



Relationships between Extraction Methods for Soil Nutrient Testing in British Columbia

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Objectives

The objectives of the project were to:

1. determine relationships between soil test phosphorus and potassium extraction methods with particular attention to the potential differences for contrasting soil characteristics such as in the Lower Fraser and Okanagan-Similkameen Valleys, and
2. evaluate the suitability of these methods for use as environmental health indicators and for provincial Nutrient Management Planning programs.

Background

Soil testing for crop production was originally developed by public agencies with leadership by the provincial government, which operated a service laboratory, together with the research by federal government Research Centres and universities (Kowalenko 1993). Early work resulted in the adoption of Bray-1 and neutral normal ammonium acetate extractions for phosphorus (P) and potassium (K), respectively (Neufeld 1980). Sodium bicarbonate was used instead of Bray-1 for awhile for P extraction of soils with considerable free carbonate, since carbonate was thought to reduce the acidity of the Bray-1 solution and its ability to extract phosphorus from the soil (Gough and Kowalenko 1993). Phosphorus was measured by colorimetry and potassium by atomic absorption spectrophotometry. With the availability of the multiple element analysis capability of inductively coupled atomic emission spectrophotometry (ICP), a new multiple element extraction (called Kelowna) was adopted by the provincial soil test laboratory to replace the previously used extractions that were developed for single elements (Gough 1991). Initial fertilizer application interpretations were documented for the Bray-1 P and ammonium acetate extractions (Neufeld 1980), and new ones were adopted for the Kelowna-extraction ICP-analysis method (Gough 1991).

After the privatization of the provincial Soil Test Laboratory in April 1988, a diversity of laboratories were being used for soil testing in the province, with many using methods other than Bray-1, ammonium acetate and Kelowna extractions. For example, two modifications of the original Kelowna were used (Qian, Schoenaru and Karamanos 1994, Ashworth and Mrazek 1995), as well as sodium bicarbonate and Mehlich-1 methods, but interpretations for these alternative methods were not documented for British Columbia crop production situations. This has made it complex and confusing for users (farmers, consultants, provincial Nutrient Management Planning advisers) of soil tests when measurements are reported from analyses by a variety of methods.

Soil nutrient surveys conducted in the Lower Fraser Valley (Kowalenko et al. 2007) and Okanagan-Similkameen (Kowalenko et al. 2009) areas compared P and K measurements by extraction with original Kelowna and Mehlich-3 extractions. The soil samples for the Lower Fraser Valley study were collected in 2005, whereas the Okanagan-Similkameen samples were collected in 2007. Samples for both studies were collected similarly, with one set obtained through the summer from pits, another set by probe in the autumn (post-harvest) and another set sampled sequentially from early to late autumn in four fields. Pits were used so that the precise soil taxonomic classification could be determined for each site directly (i.e., not relying

on extrapolation from soil maps), and the sites were distributed to obtain a good representation of the predominant soil types in each area. These samples provide an excellent set for examining relationships between extraction solutions since they represent soils from humid and arid climates, of wide-ranging geological sources and with soil types identified. Further, three sites were sampled in each field to provide a measure of natural variability where management was uniformly applied (i.e., replicates of a field), and included three consistent depths (0-15, 15-30 and 30-60 cm). All these factors facilitate the application of a variety of statistical tests to differentiate random from treatment variability.

Both the Lower Fraser (Kowalenko et al. 2007) and Okanagan-Similkameen (Kowalenko et al. 2009) studies showed that P and K extracted by original Kelowna and Mehlich-3 were highly correlated. However, regression equations within each region differed for the three depths and generally from one area to the other. This shows that some soil characteristics influence the relative extraction of P and K such that different relationships may be necessary for different regions of the province or for depths of sampling.

This report will compare the extraction of P and K by several different solutions that are used by laboratories providing analyses for British Columbia soils with extraction by the Kelowna solution. The extracting solutions include Bray-P1, Mehlich-3, the Ashworth and Mrazek (1995) modification of Kelowna (herein called Kelowna-95), bicarbonate (also called Olsen) and ammonium acetate methods. Bray-P1 (Bray and Kurtz 1945) was used by the provincial soil test laboratory prior to adoption of Kelowna solution (Neufeld 1980, van Lierop 1988, van Lierop and Gough 1989) and is still used by some laboratories. The modification proposed by Ashworth and Mrazek (1995) will be designated "Kelowna-95." This modification was made for application to Canadian prairie soils with a focus to extract more potassium. The Olsen method uses sodium bicarbonate solution and has been and is being used by various laboratories in Canada and elsewhere (Schoenau and O'Halloran 2008). This method will herein be called "bicarbonate" extraction. The Mehlich-3 extraction method (Mehlich 1984) was developed for multiple element extraction for a wide variety of soils and is used extensively in various parts of Canada and U.S.A. (Ziadi and Tran 2008). Ammonium acetate was used for K soil testing in British Columbia (Neufeld 1980) until it was replaced by Kelowna extract solution (van Lierop and Gough 1989) and has been a widely used soil test method (Bates and Richards 1993) and for determining exchangeable K in soil (Hendershot et al. 2008). In order to facilitate the interpretations of the comparisons among the various methods, soil:solution ratios and times of extraction were standardized and concentrations were calculated on an oven dry weight of soil. The extractions were conducted on a weighed rather than a scooped sample, thus the unit of measurement was mg kg^{-1} (or $\mu\text{g g}^{-1}$) rather than $\mu\text{g ml}^{-1}$. For all extracting solutions except bicarbonate, a soil:solution ratio of 1:10 and 5 minute extraction was used. For bicarbonate, the ratio was 1:20 and the extraction time was 30 minutes.

