by P/Al ratio in Mehlich-3 extraction in soils sampled at three depth in pits of representative Okanagan fields.

Factor	0 – 15 cm	15 – 30 cm	30 – 60 cm
Geology		P/Al ratio	
- fluvial	38	19	10
- fluvioglacial	17	14	16
- glaciolacustrine	15	9	9
- misc.	42	140	105
Taxonomy		P/Al ratio	
- br.chern.	20	13	9
- dk.br.chern.	17	10	9
- blk. chern.	28	14	15
- dk.gr.chern.	65	43	26
- brunisol	27	24	23
- luvisol	19	8	4
- gleysol	60	17	3
- regosol	27	23	9
- organic	74	310	230

Table 23. Factors that influenced the regression of the phosphorus extracted with Kelowna Mehlich-3 solutions from Okanagan and Lower Fraser Valley study soil samples.

Study location	Factor	Slope	Intercept
Okanagan-Similkameen		P value for regression	
	Depth	**0.022**	0.525
	Geography	**0.000**	**0.001**
	Geology	**0.000**	**0.004**
	Taxonomy	**0.000**	**0.000**
	Soil man. groups	**0.000**	**0.009**
	Crop	**0.000**	**0.006**
		Values for regression equation	
	Depth		
	- 0 – 15 cm	1.27	5.54
	- 15 – 30 cm	1.24	8.06
	- 30 – 60 cm	1.18	7.34
	- all three[y]	1.25	6.67
	Taxonomy		
	- br.chern.	1.17	7.19
	- dk.br.chern.	1.19	9.21
	- blk. chern.	1.19	12.5
	- dk.gr.chern.	1.11	31.88
	- brunisol	1.42	3.50
	- luvisol	1.34	-2.09
	- gleysol	1.24	4.01
	- regosol	1.38	1.59
	- organic	1.15	0.34
Lower Fraser Valley		P value for regression	
	Depth	**0.036**	0.571
		Values for regression equation	
	Depth		
	- 0 – 15 cm	1.40	-0.34
	- 15 – 30 cm	1.47	-4.18
	- 30 – 60 cm	1.37	-0.82
	- all three[z]	1.42	-1.31

[y] r^2 = 0.970, n = 504 for all three depths combined
[z] r^2 = 0.973, n = 486 for all three depths combined

Table 24. Factors that influenced the regression of P/Al saturation indices using either Kelowna or Mehlich-3 extraction in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	**0.000**	**0.000**
Geography	**0.000**	0.074
Geology	**0.000**	**0.002**
Taxonomy	**0.000**	0.056
Soil man. groups	**0.000**	0.469
Crop	**0.000**	**0.014**
	Values for regression equation	
Depth		
- 0 – 15 cm	0.872	7.69
- 15 – 30 cm	0.778	0.13
- 30 – 60 cm	0.565	0.79
- all three[z]	0.750	3.19
Taxonomy		
- br.chern.	1.239	-4.21
- dk.br.chern.	1.282	-2.82
- blk. chern.	0.773	3.23
- dk.gr.chern.	2.518	-35.49
- brunisol	0.533	6.11
- luvisol	0.788	-0.03
- gleysol	0.762	5.95
- regosol	1.505	-1.62
- organic	0.727	9.04

[z] r^2 = 0.791, n = 504 for all three depths combined.

Table 25. Factors that influenced the regression of aluminum extracted by Kelowna versus Mehlich-3 extraction in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	0.498	**0.000**
Geography	**0.008**	**0.000**
Geology	0.335	**0.000**
Taxonomy	**0.009**	**0.000**
Soil man. groups	**0.001**	**0.000**
Crop	**0.018**	**0.020**
	Values for regression equation	
Depth		
- 0 – 15 cm	0.966	-112.62
- 15 – 30 cm	0.920	-5.05
- 30 – 60 cm	0.929	25.39
- all three[z]	0.916	-19.14
Taxonomy		
- br.chern.	0.864	22.62
- dk.br.chern.	0.903	-34.54
- blk. chern.	0.848	-21.58
- dk.gr.chern.	1.938	-804.76
- brunisol	1.043	-57.26
- luvisol	0.667	314.82
- gleysol	0.993	-79.18
- regosol	0.447	50.80
- organic	0.810	18.58

[z] r^2 = 0.842, n = 504 for all three depths combined.

Table 26. Factors that influenced the regression of unbound phosphorus with Kelowna extracted Mg in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	**0.000**	**0.001**
Geography	**0.000**	**0.001**
Geology	**0.000**	**0.000**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.000**
Crop	**0.000**	**0.003**
	Values for regression equation	
Depth		
- 0 – 15 cm	-0.018	64.14
- 15 – 30 cm	-0.038	63.74
- 30 – 60 cm	-0.046	67.10
- all three[z]	-0.034	64.97
Taxonomy		
- br.chern.	-0.052	71.02
- dk.br.chern.	-0.015	63.69
- blk. chern.	-0.058	69.11
- dk.gr.chern.	0.058	64.24
- brunisol	-0.057	70.88
- luvisol	-0.046	62.25
- gleysol	-0.033	52.71
- regosol	-0.164	80.91
- organic	-0.012	89.38

[z] r^2 = 0.277, n = 504 with all three depths combined.

Table 27. Agronomic ratings for potassium for production of two crop groups in the Okanagan in comparison to agronomic/environmental criteria used for 2005 Lower Fraser Valley nutrient assessment study.

Rating	Okanagan		Criteria used for Lower Fraser Valley study
	Crop group 1	Crop group 4	
	mg K kg^{-1}		
Low (L)	0 – 50	0 – 100	0 – 80
Medium (M)	51 – 125	101 – 150	81 – 175
High (H)	126 – 190	151 – 250	176 – 250
Very high (VH)	> 190	> 250	> 250

Table 28. Influence of depth on soil potassium measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	Water extractable	Unbound K when treated with 50 mg K kg^{-1}	Kelowna extractable	Mehlich-3 extractable	K/Mg in Kelowna extraction
Anal. of variance	P value				
- pit (replicate)	**0.001**	0.477	**0.000**	**0.000**	**0.049**
- field	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
- depth	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
- field x depth	0.191	**0.002**	**0.002**	**0.011**	**0.000**
Content	mg K kg^{-1}	%	mg K kg^{-1}	mg K kg^{-1}	ratio
0 – 15 cm					
- mean	88 a^{z}	51 a	301 a	387 a	1.26 a
- median	65	51	251	301	1.09
- minimum	7	-22	37	56	0.11
- maximum	790	150	1426	1680	4.18
- coeff. of variation	104%	53%	78%	78%	61%
15 – 30 cm	47 b	42 b	182 b	243 b	0.90 b
30 – 60 cm	36 c	41 b	118 c	160 c	0.58 c

^{z} Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 29. Comparison of percentages of fields in different agronomic-environmental ratings for soil potassium (0 – 15 cm) sampled in pits that represented commercial fields of the Okanagan-Similkameen Valleys when measured by Kelowna extraction.

Rating	**Okanagan**		**Criteria used for Lower Fraser Valley study**
	Crop group 1	**Crop group 4**	
	% of all fields sampled		
Low (L)	0	9	5
Medium (M)	14	11	25
High (H)	20	30	20
Very high (VH)	60	50	50

Table 30. Factors that influenced the regression of water with Kelowna extracted potassium in pit sampled soils of Okanagan-Similkameen.

Factor	**Slope**	**Intercept**
	P value for regression	
Depth	0.447	**0.000**
Geography	**0.000**	**0.000**
Geology	**0.000**	**0.002**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.000**
Crop	**0.000**	**0.000**
	Values for regression equation	
Depth		
- 0 – 15 cm	0.346	-16.27
- 15 – 30 cm	0.326	-11.53
- 30 – 60 cm	0.361	-6.63
- all three[z]	0.334	-9.68
Taxonomy		
- br.chern.	0.283	-6.91
- dk.br.chern.	0.325	-11.44
- blk. chern.	0.293	-4.53
- dk.gr.chern.	0.435	-108.18
- brunisol	0.516	-31.39
- luvisol	-0.117	132.02
- gleysol	0.273	0.30
- regosol	0.277	-3.78
- organic	0.608	-3.58

[z] r^2 = 0.758, n = 504 with all three depths combined.

Table 31. Factors that influenced the regression of Kelowna with Mehlich-3 extracted potassium in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	0.450	0.168
Geography	**0.000**	**0.000**
Geology	**0.000**	**0.000**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.000**
Crop	**0.000**	**0.000**
	Values for regression equation	
Depth		
- 0 – 15 cm	1.271	4.43
- 15 – 30 cm	1.287	9.13
- 30 – 60 cm	1.248	13.41
- all three[z]	1.267	9.81
Taxonomy		
- br.chern.	1.368	-10.76
- dk.br.chern.	1.217	7.61
- blk. chern.	1.221	3.71
- dk.gr.chern.	1.508	-145.32
- brunisol	1.199	15.96
- luvisol	1.053	157.52
- gleysol	1.312	5.19
- regosol	1.356	8.82
- organic	1.183	22.63

[z] r^2 = 0.976, n = 504 with all three depths combined. A similar regression for Lower Fraser Valley soils was: Mehlich-3 = -2.03 + 1.408 Kelowna_K with r^2 = 0.981 (n = 486), with no difference by depth of sampling.

Table 32. Distribution of fields in Phase A Okanagan soil study in agronomic classifications of crops with low (Group A) and high (Group B) magnesium application requirements using Kelowna extraction values.

Crop group A			Crop group B		
Ranking	mg Mg kg^{-1}	% of fields	Ranking	mg Mg kg^{-1}	% of fields
Low (L)	0 – 50	0	Low (L)	0 – 25	0
Medium (M)	51 – 100	5	Medium (M)	26 – 50	0
High (L)	101 – 150	13	High (L)	51 – 100	5
Very high (VH)	>150	82	Very high (VH)	>100	95

Table 33. Influence of depth on soil magnesium measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	Water extractable	Kelowna extractable	Mehlich-3 extractable
Anal. of variance		P value	
- pit (replicate)	0.195	**0.000**	**0.000**
- field	**0.000**	**0.000**	**0.000**
- depth	0.209	0.296	**0.032**
- field x depth	1.000	1.000	0.509
Content		mg Mg kg^{-1}	
0 – 15 cm			
- mean	29 a	286 a	353 b
- median	20	210	253
- minimum	3	60	33
- maximum	567	3427	3428
- coeff. of variation	169%	105%	105%
15 – 30 cm	34 a	273 a	362 b
30 – 60 cm	37 a	308 a	417 a

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 34. Factors that influenced the regression of Kelowna with Mehlich-3 extracted magnesium in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	**0.001**	0.333
Geography	**0.000**	**0.028**
Geology	**0.000**	**0.023**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.000**
Crop	**0.000**	**0.000**
	Values for regression equation	
Depth		
- 0 – 15 cm	0.070	8.94
- 15 – 30 cm	0.123	-0.19
- 30 – 60 cm	0.116	1.67
- all three[z]	0.103	3.54
Taxonomy		
- br.chern.	0.079	6.12
- dk.br.chern.	0.025	13.05
- blk. chern.	0.082	0.19
- dk.gr.chern.	0.024	4.61
- brunisol	0.377	-43.78
- luvisol	0.177	-4.57
- gleysol	0.194	-21.69
- regosol	0.104	-2.46
- organic	0.359	-120.96

[z] $r^2 = 0.338$, n = 504 with all three depths combined.

Table 35. Distribution of fields in Phase A Okanagan soil study in agronomic classifications of crops for sulphur application requirements using Kelowna extraction values.

Ranking	mg S kg^{-1}	% of fields
Low (L)	0 – 20	74
Medium (M)	21 – 25	5
High (L)	26 – 35	5
Very high (VH)	>35	16

Table 36. Influence of depth on soil sulphur measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	Water extractable sulphate	Kelowna extractable S	Mehlich-3 extractable S
Anal. of variance		P value	
- pit (replicate)	0.180	0.150	0.118
- field	**0.000**	**0.000**	**0.000**
- depth	0.830	0.947	0.973
- field x depth	1.000	1.000	1.000
Content		mg S kg^{-1}	
0 – 15 cm			
- mean	58 a	56 a	91 a
- median	6	11	18
- minimum	1	2	5
- maximum	5374	3923	6598
- coeff. of variation	726%	564%	637%
15 – 30 cm	71 a	62 a	94 a
30 – 60 cm	58 a	56 a	87 a

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 37. Factors that influenced the regression of Kelowna extracted total sulphur with water extracted sulphate-S in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	**0.000**	0.077
Geography	**0.000**	0.107
Geology	**0.000**	**0.004**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.002**
Crop	**0.000**	**0.002**
	Values for regression equation	
Depth		
- 0 – 15 cm	1.34	-16.31
- 15 – 30 cm	1.31	-10.54
- 30 – 60 cm	1.44	-9.36
- all three[z]	1.36	-11.55
Taxonomy		
- br.chern.	1.55	-10.70
- dk.br.chern.	0.39	2.17
- blk. chern.	1.09	-17.52
- dk.gr.chern.	0.60	-1.09
- brunisol	1.38	-3.94
- luvisol	0.34	5.05
- gleysol	1.15	-6.97
- regosol	1.51	-13.50
- organic	1.44	-144.27

[z] $r^2 = 0.984$, n = 504 with all three depths combined.

Table 38. Factors that influenced the regression of Kelowna with Mehlich-3 extracted sulphur in pit sampled soils of Okanagan-Similkameen.

Factor	Slope	Intercept
	P value for regression	
Depth	**0.000**	0.214
Geography	**0.000**	0.312
Geology	**0.000**	**0.000**
Taxonomy	**0.000**	**0.000**
Soil man. groups	**0.000**	**0.028**
Crop	**0.000**	**0.026**
	Values for regression equation	
Depth		
- 0 – 15 cm	1.63	-9.88
- 15 – 30 cm	1.75	-15.60
- 30 – 60 cm	1.39	-5.28
- all three[z]	1.61	-11.77
Taxonomy		
- br.chern.	1.26	0.89
- dk.br.chern.	1.03	1.03
- blk. chern.	1.12	4.67
- dk.gr.chern.	0.70	13.64
- brunisol	1.69	-5.37
- luvisol	1.11	1.91
- gleysol	1.20	4.09
- regosol	1.25	1.83
- organic	1.23	-31.71

[z] $r^2 = 0.981$, n = 504 with all three depths combined. Visual inspection suggests the relationship was slightly curvilinear.

Table 39. Distribution of fields in Phase A Okanagan soil study in agronomic pH classifications.

Ranking	pH	% of fields
Low (L)	<5.6	2
Medium (M)	5.6 – 6.5	14
High (L)	6.6 – 7.5	57
Very high (VH)	>7.5	27

Table 40. Influence of depth on soil pH measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	pH
Anal. of variance	P value
- pit (replicate)	0.300
- field	**0.000**
- depth	**0.000**
- field x depth	**0.000**
Content	Measurement value
0 – 15 cm	
- mean	7.12 c
- median	7.25
- minimum	5.00
- maximum	8.46
- coeff. of variation	10%
15 – 30 cm	7.31 b
30 – 60 cm	7.61 a

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 41. Distribution of soil boron contents of pit-sampled fields in the Okanagan-Similkameen Valleys according to hot water extraction agronomic criteria for water, Kelowna and Mehlich-3 extract measurements.

Ranking	Ranges for hot water extraction	Water	Kelowna	Mehlich-3
	mg B kg^{-1}	% of fields		
Low (L)	0 – 0.40	60	11	18
(< detection limit)	Varies with extraction[z]	(4)	(7)	(0)
Medium (M)	0.41 – 0.80	32	25	32
High (H)	0.81 – 1.00	4	11	16
Very high (VH)	>1.00	4	53	34

[z] Detection limits were 0.021, 0.036 and 0.022 mg B kg^{-1} for water, Kelowna and Mehlich-3 extractions, respectively.

Table 42. Influence of depth on soil boron measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	Water extraction	Kelowna extraction	Mehlich-3 extraction
Anal. of variance		P value	
- pit (replicate)	**0.050**	**0.016**	**0.012**
- field	**0.000**	**0.000**	**0.000**
- depth	**0.000**	**0.000**	**0.000**
- field x depth	0.998	0.328	0.357
Coefficient of variation	119%	69%	62%
Content		mg B kg^{-1}	
0 – 15 cm	0.378 a[z]	1.310 a	0.809 a
15 – 30 cm	0.284 b	0.882 b	0.562 b
30 – 60 cm	0.160 c	0.514 c	0.342 c

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 43. Distribution of soil zinc contents of pit-sampled fields in the Okanagan-Similkameen Valleys according to DTPA extraction criteria for water, Kelowna and Mehlich-3 extract measurements.

Category[z]	Water	Kelowna	Mehlich-3
		% of fields	
Below detection limit	5	0	0
Deficient	99	14	0
Sufficient	1	86	100

[z] Detection limits were 0.050, 0.045 and 0.021 mg Zn kg^{-1} for water, Kelowna and Mehlich-3 extractions, respectively, and fields were classed as deficient when DTPA extractable Zn was <1.0 mg kg^{-1}.

Table 44. Influence of depth on soil zinc measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	Water extraction	Kelowna extraction	Mehlich-3 extraction
Anal. of variance		P value	
- pit (replicate)	0.051	0.274	0.202
- field	**0.000**	**0.000**	**0.000**
- depth	**0.000**	**0.000**	**0.000**
- field x depth	**0.000**	**0.000**	**0.000**
Coefficient of variation	54%	71%	63%
Content		mg Zn kg^{-1}	
0 – 15 cm	0.28 a[z]	6.76 a	25.62 a
15 – 30 cm	0.21 b	1.64 b	5.76 b
30 – 60 cm	0.19 b	0.46 c	1.61 c

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly ($P < 0.05$) different according to Least Significant Difference test.

Table 45. Distribution of soil copper contents of pit-sampled fields in the Okanagan-Similkameen Valleys according to DTPA extraction criteria for water, Kelowna and Mehlich-3 extract measurements.

Category[z]	Water	Kelowna	Mehlich-3
		% of fields	
Below detection limit	14	0	0
Deficient	88	75	0
Sufficient	12	25	100

[z] Detection limits were 0.045, 0.048 and 0.086 mg Cu kg^{-1} for water, Kelowna and Mehlich-3 extractions, respectively, and fields were classed as deficient when DTPA extractable Cu was < 0.3 mg kg^{-1}.

Table 46. Influence of depth on soil copper measurements sampled in pits in representative Okanagan-Similkameen Valley commercial fields.

Source/value	**Water extraction**	**Kelowna extraction**	**Mehlich-3 extraction**
Anal. of variance		P value	
- pit (replicate)	**0.004**	0.982	**0.008**
- field	**0.000**	**0.000**	**0.000**
- depth	0.765	**0.087**	**0.000**
- field x depth	**0.000**	0.056	**0.000**
Coefficient of variation	62%	80%	42%
Content		mg Cu kg^{-1}	
0 – 15 cm	0.169 a[z]	0.238 b	5.51 a
15 – 30 cm	0.162 a	0.274 ab	4.83 b
30 – 60 cm	0.162 a	0.289 a	4.37 c

[z] Values for three subsequent depths for each measurement followed by the same letter are not significantly (P < 0.05) different according to Least Significant Difference test.

Table 47. Extraction of calcium (Ca) and sodium (Na) in samples from different fields and depths from pits in representative Okanagan-Similkameen Valley commercial fields.

Extract solution	Depth	Ca	Na
	cm	mg kg^{-1}	
Water	0 - 15	147 a[y]	23 b
	15 – 30	151 a	33 ab
	30 - 60	171 a	38 b
	Coeff. of var.[z]	284%	20%
Kelowna	0 - 15	2304 b	32 b
	15 – 30	2543 b	48 ab
	30 - 60	3327 a	58 a
	Coeff. of var.	131%	223%
Mehlich-3	0 - 15	3870 b	36 b
	15 – 30	3877 b	53 ab
	30 - 60	4858 a	63 a
	Coeff. of var.	93%	211%

[y] For all extracts and both elements field main effects were significant ($P<0.05$) by analysis of variance, and depth main effect was significant only for Kelowna and Mehlich-3 extraction of Ca; there were no field x depth interaction effects. Values for depth for each extract and element followed by the same letter were not significantly different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for each analysis of variance.