Materials and Methods

The soil samples used for this study were the samples that were obtained via pits for surveys of soils in commercial fields of the Lower Fraser Valley and Okanagan-Similkameen areas in 2005 and 2007, respectively (Kowalenko et al. 2007, 2009). The sites for these surveys were selected to provide a good representation of soils of the dominant geologic origins and soil taxonomic classes in the areas. The use of pits allowed definitive classification of each sampling location. Fields having a variety of different crop types were included but the primary focus was to obtain samples that represent a range of geological and soil types (Table 1). Three pits were dug in each field to provide a degree of replication and the samples were obtained at 0-15, 15-30 and 30-60 cm depths from the face of the pit using a standard volume sampler. Samples from several locations in the pit were combined into one to provide a representative sample. Samples were taken at each of the three depths from three pits (each pit was considered a replicate for the field) in 110 fields (54 in the Lower Fraser and 56 in the Okanagan-Similkameen Valley areas) for a total of 990 samples when replicates and depths were included. The samples were air dried and sieved to less than 2 mm after crushing aggregates with a wooden rolling pin. Particles greater than 2 mm (pebbles and stones) were discarded.

Each sample was extracted with six soil test solutions with the following chemical compositions:

- Kelowna 0.015 M ammonium fluoride (NH_4F) + 0.25 M acetic acid (CH_3COOH)
- Bray-1 0.03 M NH_4F + 0.025M hydrochloric acid (HCl)
- Mehlich-3 0.015 M NH_4F + 0.2 M CH_3COOH + 0.013 M nitric acid (HNO_3) + 0.25 M ammonium nitrate ((NH_4NO_3)) + 0.001 M ethylenediaminetetraacetic acid (EDTA)
- Kelowna-95 0.015 M ammonium fluoride (NH_4F) + 0.5 M acetic acid (CH_3COOH) + 1.0 M ammonium acetate ($\text{CH}_3\text{COONH}_4$)
- ammonium acetate 1.0 M ammonium acetate ($\text{CH}_3\text{COONH}_4$) at pH 7.0
- bicarbonate (Olsen) 0.5 M sodium bicarbonate (NaHCO_3) at pH 8.5

Four grams (g) of air dried soil was extracted with 40 mL of the above solutions (1:10 soil-weight:solution-volume), except bicarbonate, for 5 minutes before filtering. In the case of bicarbonate, 2 g was extracted with 40 mL (1:20 soil-weight:solution-volume) for 30 minutes. In all cases, several drops of toluene were added before shaking and again to the solution after filtering to discourage potential microbial activity. The bicarbonate extracts were acidified with concentrated nitric acid prior to ICP analyses to eliminate problems of carbon dioxide gas during the analyses. Appropriate adjustments were made to calculations if volumes were changed. Elements were measured in the filtered solution by ICP with appropriate matrix matching of the standards. A reference soil and occasional duplicate analyses of study samples were included to monitor and evaluate quality of analyses. The concentrations of the elements in the soil samples were calculated to a gram oven-dry weight using water contents determined on separate air dry samples.

Since the samples in this study were “replicated” (three pits were sampled in each field), analysis of variance was applied to examine area or pH and depth of sampling effects including

the interaction of the factors. The pH selected for the distinction of two groups was 7.2. This value was previously used to determine the type of solution (Bray-1 for soils less than that value and bicarbonate for those that were greater) that would be selected for different soils. These two solutions were apparently used by the provincial laboratory up to 1983 (van Lierop 1988). The pH value was selected on the basis of the potential for the presence of free carbonates. Standard regression analyses were used to examine the relationships between the amounts of elements extracted by the different soil test solutions. Graphs of the regressions were also examined to determine if there were adequate distributions of the data for the regressions and if there were any evident departures from linearity. The study considered the Kelowna soil test solution to be the standard for use in British Columbia due to its development and use in the province. The focus of the examination of the relationships among the different extracting solutions was relative to Kelowna solution.

Results and Discussion

Comparison of soil test values in Lower Fraser Valley and Okanagan-Similkameen areas

Analysis of variance showed that the mean amounts of phosphorus and potassium were different in the two areas of the province where the samples were obtained, with the Lower Fraser Valley having more phosphorus and less potassium than the Okanagan-Similkameen area (Table 2). There was, however, overlap of the contents and they differed with depth of sampling. There was generally more phosphorus extracted from samples in the surface two depths of the Lower Fraser Valley than the Okanagan-Similkameen areas, but similar contents in the 30-60 cm depth. The amount of potassium extracted was generally greater in all the depths in the Okanagan-Similkameen than in the Lower Fraser Valley.

Mean values differed between the Lower Fraser Valley and Okanagan-Similkameen areas for a range of soil test measurements with pH, manganese, silicon and zinc differing with depth (area x depth interaction, Table 2). There were also differences of aluminum, iron, copper, calcium, magnesium and sulphur extracted from samples from the two areas. However, the differences were largely independent of depth (no area x depth interaction). The mean amounts of sodium extracted in the two areas were similar, with generally an increasing amount as sampling depth increased. In general, nutrients and associated elements extracted from the two areas differed. However, there was sufficient overlap of the values to show that the values were not distinct in each of the areas.

Phosphorus

The median amount of phosphorus extracted by the different soil test solutions examined in the study differed in both of the areas and for soils with pH greater and less than 7.2 (Table 3). Kelowna-95 and bicarbonate extracted somewhat similar amounts of phosphorus as Kelowna, whereas Bray-1 and Mehlich-3 solutions tended to extract more. Ammonium acetate solution and water extracted similar amounts of phosphorus but substantially less than Kelowna solution with little differences between areas and pH groupings.

Regression analyses show that the relationship between phosphorus extracted with Bray-1 and Kelowna were generally very good when all values were considered or when separated according to pH grouping and area, but the nature of the relationship (shown by the slope) differed according to pH grouping and area (Table 4). Bray-1 extracted more (approximately 25%) phosphorus than Kelowna solution in soils with pH less than 7.2 and in the Lower Fraser

Valley than samples of pH>7.2 and from the Lower Fraser Valley area compared to the Okanagan-Similkameen area. In the Okanagan-Similkameen and for pH>7.2 grouping, Bray-1 and Kelowna extracted similar amounts of phosphorus. Depth of sampling had a smaller influence on the relationship than pH grouping and area.

The relationships of Mehlich-3 and Kelowna-95 extraction values were generally very good, with little influence by distinguishing the samples group according to pH, area or depth (Table 4). Mehlich-3 solution extracted about 25% more phosphorus than the Kelowna solution, whereas Kelowna-95 solution extracted about 25% less than Kelowna solution. The decreased extraction of phosphorus by Kelowna-95 solution compared to the Kelowna solution was interesting since the modification was the addition of 1.0 M ammonium acetate. The reason for the reduced amount of phosphorus extracted from the soil due to the addition of this reagent is not known, but could relate to the increased amount of total salts from the ammonium acetate addition or from increased extraction of other elements (e.g., calcium, magnesium, iron, aluminum, iron) that may have caused phosphorus to re-precipitate during the extraction (Kowalenko 2008).

The general relationship between the amount of phosphorus extracted by bicarbonate and Kelowna solutions was not as good as with the other three solutions, but similar to that found for Bray-1 extractions, pH groupings and area had a decided influence on the relationship (Table 4). There was a much better relationship between the extract solutions for the pH>7.2 grouping and Okanagan-Similkameen area than for the pH<7.2 grouping and the Lower Fraser Valley area. Bicarbonate solution extracted considerably less phosphorus from the pH>7.2 grouping and Okanagan-Similkameen area samples, whereas similar amounts were extracted for pH<7.2 and Lower Fraser Valley samples. The Okanagan-Similkameen area soils tended to have more high than low pH samples (Table 3). Depth of sampling had a moderate effect on the relationship (Table 4).

In most cases, the constants of the relationships between the different solutions were either not significant or were numerically small. This supports the observation that the relationships were quite good, and were linear with the line going close to or through the origin (Figure 1). The larger constants occurred for the relationship of bicarbonate with Kelowna solution values and where the regression coefficient tended to be lower than for the other solutions.