Table 48. Extraction of aluminum (Al), iron (Fe), manganese (Mn) and silicon (Si) in samples from different fields and depths from pits in representative Okanagan-Similkameen Valley commercial fields.

Extract solution	Depth	Al	Fe	Mn	Si
	cm	mg kg^{-1}			
Water	0 – 15	50 b[y]	42 c	0.60 b	125 b
	15 – 30	79 a	67 b	0.88 a	179 a
	30 – 60	89 a	83 a	0.85 a	200 a
	Coeff. of var.[z]	67%	73%	62%	61%
Kelowna	0 – 15	410 b	-5 c	12 a	335 b
	15 – 30	511 a	-1 b	8 b	378 a
	30 – 60	438 b	8 a	7 b	363 a
	Coeff. of var.	35%	2152%	61%	20%
Mehlich-3	0 – 15	541 a	197 a	80 a	372 c
	15 – 30	561 a	172 b	64 b	412 a
	30 – 60	444 b	141 c	54 c	392 b
	Coeff. of var.	30%	24%	33%	20%

y Field, depth and field x depth were significant ($P<0.05$) by analysis of variance in all cases except field x depth for Mehlich-3 extracted Mn. Values for depth for each extract and element followed by the same letter were not significantly different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for each analysis of variance.

Table 49. Extraction of geological elements from Okanagan samples obtained in pits of representative soil types that may be present in significant amounts and behave similar to nutrient cations such as calcium and potassium.

Element	Extraction	Depth	Mean	Maximum	Detection limit
			mg kg^{-1}		
Strontium (Sr)	Water	0 – 15	1.05	70.92	0.01
	Kelowna	0 – 15	10.90	68.28	0.19
	Mehlich-3	0 – 15	27.68	266.27	0.26
	Mehlich-3	15 – 30	27.81	302.32	0.26
	Mehlich-3	30 – 60	28.49	216.83	0.26
Barium (a)	Water	0 – 15	-0.36	1.62	0.01
	Kelowna	0 – 15	5.79	24.69	0.05
	Mehlich-3	0 – 15	34.43	96.80	0.34
	Mehlich-3	15 – 30	37.08	141.25	0.34
	Mehlich-3	30 – 60	32.43	156.28	0.34
Lithium (Li)	Water	0 – 15	0.04	0.25	0.02
	Kelowna	0 – 15	0.10	0.81	0.02
	Mehlich-3	0 – 15	0.12	0.83	0.02
	Mehlich-3	15 – 30	0.14	1.03	0.02
	Mehlich-3	30 – 60	0.15	0.89	0.02
Rubidium (Rb)	Water	0 – 15	0.00	0.79	0.90
	Kelowna	0 – 15	0.16	1.09	1.10
	Mehlich-3	0 – 15	0.34	1.85	1.10
	Mehlich-3	15 – 30	0.41	2.08	1.10
	Mehlich-3	30 – 60	0.36	2.02	1.10

Table 50. Extraction of geological elements from Okanagan samples obtained in pits of representative soil types that may be present in small amounts and behave similar to nutrient cations such as calcium and potassium.

Element	Extraction	Depth	Mean	Maximum	Detection limit
		cm	mg kg^{-1}		
Beryllium (Be)	Water	0 – 15	-0.01	-0.00	0.001
	Kelowna	0 – 15	0.05	0.16	0.002
	Mehlich-3	0 – 15	0.09	0.20	0.002
	Mehlich-3	15 – 30	0.09	0.23	0.002
	Mehlich-3	30 – 60	0.07	0.19	0.002
Scandium (Sc)	Water	0 – 15	0.06	0.17	0.01
	Kelowna	0 – 15	0.11	0.43	0.01
	Mehlich-3	0 – 15	0.40	1.28	0.01
	Mehlich-3	15 – 30	0.43	1.62	0.01
	Mehlich-3	30 – 60	0.39	1.60	0.01
Titanium (Ti)	Water	0 – 15	1.64	14.53	0.01
	Kelowna	0 – 15	2.43	10.78	0.02
	Mehlich-3	0 – 15	2.72	9.33	0.04
	Mehlich-3	15 – 30	3.41	14.02	0.04
	Mehlich-3	30 – 60	3.26	26.27	0.04
Vanadium (V)	Water	0 – 15	0.14	0.67	0.07
	Kelowna	0 – 15	0.07	0.35	0.14
	Mehlich-3	0 – 15	0.81	2.64	0.11
	Mehlich-3	15 – 30	0.96	3.59	0.11
	Mehlich-3	30 – 60	1.23	3.69	0.11
Yttrium (Y)	Water	0 – 15	0.01	0.07	0.01
	Kelowna	0 – 15	0.40	0.98	0.02
	Mehlich-3	0 – 15	2.31	5.47	0.02
	Mehlich-3	15 – 30	2.50	6.94	0.02
	Mehlich-3	30 – 60	2.14	6.67	0.02
Zirconium (Zr)	Water	0 – 15	0.98	1.77	0.05
	Kelowna	0 – 15	2.91	9.51	0.07
	Mehlich-3	0 – 15	5.21	13.43	0.08
	Mehlich-3	15 – 30	5.72	15.23	0.08
	Mehlich-3	30 – 60	4.10	13.59	0.08
Cerium (Ce)	Water	0 – 15	0.05	0.20	0.17
	Kelowna	0 – 15	0.35	0.87	0.21
	Mehlich-3	0 – 15	1.33	3.87	0.17
	Mehlich-3	15 – 30	1.55	5.38	0.17
	Mehlich-3	30 – 60	1.79	6.02	0.17

Table 51. Extraction of other elements from Okanagan samples obtained in pits of representative soil types that are usually present in small amounts and may have plant nutrient or environmental significance.

Element	Extraction	Depth	Mean	Maximum	Detection limit
		cm	mg kg^{-1}		
Lead (Pb)	Water	0 – 15	0.01	0.65	0.90
	Kelowna	0 – 15	0.39	2.39	1.00
	Mehlich-3	0 – 15	18.36	263.84	1.30
	Mehlich-3	15 – 30	7.22	91.55	1.30
	Mehlich-3	30 – 60	2.13	1.46	1.30
Arsenic (As)	Water	0 – 15	0.19	2.14	1.80
	Kelowna	0 – 15	0.80	8.56	2.50
	Mehlich-3	0 – 15	1.13	10.79	2.10
	Mehlich-3	15 – 30	1.01	10.62	2.10
	Mehlich-3	30 – 60	2.13	33.02	2.10
Nickel (Ni)	Water	0 – 15	0.05	0.81	0.30
	Kelowna	0 – 15	0.14	1.11	0.50
	Mehlich-3	0 – 15	1.30	1.02	0.30
	Mehlich-3	15 – 30	1.27	4.88	0.30
	Mehlich-3	30 – 60	1.15	5.02	0.30
Cadmium (Cd)	Water	0 – 15	-0.00	0.09	0.07
	Kelowna	0 – 15	0.01	0.13	0.16
	Mehlich-3	0 – 15	0.16	0.41	0.18
	Mehlich-3	15 – 30	0.12	0.38	0.18
	Mehlich-3	30 – 60	0.09	0.34	0.18
Cobalt (Co)	Water	0 – 15	-0.00	0.08	0.08
	Kelowna	0 – 15	0.03	0.22	0.14
	Mehlich-3	0 – 15	0.72	2.21	0.12
	Mehlich-3	15 – 30	0.67	2.73	0.12
	Mehlich-3	30 – 60	0.66	2.24	0.12
Chromium (Cr)	Water	0 – 15	0.06	0.62	0.06
	Kelowna	0 – 15	0.05	0.21	0.11
	Mehlich-3	0 – 15	0.13	0.45	0.08
	Mehlich-3	15 – 30	0.14	0.53	0.08
	Mehlich-3	30 – 60	0.16	0.66	0.08
Tungsten (W)	Water	0 – 15	0.02	1.05	1.01
	Kelowna	0 – 15	0.07	1.07	0.97
	Mehlich-3	0 – 15	0.44	1.73	0.64
	Mehlich-3	15 – 30	0.18	0.89	0.64
	Mehlich-3	30 – 60	0.10	0.81	0.64

Table 52. Distribution of residual soil nitrate in 173 fields[x] that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
	number of fields (proportion of all)						
Low (0 - 49)	27	19	21	5	10	14	96 (56%)
Med. (50 - 99)	11	10	2	5	5	8	41 (24%)
High (100 -199)	12	5	3	2	2	1	25 (14%)
V. high (200+)	6	1	2	1	0	1	11 (6%)
	kg N ha^{-1} to 60 cm						
Mean	106 a[y]	57 b	65 b	78 ab	47 b	61 b	75
Maximum	712	208	609	237	132	230	712
	%						
Coeff. of var.[z]	36	35	61	24	23	32	40

[x] Note: seven of the 180 fields sampled in this study could not be sampled to 60 cm because of stones and are not included in these analyses. This included one apple (Nahun soil series) and one alfalfa (Schunter soil series) field in Vernon region and one other fruit tree and four alfalfa/grass mix fields in Similkameen region. All fields not sampled in Similkameen region were Similkameen soil series.
[y] Values for each region followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 53. Distribution of residual soil **ammonium** in 173 fields[x] that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
			number of fields (proportion of all)				
Low (0 - 49)	49	35	27	13	17	24	165 (95%)
Med. (50 - 99)	4	0	1	0	0	0	5 (3%)
High (100 - 199)	2	0	0	0	0	0	2 (1%)
V. high (200+)	1	0	0	0	0	0	1 (1%)
			kg N ha^{-1} to 60 cm				
Mean	33 a[y]	20 b	21 b	21 b	11 b	15 b	23
Maximum	328	30	54	48	33	25	328
			%				
Coeff. of var.[z]	71	30	22	52	38	22	62