Considerable improvements to the relationships of Bray-1 and bicarbonate with Kelowna extraction solution were accomplished by including various other elements extracted by the use of a stepwise regression. The improvements for Mehlich-3 and Kelowna-95 solutions (Table 4) were small due to the relatively good relationships that occurred without considering the incorporation of other elements extracted. Aluminum was the element that improved the relationships for both Bray-1 and bicarbonate methods. This could be considered as a way to calculate a value equivalent to Kelowna from Bray-1 and bicarbonate values. This could only be done if the analyses on these extracted solutions included multiple element measurements, such as use of sequential or simultaneous ICP instrumentation. Results from regression analyses comparing the extraction of other elements often associated with phosphorus in soils (aluminum, iron, manganese, calcium and magnesium) show considerable variability, and this probably accounts for the differences in the amount of phosphorus extracted from the soil (Table 5). This is consistent with the observations made by Kowalenko (2008) where there were decreases in the amount of phosphorus extracted by various solutions as the time of shaking was increased due to re-precipitation by other elements extracted simultaneously as time progressed.

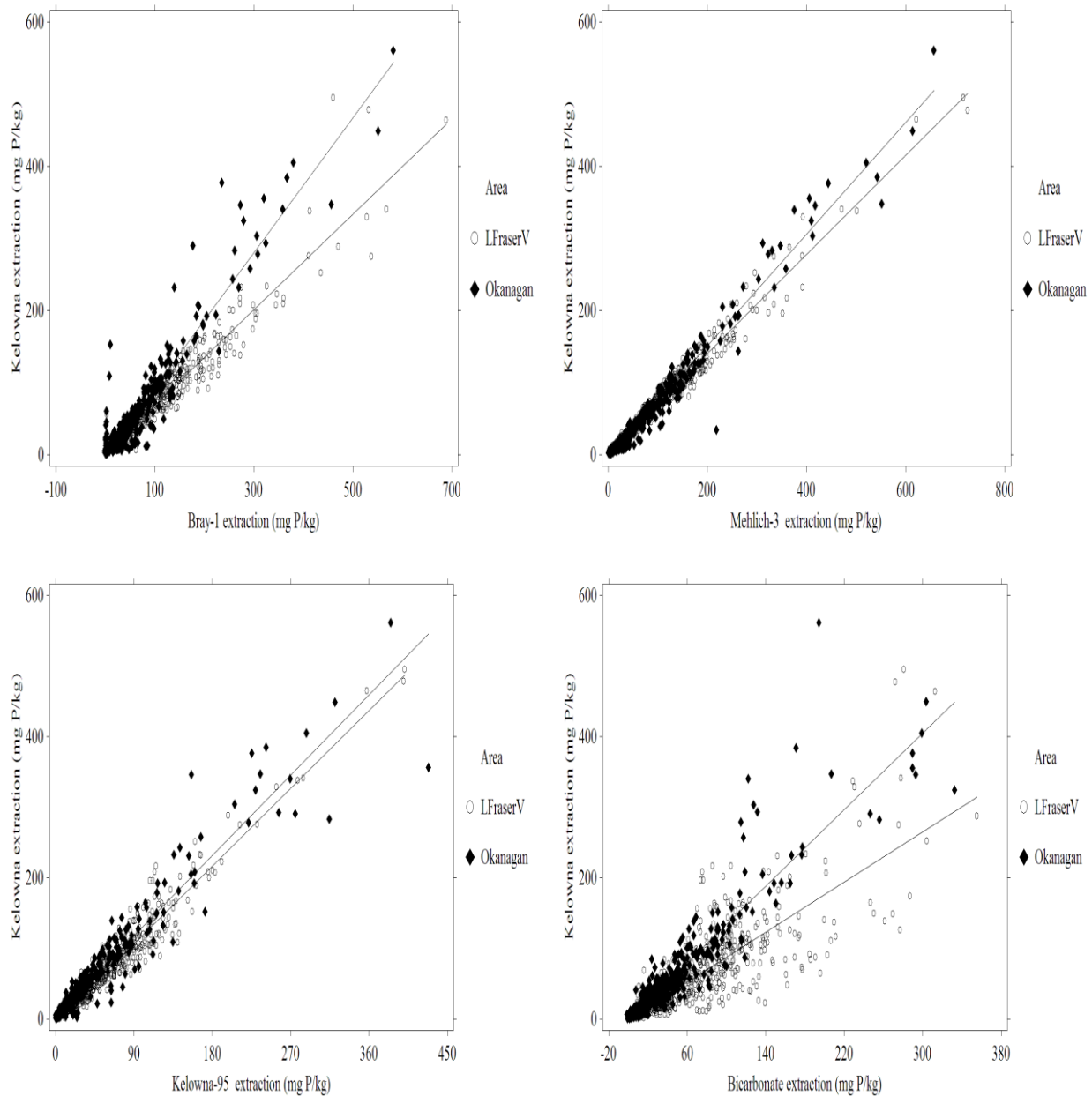


Figure 1. Comparison of extraction of phosphorus by four soil test methods with Kelowna soil test solution from soil samples from Lower Fraser Valley (LFraserV) and Okanagan-Similkameen (Okanagan) areas of British Columbia.