[x] Note: seven of the 180 fields sampled in this study could not be sampled to 60 cm because of stones and are note included in these analyses. This included one apple (Nahun soil series) and one alfalfa (Schunter soil series) field in Vernon region and one other fruit tree and four alfalfa/grass mix fields in Similkameen region. All fields not sampled in Similkameen region were Similkameen soil series.
[y] Values for each region followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 54. Distribution of **total nitrogen** in surface (0 – 15 cm) samples of 173 fields[x] to potentially release inorganic nitrogen in the soil in fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
	number of fields (proportion of all in brackets)						
Low (0 – 0.30)	43	33	27	10	17	25	155 (86%)
Med. (0.31 – 0.60)	7	3	1	3	0	4	18 (10%)
High (0.61 – 1.21)	0	1	0	0	0	0	1 (1%)
V. high (>1.21)	6	0	0	0	0	0	6 (3%)
	% total N in surface 15 cm						
Mean	0.456 a[y]	0.216 b	0.140 b	0.236 b	0.102 b	0.214b	0.269
Maximum	2.544	0.714	0.485	0.516	0.281	0.437	2.544
	%						
Coeff. of var.[z]	7	9	12	10	21	8	9

[x] Note: seven of the 180 fields sampled in this study could not be sampled to 60 cm because of stones and are not included in these analyses. This included one apple (Nahun soil series) and one alfalfa (Schunter soil series) field in Vernon region and one other fruit tree and four alfalfa/grass mix fields in Similkameen region. All fields not sampled in Similkameen region were Similkameen soil series.
[y] Values for each region followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation on total N content of surface soil depth.

Table 55. Mean residual **nitrate and total nitrogen** contents in 173 fields[x] that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia compared to reported nitrogen applied as fertilizer or organic amendment applied in 2007.

Factor	Nitrate	Total N	Soil applied N in 2007		
			Mean	Minimum	Maximum
Crop group	kg N ha^{-1} to 60 cm	mg N kg^{-1}	kg N ha^{-1}		
- apple	56 d[y]	0.179[z]	30	0	114
- cherry	64 cd	0.183	79	0	290
- other tree fruit	102 bc	0.173	77	0	234
- grape	26 d	0.094	40	0	328
- alfalfa	46 d	0.216	30	0	369
- alfalfa/grass or barley mix	55 d	0.335	124	0	539
- grass (cultivated or natural)	121 ab	0.686	115	0	462
- forage corn	113 abc	0.283	260	52	477
- cereal	158 a	0.240	99	0	369
- vegetable	105 bc	0.146	54	0	160
Management	kg N ha^{-1} to 60 cm	mg N kg^{-1}	kg N ha^{-1}		
- conventional	77 a	0.283 a	81	0	539
- organic	51 a	0.143 b	37	0	290
- transitional	74 a	0.180 ab	103	0	310
- unknown or other	86 a	0.353 a	7	0	15

[x] Note: seven of the 180 fields sampled in this study could not be sampled to 60 cm because of stones and are not included in these analyses. This included one apple (Nahun soil series) and one alfalfa (Schunter soil series) field in Vernon region and one other fruit tree and four alfalfa/grass mix fields in Similkameen region. All fields not sampled in Similkameen region were Similkameen soil series. Data for only 165 of these fields was available for reported nitrogen applications.
[y] Values for each nitrogen measurement within each factor followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[z] Analysis of Variance showed a significant crop effect but there was too much variability to calculate L.S.D. values.

Table 56. Distribution of residual Kelowna (0 – 15 cm) depth extractable **phosphorus** in 180 fields that represent crops grown in Okanagan-Similkameen Valleys of British Columbia in various risk categories based on different crop type and water-extractable considerations.

Category[z]	Crop group 1	Crop group 2 - 5	Assuming 15% water extractable
	% of all fields		
Low	4	7	0
Medium	5	18	4
High	47	31	21
Very high	44	44	75

[z] Phosphorus contents for the categories vary depending on crop type or water extractable criteria.

Table 57. Distribution of residual Kelowna (0 – 15 cm) depth extractable **phosphorus** in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia in crop group 2 – 5 risk categories.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
Crop group 2 - 5	fields within each region and overall						
Low (0 – 20)	5	1	0	1	0	6	13
Med. (21 – 50)	3	7	3	1	6	12	32
High (51 – 100)	20	11	8	7	4	6	56
V. high (>100)	28	18	17	4	7	5	79
	mg P kg^{-1}						
Mean	149 a[y]	111 bc	117 b	80 cd	91 bc	58 d	111
Maximum	758	328	280	132	196	185	758
	%						
Coeff. of var.[z]	18	17	18	22	19	18	19

[y] Values for each region followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 58. Mean residual Kelowna extractable **phosphorus** contents (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia in comparison to reported 2007 soil applied P.

Factor	Kelowna extraction	Soil applied P in 2007[x]		
		Mean	Minimum	Maximum
Crop group	mg P kg^{-1}	kg P_2O_5 ha^{-1}		
- apple	122 b[y]	3	0	26
- cherry	106 bc	23	0	154
- other tree fruit	83 cd	14	0	60
- grape	94 bcd	18	0	78
- alfalfa	122 b	13	0	116
- alfalfa/grass or barley mix	74 d	19	0	82
- grass (cultivated or natural)	70 d	24	0	110
- forage corn	237 a	38	0	67
- cereal	206 a	23	0	116
- vegetable	105 bc	28	0	94
Management	mg P kg^{-1}	kg P_2O_5 ha^{-1}		
- conventional	115 a[z]	17	0	116
- organic	102 a	20	0	154
- transitional	107 a	32	0	94
- unknown or other	75 a	31	0	62

[x] Data for only 165 of these fields were available for reported P applications.
[y] Values for each factor followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference multiple range test.
[z] Analysis of variance showed that the effect of management was not significant ($P = 0.08$).

Table 59. Distribution of residual Kelowna extractable **potassium** (0 – 15 cm depth) in 180 fields that represent crops grown in Okanagan-Similkameen Valleys of British Columbia in various risk categories based on different types of criteria.

Category[z]	Okanagan area		Criteria used in the 2005 Lower Fraser Valley study
	Crop group 1	Crop group 4	
	% of all fields		
Low	2	10	7
Medium	14	23	34
High	32	24	16
Very high	52	43	43

[z] Potassium contents for the categories vary depending on crop type or provincial region.

Table 60. Distribution of residual Kelowna extractable **potassium** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating for crop group 1	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
				number of fields			
Low (0 – 50)	2	0	0	0	0	2	4
Med. (51 – 125)	9	3	0	0	5	9	26
High (126 -190)	13	12	12	6	6	8	57
V. high (>190)	32	22	16	7	6	10	93
				mg K kg^{-1}			
Mean	301 b[y]	375 a	266 bc	290 bc	201 cd	167 d	279
Maximum	1205	1604	533	743	432	420	1604
				%			
Coeff. of var.[z]	21	8	11	17	12	12	15

[y] Values for each region followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 61. Mean residual Kelowna extractable **potassium** contents (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia compared to reported soil K applied.

Factor	Kelowna extraction	Soil applied K in 2007[x]		
		Mean	Minimum	Maximum
Crop group	mg K kg^{-1}	kg K_2O ha^{-1}		
- apple	268 bc[y]	4	0	29
- cherry	271 bc	27	0	188
- other tree fruit	234 c	31	0	141
- grape	226 c	40	0	340
- alfalfa	231 c	36	0	224
- alfalfa/grass or barley mix	244 c	94	0	454
- grass (cultivated or natural)	338 b	77	0	303
- forage corn	474 a	162	0	298
- cereal	436 a	48	0	235
- vegetable	268 bc	33	0	106
Management	mg K kg^{-1}	kg K_2O ha^{-1}		
- conventional	287 a[z]	51	0	454
- organic	219 a	25	0	188
- transitional	246 a	75	0	234
- unknown or other	300 a	112	0	224

[x] Data for only 165 of these fields were available for reported K applications.
[y] Values for each factor followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference multiple range test.
[z] Analysis of variance showed that the effect of management was not significant ($P = 0.18$).

Table 62. Distribution of post harvest (0 – 15 cm depth) soil **pH** in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
	number of fields (% of all)						
Low (4.6 – 5.5)	4	0	0	0	0	0	4 (2)
Med. (5.6 – 6.5)	26	15	9	4	0	0	54 (30)
High (6.6 – 7.5)	25	19	13	4	9	14	84 (47)
V. high (>7.5)	1	3	6	5	8	15	38 (21)
	pH						
Mean	6.4 d[y]	6.8 c	7.0 b	7.1 b	7.6 a	7.5 a	6.9
Minimum	4.6	5.8	5.6	5.6	7.0	6.6	4.6
Maximum	7.8	7.9	8.0	8.0	8.2	8.3	8.3
	%						
Coeff. of var.[z]	1	2	2	2	1	1	2

[y] Values for each region followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 63. Mean post harvest (0 – 15 cm depth) soil **pH** in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	pH
Crop group	
- apple	6.7 ef[z]
- cherry	7.1 bc
- other tree fruit	7.4 ab
- grape	7.6 a
- alfalfa	6.5 f
- alfalfa/grass or barley mix	7.0 cd
- grass (cultivated or natural)	6.8 de
- forage corn	6.6 ef
- cereal	6.4 f
- vegetable	7.2 bc
Management	
- conventional	6.9 b[z]
- organic	7.2 a
- transitional	6.8 b
- unknown or other	7.0 ab

[z] Values for each factor followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.