Comparisons of the relationships between the various extractions methods used in this study with other studies are complicated by the difference of methods to quantify the phosphorus in the extracted solutions. This is particularly important where ICP versus colorimetric method measurements were compared, since Kowalenko and Babuin (2007) showed that the colorimetric method is subject to substantial interferences. It appears that van Lierop (1988) had measured phosphorus by ICP in both Kelowna and Bray-1 solutions during the initial development of the Kelowna soil test method, but had used colorimetry for measuring

phosphorus in the bicarbonate solution. The regression relationship that van Lierop (1988) had reported between Bray-1 and Kelowna methods was only given for soils with pH<7 and was:

$$\text{Kelowna} = -5.4 + 0.97 \times \text{Bray-1} \quad (n = 39, r^2 = 0.85).$$

This contrasts somewhat from results in the current study where Bray-1 tended to extract more phosphorus than Kelowna for soils with pH<7.2. The regression relationship was:

$$\text{Kelowna} = 1.69 + 0.73 \times \text{Bray-1} \quad (n = 673, r^2 = 0.92; \text{Table 4}).$$

Van Lierop (1988) had not documented the relationship between Bray-1 and Kelowna methods for soils with pH>7 likely because at that time calcareous soils were extracted with bicarbonate solution. He reported that the relationship between Kelowna and bicarbonate for acid and calcareous soils was:

$$\text{Kelowna} = -4.6 + 2.56 \times \text{bicarbonate} \quad (n = \text{unknown}, r^2 = 0.97).$$

The comparable relationship found in the current study was:

$$\text{Kelowna} = 0.85 + 1.01 \times \text{bicarbonate} \quad (n = 989, r^2 = 0.70).$$

The difference in the results between the two studies may be due to the difference in the measurement of phosphorus in the bicarbonate solutions (ICP versus colorimetry for Kelowna and bicarbonate, respectively). The difference between these results probably was due to interference problems with the colorimetric method and its theoretical measurement of only inorganic phosphorus. Kowalenko (2008) found that bicarbonate extracted more organic phosphorus than other common soil test solutions. Soon (1990) reported that Kelowna solution extracted more phosphorus than bicarbonate solution from Peace River soil samples; however, he used colorimetry for phosphorus quantification in both the solutions. The relationship reported was:

$$\text{Kelowna} = 0.08 + 1.13 \times \text{bicarbonate} \quad (n = 49, r^2 = 0.78).$$

There have been various reports that show comparisons of phosphorus extracted by various methods for locations outside of British Columbia. However, differences in the quantification of phosphorus, especially the use of interference-prone colorimetry, and different types of soils make it difficult to define universal comparative relationships (Ige et al. 2006, Kowalenko 2004). The development of environmental interpretations for soil test extractable phosphorus in British Columbia has utilized the relationship of these tests with the amount of phosphorus that could be removed from the soil during runoff as determined by water extraction and the measurement of the relative binding of applied phosphorus (Kowalenko et al. 2007, 2009, Sharpley et al. 2008). The relationship of water extracted inorganic phosphorus with the five soil test methods were modest (r^2 from 0.274 to 0.450) when data for both areas were considered (Table 6). When the samples were divided according to pH, the relationships for soils of pH>7.2 were substantially improved (r^2 from 0.757 to 0.856) whereas they remained modest for soils of pH<7.2. There were consistently small amounts of inorganic phosphorus extracted by water from soils of pH<7.2, but a wider range from soils of pH>7.2. This indicates that a threshold must be reached before an appreciable amount of phosphorus extracted by the standard soil test solutions can be extracted by water, i.e., the relationship is not linear for soils of a wide pH range. The occurrence of a threshold before phosphorus becomes extractable with water also accounts for the poor relationship of the ability of soils to bind applied phosphorus with the five soil test measurements (Table 7). This shows that the interpretations of the relationships of water extractable inorganic phosphorus and the ability of soils to bind phosphorus with the five soil test methods for environmental considerations cannot be based on a simple linear fit of the data.