Table 64. Distribution of residual Kelowna extractable **magnesium** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
				number of fields (% of all)			
Low (0 – 20)	0	0	0	0	0	0	0 (0)
Med. (21 – 25)	0	3	4	2	0	0	9 (5)
High (26 – 35)	4	7	8	3	6	1	29 (16)
V. high (>35)	52	27	16	8	11	28	142 (79)
				mg Mg kg^{-1}			
Mean	351 a[y]	265 b	220 bc	332 a	173 c	346 a	294
Minimum	114	60	65	88	110	130	60
Maximum	898	1127	528	1000	333	815	1127
				%			
Coeff. of var.[z]	8	8	10	18	10	7	10

[y] Values for each region followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 65. Mean residual Kelowna extractable **magnesium** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	Kelowna extraction
Crop group	mg Mg kg^{-1}
- apple	183[y]
- cherry	262
- other tree fruit	293
- grape	194
- alfalfa	297
- alfalfa/grass or barley mix	358
- grass (cultivated or natural)	440
- forage corn	369
- cereal	267
- vegetable	281
Management	mg Mg kg^{-1}
- conventional	296 a[z]
- organic	225 b
- transitional	340 a
- unknown or other	319 a

[y] Analysis of variance showed that the effect of crop was significant (P = 0.00) but variability was too great to perform Least Significant Difference (L.S.D.) multiple range test.
[z] Values for management followed by the same letter were not significantly (P<0.05) different according to L.S.D. multiple range test.

Table 66. Distribution of residual Kelowna extractable **sulphur** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Risk/rating	Arm-strong	Vernon	Kelowna	Summer-land	Oliver	Similka-meen	All
				number of fields (% of all)			
Low (0 – 20)	39	29	26	9	17	15	135 (75)
Med. (21 – 25)	1	2	1	1	0	3	8 (4)
High (26 – 35)	5	3	1	0	0	0	9 (5)
V. high (>35)	11	3	0	3	0	11	28 (16)
				mg S kg^{-1}			
Mean	56 ab[y]	77 a	12 b	21 ab	8 b	93 a	52
Minimum	3	5	3	5	0	5	0
Maximum	621	2152	28	56	21	1455	2152
				%			
Coeff. of var.[z]	39	34	51	31	63	63	56

[y] Values for each region followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference multiple range test.
[z] Coefficient of variation for Analysis of Variance model calculation.

Table 67. Mean residual Kelowna extractable **sulphur** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	Kelowna extraction
Crop group	mg S kg^{-1}
- apple	15 [y]
- cherry	28
- other tree fruit	27
- grape	8
- alfalfa	15
- alfalfa/grass or barley mix	111
- grass (cultivated or natural)	184
- forage corn	26
- cereal	20
- vegetable	18
Management	mg S kg^{-1}
- conventional	46 b [z]
- organic	21 b
- transitional	10 b
- unknown or other	203 a

[y] Analysis of variance showed that the effect of crop was significant (P = 0.00) but variability was too great to perform Least Significant Difference (L.S.D.) multiple range test.
[z] Values for management followed by the same letter were not significantly (P<0.05) different according to L.S.D. multiple range test.

Table 68. Mean residual Mehlich-3 extractable **boron** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	Mehlich-3 extraction
Region	mg B kg^{-1}
- Armstrong	0.55 bc[x]
- Vernon	0.69 b
- Kelowna	0.52 bc
- Summerland	1.13 a
- Oliver	0.43 c
- Similkameen	1.35 a
All six regions	
- mean	0.73
- minimum	-0.13[y]
- maximum	3.66
Rating (using hot water extractable criteria)	% of fields
- low (0 – 0.40)	42
- medium (0.41 – 0.80)	23
- high (0.81 – 1.00)	11
- very high (>1.00)	24
Crop group	mg B kg^{-1}
- apple	0.72[z]
- cherry	0.99
- other tree fruit	1.18
- grape	0.46
- alfalfa	0.46
- alfalfa/grass or barley mix	0.85
- grass (cultivated or natural)	0.99
- forage corn	0.63
- cereal	0.45
- vegetable	0.69
Management	mg B kg^{-1}
- conventional	0.75 a
- organic	0.65 ab
- transitional	0.45 b
- unknown or other	0.90 a

[x] Values for factor followed by the same letter were not significantly (P<0.05) different according to Least Significant Difference (L.S.D.) multiple range test.
[y] Thirty-three of the 180 fields were below the detection limit of 0.2 mg B kg^{-1}.
[z] Analysis of variance showed that the effect of crop was significant (P = 0.00) but variability was too great to perform L.S.D. multiple range test.

Table 69. Mean residual Mehlich-3 extractable **zinc and copper** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	Zinc	Copper
Region	mg Zn kg^{-1}	mg Cu kg^{-1}
- Armstrong	12 c[w]	5 c
- Vernon	21 b	5 c
- Kelowna	22 b	4 c
- Summerland	41 a	6 c
- Oliver	17 bc	11 b
- Similkameen	19 b	14 a
All six regions	mg Zn kg^{-1}	mg Cu kg^{-1}
- mean	20	6
- minimum	1.7[x]	1.0[y]
- maximum	118.9	52
Crop group	mg Zn kg^{-1}	mg Cu kg^{-1}
- apple	47 a	4[z]
- cherry	41 a	6
- other tree fruit	22 b	15
- grape	14 c	3
- alfalfa	10 c	6
- alfalfa/grass or barley mix	11 c	6
- grass (cultivated or natural)	13 c	7
- forage corn	16 bc	5
- cereal	9 c	4
- vegetable	9 c	12
Management	mg Zn kg^{-1}	mg Cu kg^{-1}
- conventional	20 b	7 a
- organic	29 a	6 a
- transitional	8 c	7 a
- unknown or other	12 c	5 a

[w] Values for factor followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[x] All 180 fields had values that were >1.0 mg Zn kg^{-1}, which is considered to be the critical value between sufficient and deficient concentration.
[y] All 180 fields had values that were >0.3 mg Cu kg^{-1}, which is considered to be the critical value between sufficient and deficient concentration using DTPA extraction criteria.
[z] Analysis of variance showed that the effect of crop was significant ($P = 0.00$) but variability was too great to perform L.S.D. multiple range test.

Table 70. Mean residual Mehlich-3 extractable **lead** (0 – 15 cm depth) in 180 fields that represent crops grown in six regions of Okanagan-Similkameen Valleys of British Columbia.

Factor	Mean	Minimum	Maximum
Region		mg Pb kg^{-1}	
- Armstrong	2.2 c[y]	1.2[z]	3.2
- Vernon	13.3 b	1.3	58.2
- Kelowna	25.8 a	0.9	102.1
- Summerland	23.3 a	2.4	64.7
- Oliver	7.4 bc	0.0	57.2
- Similkameen	2.9 c	0.6	4.9
Crop group		mg Pb kg^{-1}	
- apple	31.4 a	1.3	96.6
- cherry	33.4 a	1.4	102.1
- other tree fruit	7.8 b	1.1	58.2
- grape	3.9 b	0.0	32.0
- alfalfa	3.4 b	1.2	32.7
- alfalfa/grass or barley mix	3.2 b	0.6	23.9
- grass (cultivated or natural)	5.8 b	1.2	89.2
- forage corn	2.1 b	1.4	2.7
- cereal	2.4 b	1.7	3.4
- vegetable	7.8 b	1.3	41.0

[y] Values for factor followed by the same letter were not significantly ($P<0.05$) different according to Least Significant Difference (L.S.D.) multiple range test.
[z] Eighteen of the 180 (11%) fields were below the detection limit of 1.3 mg Pb kg^{-1}.

Table 71. Mehlich-3 extractable residual arsenic in soil of six of 180 fields where substantial concentrations were noted in the Okanagan-Similkameen Valleys and all were in Similkameen region.

Field	0 – 15 cm	15 – 30 cm	30 – 60 cm	Mean
		mg As kg^{-1}		
A	35 ab[z]	43 a	11 efgh	30 A
B	23 cd	31 bc	25 cd	27 A
C	18 de	12 efg	3 gh	11 B
D	15 def	11 efgh	5 fgh	10 B
E	12 efg	6 fgh	2 gh	7 B
F	9 efgh	7 fgh	2 h	6 B
Mean	19 A	18 A	8 B	

[z] Values for field and depth main effect means followed by the same upper case letter and field x depth interaction effect means were not significantly (P<0.05) different according to Least Significant Difference (L.S.D.) multiple range test.

Table 72. Number of verification pits and pedons for each soil management group sampled.

Soil Management Group	Verification	Pedons	Soil Series in Soil Management Group
Chopaka	10	7	Chopaka, Ida, Mara, Nisconlith
Gammil	19	4	Gammil, Nahun, Rutland
Glenmore	18	5	Boucherie, Broadview, Glenmore, Spallumcheen
Greata	1	0	Greata
Guisachan	2	1	Guisachan
Kelowna	1	0	Kelowna
Keremeos	3	2	Cawston, Keremeos
Munson	11	10	Enderby, Munson, Olhausen, Penticton
Osoyoos	14	6	Grandview, Haynes, Osoyoos, Parkill, Shuswap, Trepanier
Rumohr	2	1	Waby
Similkameen	11	4	Kalamalaka, Similkameen
Skaha	4	3	Acland Creek, Agar Lake, Dartmouth, Paradise
Stemwinder	23	5	Lumby, Ratnip, Stemwinder, Tomlin
Shuswap	1	0	Monashee
Total	120	48	-

Table 73. Bulk density (g cm^{-3}) values for pedons.

Soil Series	1st Horizon	2nd Horizon	3rd Horizon
Acland Creek	1.44	1.54	1.68
Boucherie	1.10	1.31	1.53
Broadview	1.47	1.42	1.44
Cawston*	1.39	1.35	1.33
Chopaka*	1.39	1.28	1.44
Dartmouth	1.43	1.74	1.33
Enderby	1.48	1.73	1.48
Glenmore	1.28	1.42	1.46
Grandview	1.22	0.97	1.28
Guisachan	1.34	1.47	1.49
Ida	1.36	1.46	1.60
Kalamalka*	0.89	1.36	1.41
Nahun	1.39	1.67	1.62
Nisconolith*	1.16	1.36	1.39
Olhausen	1.10	1.47	1.55
Osoyoos *	1.56	1.59	1.52
Paradise	1.03	1.65	1.74
Parkill	1.40	1.60	1.44
Penticton*	1.24	1.40	1.38
Ratnip*	1.14	1.69[!]	2.31[!]
Rutland*	1.19	1.69[!]	2.21[!]
Shuswap*	1.77	1.94	1.69[!]
Similkameen*	1.45	1.47	1.74[!]
Spallumcheen	1.39	1.36	1.58
Stemwinder	1.80[!]	1.88[!]	1.88[!]
Waby	0.32	0.23	0.17

* Average values presented
[!] Includes values determined by excavation

Table 74. Soil texture classes for K_{sat} cores and field K_{sat}.

Texture Group	Soil Texture Classes	K_{sat} Cores	Field K_{sat}
Coarse	Sand, Loamy Sand, Sandy Loam	131	64
Medium	Silt, Silt Loam, Loam, Sandy Clay Loam, Silty Clay Loam, Clay Loam	259	135
Fine	Silty Clay, Clay, Sandy Clay, Heavy Clay	12	12
Coarse (Organic)	Fibric	10	9
Medium (Organic)	Mesic	1	0

Table 75. K_{sat} classes and corresponding range.

K_{sat} Class	Descriptive Name	Range (cm hr^{-1})
H2	High 2	> 50
H1	High 1	> 15 – 50
M3	Moderate 3	> 5 – 15
M2	Moderate 2	> 1.5 – 5
M1	Moderate 1	> 0.5 – 1.5
L3	Low 3	> 0.15 – 0.5
L2	Low 2	> 0.05 – 0.15
L1	Low 1	< 0.05

Table 76. Estimates of available water storage capacity (AWSC) for 544 soil samples from the Okanagan and Similkameen Valleys averaged according to soil texture.

	AWSC (%)			
Texture	**Default average[z]**	**Measured average**	**Average of default and measured values**	**Range**
Coarse sand	6	9.0	**8.4**	3.5 - 14.9
Sand	10	8.2	**8.2**	3.5 - 19.2
Loamy sand	12.5	14.7	**13.2**	5.3 - 21.6
Sandy loam	14.2	13.4	**13.2**	5.3 - 20.7
Fine sandy loam	14.2	20.0	**17.8**	14.2 - 25.3
Loam	16.7	15.5	**15.8**	8.6 - 23.3
Sandy clay loam	16.7	13.8	**15.1**	9.2 - 22.6
Silt	19.2	14.2	**15.0**	11.0 - 17.4
Silt loam	20	18.4	**18.7**	11.5 - 26.6
Silty clay loam	20	28.5	**21.3**	14.4 - 35.5
Clay	20.8	n/a	**20.0**	n/a
Clay loam	20.8	23.5	**20.2**	19.0 - 27.9
Silty clay	25	n/a	**20.8**	n/a
Mesic	n/a	24.6	**24.8**	19.6 - 31.2
Fibric	16.7	16.2	**16.2**	n/a

[z] Default averages for each texture as per the BC Trickle Irrigation Manual (Van der Gulik 1999). A default average for *Mesic* is not provided.

Table 77. Average available water storage capacity (%) for major soil management groups at three soil depths for the verification pit samples and all samples.

Soil Management Group	0 – 15 cm	15 – 30 cm	30 – 60 cm	Verification pit	All samples
Chopaka	21.3	19.3	18.2	19.6	17.8
Gammil	13.9	14.0	11.8	13.2	13.2
Glenmore	21.0	20.5	20.0	20.5	20.5
Greata	20.0	5.4	9.1	11.5	11.5
Guisachan	16.7	20.0	18.4	18.4	17.6
Kelowna	8.7	10.8	14.5	11.3	11.3
Keremeos	19.8	17.8	12.4	16.7	16.2
Munson	17.8	17.1	18.0	17.6	17.2
Osoyoos	10.3	11.5	11.3	11.0	10.6
Rumohr	25.0	25.0	22.3	24.1	24.0
Shuswap	10.4	3.5	6.0	6.6	6.6
Similkameen	16.8	15.1	15.0	15.7	16.0
Skaha	13.9	15.7	14.7	14.8	12.1
Stemwinder	13.8	14.4	14.9	14.3	14.0

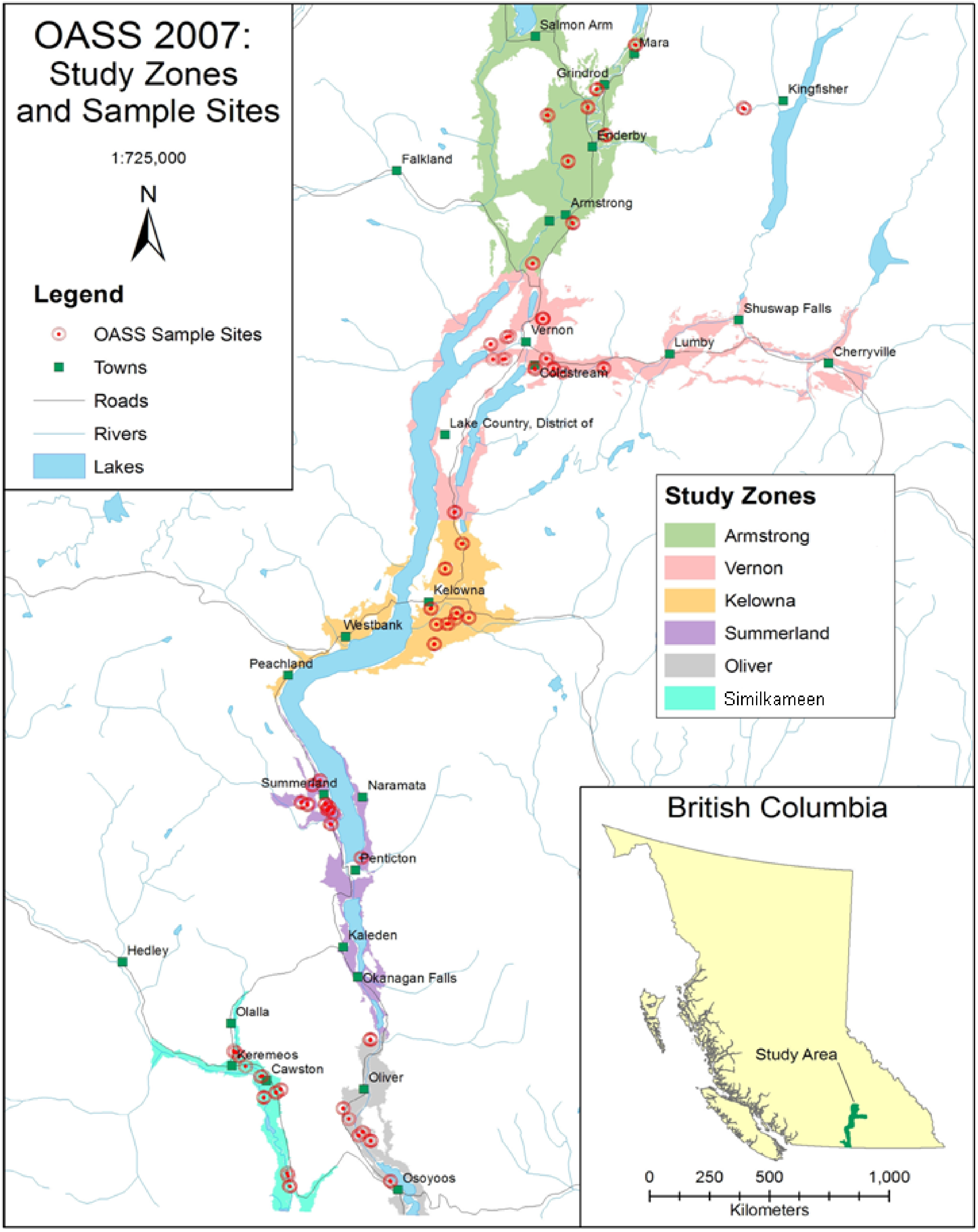
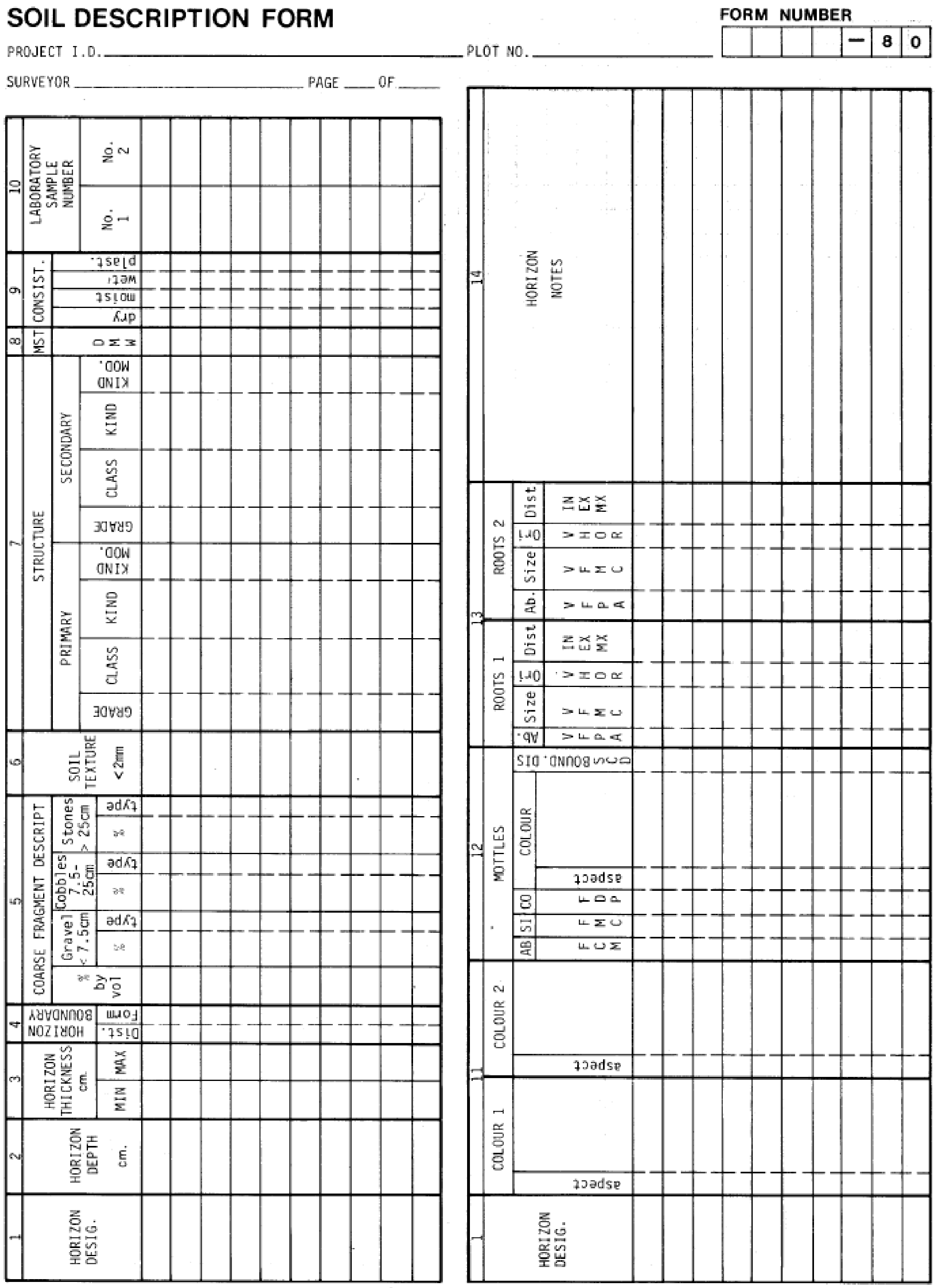


Figure 1. Study zone and sample sites.