It appeared that a number of factors were used to convert from the use of element-specific extract solutions (Bray-1 and bicarbonate) to the multiple-element solution (Kelowna) for British Columbia soil tests for phosphorus beyond simply using regression relationships of the differences in the amount of phosphorus extracted. For example, the recommendations

documented by Neufeld (1980) with the element-specific method showed only one table for phosphorus recommendations with four crop groups. The locations documented in the table were Vancouver Island, Lower Mainland, Okanagan, Kootenay, Kamloops and Williams Lake. The new recommendations when the multiple-element extraction method was adopted (Gough 1991), however, had five crop groups and three different tables depending on regional locations from which the samples were derived. The regions were:

- Vancouver Island, Lower Mainland, Okanagan, Kootenays, Kamloops, Williams Lake, and Quesnel

- McBride, Prince George, Vanderhoof, and Smithers

- Peace River

Reports where soil test analyses were compared with crop response (i.e., correlation or calibration studies under greenhouse and field conditions) showed there were only small difference between different methods (Kelowna, Bray-1, bicarbonate and Mehlich-3) (Soon 1990, van Lierop and Tran 1990, Yee and Broersma 1987). This shows that a variety of soil test extractions can be used equally effectively for making fertilizer recommendations. However, the data to derive the recommendations must be specific for the method selected since the amounts of phosphorus extracted differs between methods (Mallarino 2003).

Potassium

The six solutions in the study extracted variable amounts of potassium in the two areas from which the samples were obtained (Table 8). Kelowna solution tended to extract the least amount of potassium. In general, all of the soil test solutions were related quite well with Kelowna solution (Figure 2), with r^2 almost entirely greater than 0.9 (Table 9). Differences occurred with pH groupings, source of the samples within the province and depth of sampling. However, the degree of the differences were relatively small such that universal (using values from data for all samples) relationships would suffice for practical purposes. Since the relationships were quite close in all cases, the incorporation of other extractable elements in the relationships derived from the stepwise regressions would also not result in large improvements. The close relationships between the various extract types probably reflects the simpler forms of potassium in the soil (inorganic forms in solution, exchangeable, fixed, etc.) compared with phosphorus (organic and inorganic forms of variable solubility, etc.). The differences in the amounts of potassium extracted by the various solutions probably relate to the amount of displacing cations (ammonium, sodium and hydrogen) in the various solutions. Kelowna soil test solution, for example, contains the lowest concentration of ammonium of the five neutral to acidic extract solutions (i.e., Kelowna, ammonium acetate, Mehlich-3, Kelowna-95, Bray-1). The bicarbonate solution contains a substantial amount of sodium, a cation that can displace potassium from exchange sites. Kelowna-95 was modified by the addition of ammonium acetate in order to extract more potassium (Ashworth and Mrazek 1995). "Neutral normal" ammonium has been widely accepted as the standard solution for extracting soluble and exchangeable potassium (Pratt 1965).

Van Lierop and Gough (1989) also found that Kelowna solution extracted less potassium than ammonium acetate and there was little difference in the relationship of the amount of potassium extracted by the two solutions whether they were acidic or calcareous:

Kelowna = $-8 + 0.85 \times \text{amm. acetate}$ for acidic soils ($n = 30$, $r^2 = 0.96$), and

Kelowna = $1 + 0.84 \times \text{amm. acetate}$ for calcareous soils ($n = 30$, $r^2 = 0.96$).

This compares very closely to what was determined in the current study:

Kelowna = $-5.36 + 0.82 \times \text{amm. acetate}$ for all soils ($n = 990$, $r^2 = 0.96$).