SOIL DESCRIPTION FORM

FORM NUMBER — 8 0

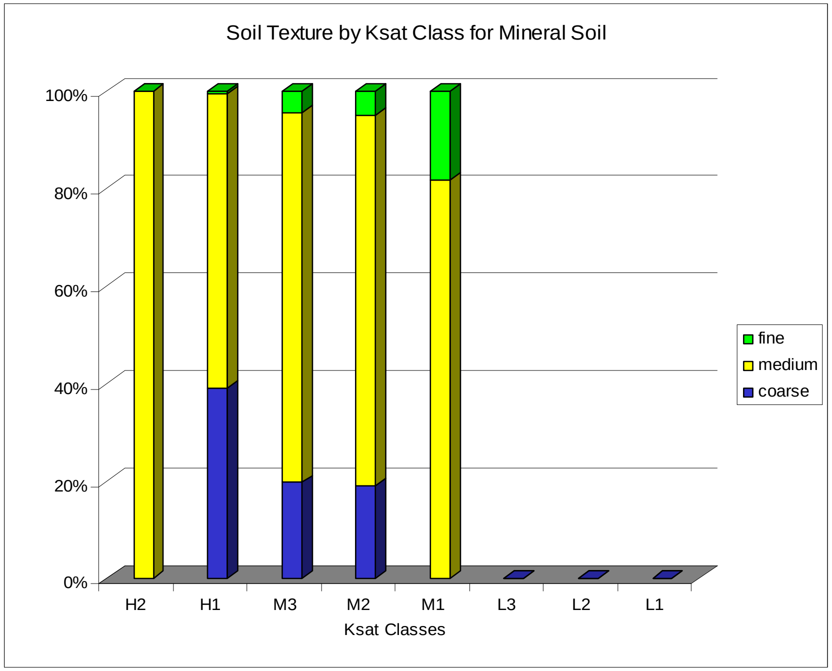
PROJECT I.D. ____ PLOT NO. ____

SURVEYOR ____ PAGE ____ OF ____

1 HORIZON DESIG.
2 HORIZON DEPTH cm.
3 HORIZON THICKNESS cm. MIN MAX
4 HORIZON BOUNDARY Dist. Form
5 COARSE FRAGMENT DESCRIPT. % by vol; Gravel < 7.5cm % type; Cobbles 7.5-25cm % type; Stones > 25cm % type
6 SOIL TEXTURE < 2mm
7 STRUCTURE PRIMARY GRADE CLASS KIND KIND MOD.; SECONDARY GRADE CLASS KIND KIND MOD.
8 MST D M W
9 CONSIST. dry moist wet plast.
10 LABORATORY SAMPLE NUMBER No. 1 No. 2

1 HORIZON DESIG.
11 COLOUR 1 aspect; COLOUR 2 aspect
12 MOTTLES AB F C M; SI F M C; CO F D P; aspect; COLOUR; BOUND. DIS S C D
13 ROOTS 1 Ab. V F P A; Size V F M C; Ori. V H O R; Dist IN EX MX; ROOTS 2 Ab. V F P A; Size V F M C; Ori. V H O R; Dist IN EX MX
14 HORIZON NOTES

Figure 2. Excerpt from the soil description form for pedons.



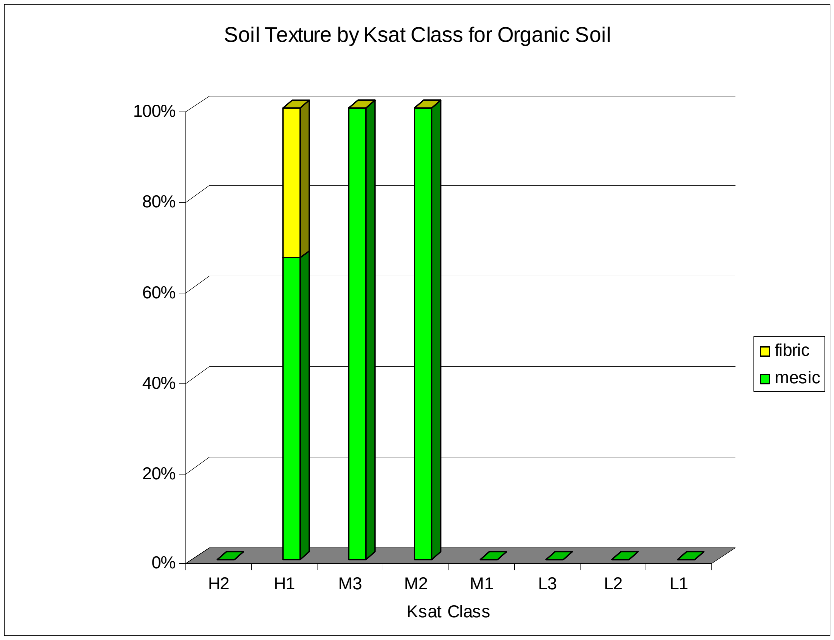
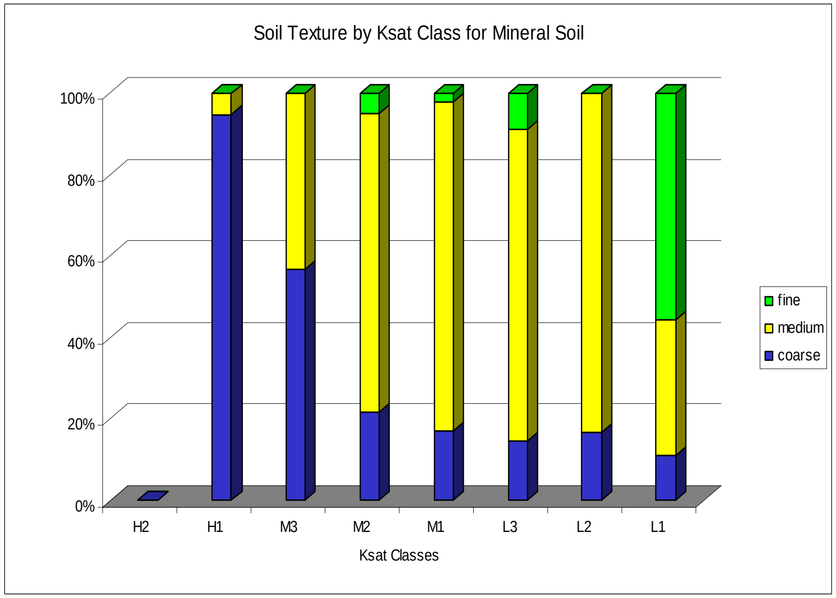


Figure 3. Soil texture by K_{sat} classes for the soil core samples.



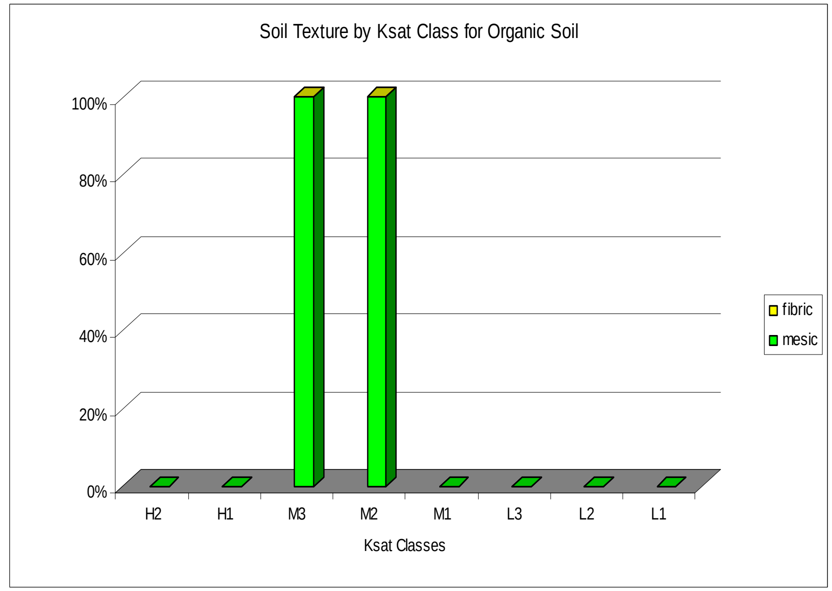


Figure 4. Soil texture by K_{sat} classes for the soil Guelph Permeameter samples.