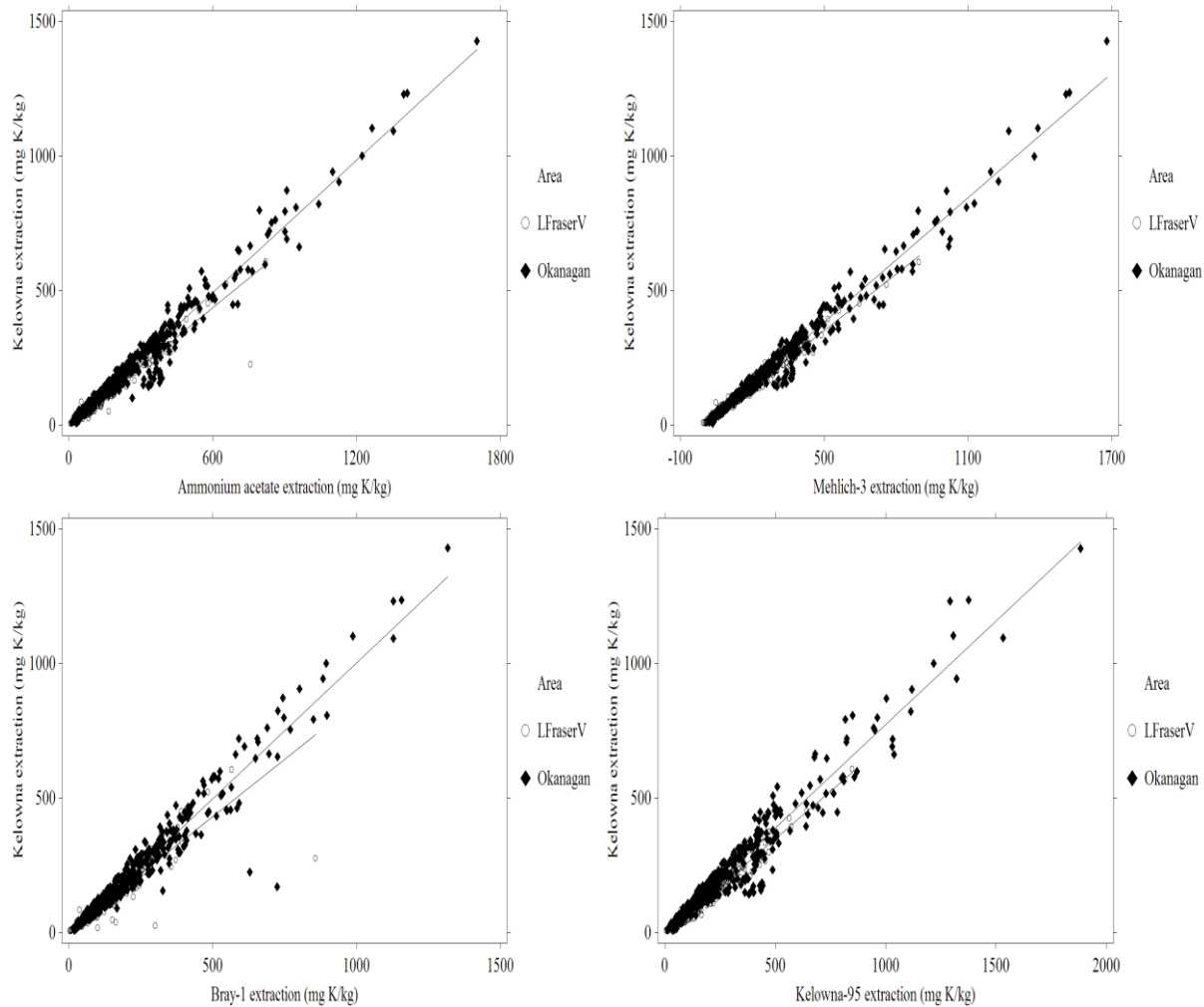


Figure 2. Comparison of extraction of potassium by four soil test methods with Kelowna soil test solution from soil samples from Lower Fraser Valley (LFraserV) and Okanagan-Similkameen (Okanagan) areas of British Columbia.

Similar to phosphorus, the rationale for the conversion from the use of the element-specific extraction of potassium (ammonium acetate) to the use of the multiple-element extraction is not documented and appears to have involved other information beyond the relationship of potassium extracted by the different solutions. The recommendations for the single-element solution (Neufeld 1980) was based on four crop groups with only one table (Table 2) for the area that included Vancouver Island, Lower Mainland, Okanagan, Kootenay, Kamloops and Williams Lake. The number of crop groups for recommendations based on the new multiple-element method was increased to five with tables for three areas of the province. The areas were:

- Vancouver Island and Lower Mainland,
- Okanagan, Kootenays, Kamloops, Williams Lake, and Quesnel
- McBride, Prince George, Vanderhoof, Smithers, and Peace River

This shows that the recommendations that were adopted for the new system varied to account for crop and regional differences in the province. The regional differences would reflect differences in soil types and climatic conditions.

Summary and Conclusions

This study has shown that different soil test solutions extract different quantities of phosphorus and potassium, and that there are general relationships between them but they are variable, especially for phosphorus. Simplified multipliers are proposed to convert the amount extracted by a variety of methods to an equivalent Kelowna extraction measurement (Table 10). Since soil pH appeared to modify the relationship of phosphorus extracted by Bray-1 and bicarbonate, specific factors are proposed for soils that are acidic (pH<7.2) versus those that are calcareous (pH>7.2). Multipliers are also proposed for samples from the Lower Fraser Valley versus Okanagan-Similkameen areas. These multipliers for the two areas largely reflect the dominance of acidic soils in the Lower Fraser Valley and calcareous soils of the Okanagan-Similkameen area. The multipliers were slightly different for the areas than for the pH groupings even though the areas tended to be dominated by acid (Lower Fraser valley) or calcareous (Okanagan-Similkameen) soils. An alternative adjustment to the different multipliers for different pH groups or from different areas of the province for phosphorus is to include aluminum measurements in the Bray-1 or bicarbonate solutions in the conversion equations:

$$\text{Kelowna_P} = 15.43 + 0.77 \times \text{Bray1_P} - 0.02 \times \text{Bray1_Al}, \text{ and}$$

$$\text{Kelowna_P} = 6.60 + 1.11 \times \text{Bicarb_P} - 0.49 \times \text{Bicarb_Al}.$$

Although samples for this study were restricted to only the two areas of British Columbia, the multiplier factors for the two pH groupings or the extended regression equation are proposed for use for soils from throughout the province. The relationships for the other extraction methods for phosphorus, and for potassium for all the solutions were not influenced much by soil pH, source area and depth such that one multiplier is proposed for soils from across the province.