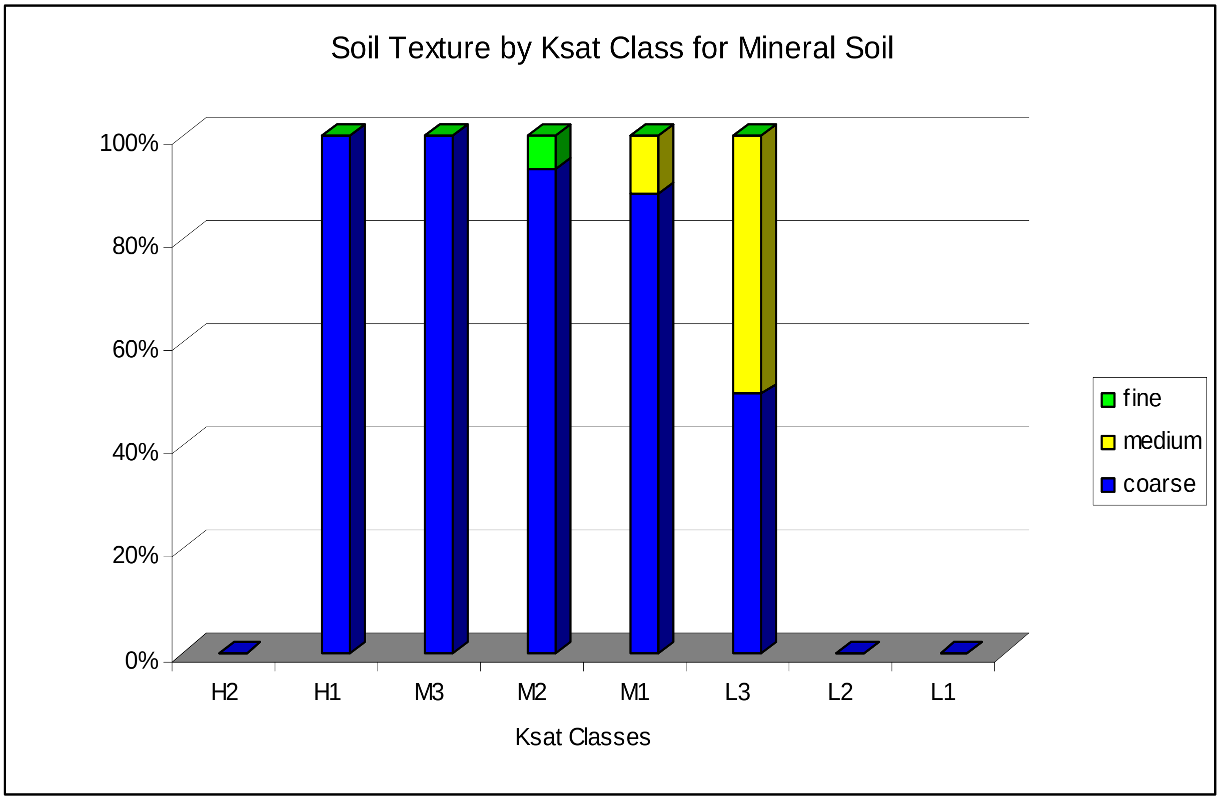
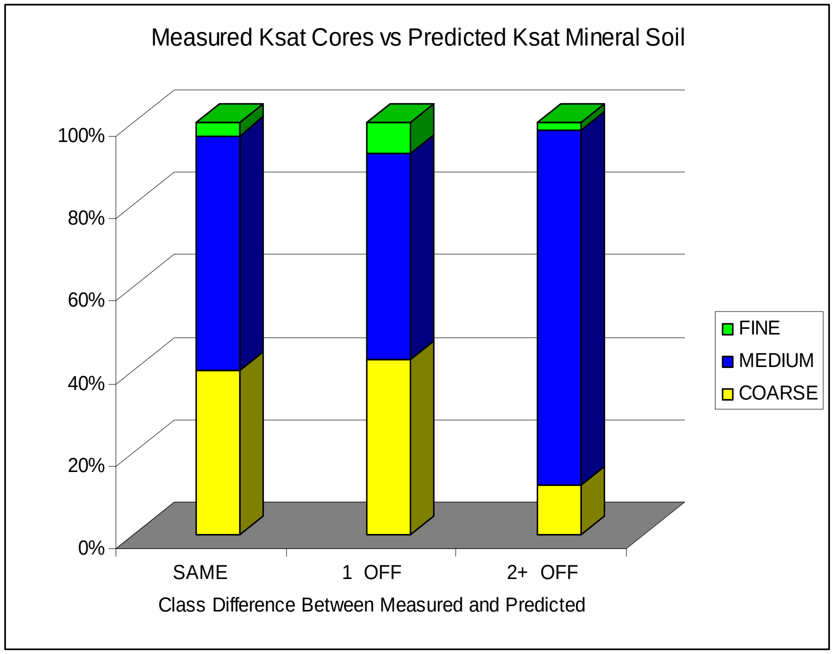


Figure 5. Soil texture by K_{sat} classes for Guelph Permeameter data.



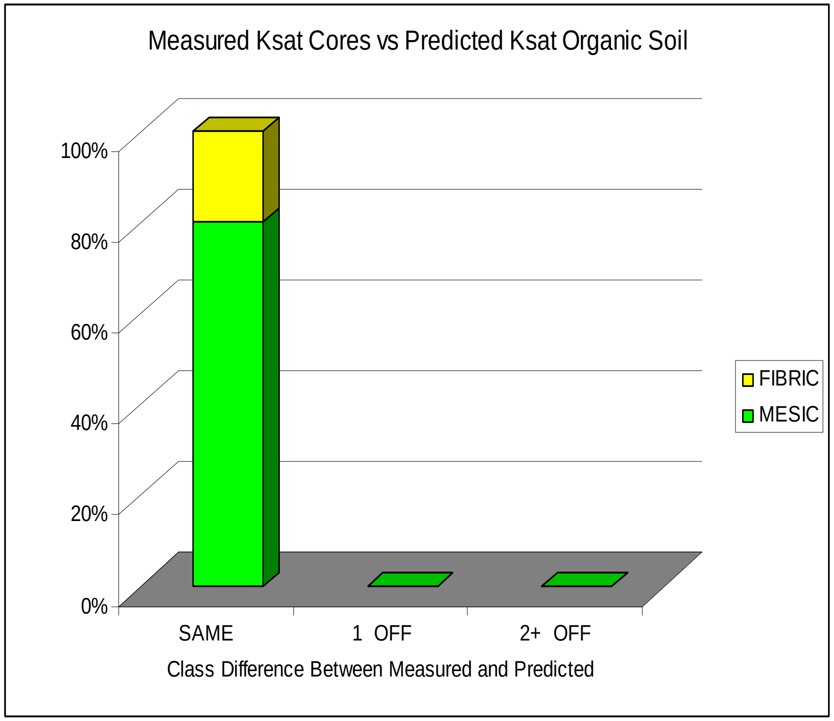
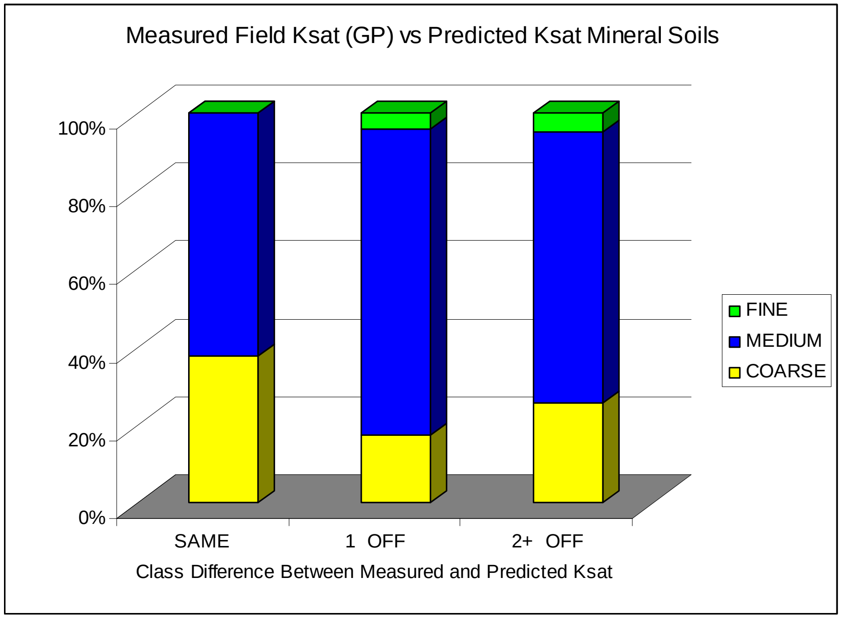


Figure 6. Measured K_{sat} (Core Samples) vs Predicted K_{sat}.



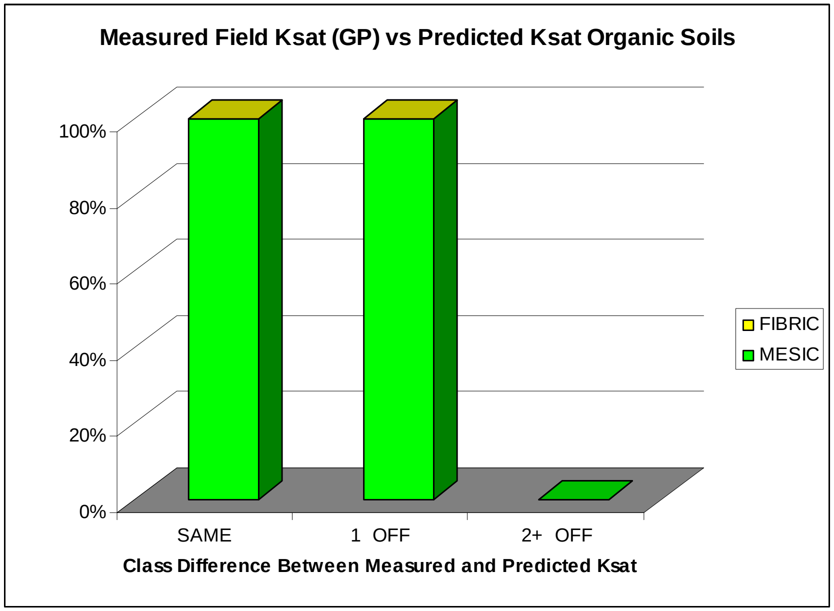


Figure 7. Measured Field K_{sat} (Guelph Permeameter (GP)) vs Predicted K_{sat}.