Although these conversion factors are based on a large sample set and the regression coefficients were quite large, the adjusted values need to be considered estimates with a possibility of variation, and should only be considered to be approximations. A better alternative would be to use comparisons of methods that are sample-specific, such as having different analyses on the same sample such as portions of previously analysed (historic) samples. Historic samples would have to be appropriately prepared (air dried, sieved and mixed) before analyses and storage.

Since the various extraction methods provide values that are related to one another and to water extractable inorganic phosphorus (phosphate), it should be possible to develop environmental interpretations similar to those proposed in previous studies for the various extraction methods (Kowalenko 2007, 2009) provided that appropriate adjustments are made to the amount of phosphorus each solution extracts. It is important to remember that phosphorus was determined by ICP in this study, which measures total phosphorus. Caution should be taken when comparing these measurements with ion chromatography and especially with colorimetric analysis, which is prone to interferences (Kowalenko and Babuin 2007). The interferences in the colorimetric method caused values to be less or greater than equivalent ICP measurements. This suggests that colorimetric and ICP measurements could be considered equivalent, but there would be very large variability between the measurements. Ion chromatography will measure inorganic phosphorus, and should not be assumed to be the same as measurements by ICP because of the probability of organic phosphorus in the extract. A similar problem should not occur for potassium since organic potassium compounds do not occur although the element can be closely associated or bound by organic matter. Thus measurements of potassium by various methods (e.g., colorimetric, flame emission spectrophotometry, atomic absorption spectrophotometry, ICP) should be equivalent.

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Tables

Table 1. Characteristics of fields sampled in the Lower Fraser and Okanagan-Similkameen Valleys from pit excavations.				
Area	Region	Geology	Taxonomy	Crop group
Lower Fraser Valley	Delta Cloverdale Matsqui west Matsqui south Matsqui north Hatzic Nicomen Sumas west Sumas Chilliwack Kent	Deltaic Littoral Outwash Eolian-outwash Eolian-glacial till Glaciomarine Lacustrine Floodplain Local stream	Gleysol Brunisol Podzol Luvisol Regosol	Forage grass Forage corn Annual horticultural crops Perennial horticultural crops
Okanagan-Similkameen Valley	Armstrong Vernon Kelowna Summerland Oliver Similkameen	Fluvial Fluvial-Glacial Glacial-Lacustrine Miscellaneous	Brown chernozem Dark brown chernozem Black chernozem Dark grey chernozem Brunisol Luvisol	Apple Cherry Grape Grass, natural grassland, barley Alfalfa-grass mixtures Fallow Miscellaneous crops Mix of crops within sampled field

Table 2. Comparison of phosphorus, potassium extracted with Kelowna soil test solution with pH, and other nutrients extracted with Kelowna solution in samples from fields that represent dominant soil types in Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia.

Element	Area	Depth (cm)				Mean	Median	Minimum	Maximum
		0-15	15-30	30-60					
Phosphorus (mg kg ⁻¹)	LFV	105a^z	69c	19e	64A	43	1	494	
	O.-S.	83b	42d	22e	49B	25	1	561	
	Mean	94A	55B	21C					
Potassium (mg kg ⁻¹)	LFV	129c	94d	57e	93B	66	5	605	
	O.-S.	301a	182b	118cd	200A	139	7	1426	
	Mean	215A	138B	87C					
pH	LFV	5.63e	5.69de	5.80d	5.70B	5.68	4.25	7.73	
	O.-S.	7.12c	7.31b	7.61a	7.35A	7.45	5.00	9.16	
	Mean	6.38C	6.50B	6.70A					
Manganese (mg kg ⁻¹)	LFV	12a	8b	4c	8B	6	0	55	
	O.-S.	12a	8b	7b	9A	7	1	82	
	Mean	12A	8B	6C					
Silicon (mg kg ⁻¹)	LFV	177e	211d	287c	225B	210	27	846	
	O.-S.	335b	378a	363a	359A	355	6	676	
	Mean	256C	295B	325A					
Zinc (mg kg ⁻¹)	LFV	2.24b	1.28cd	0.58de	1.36B	0.91	0.00	12.71	
	O.-S.	6.76a	1.64bc	0.46e	2.95A	0.84	0.07	39.76	
	Mean	4.50A	1.46B	0.52C					
Aluminum (mg kg ⁻¹)	LFV	1029a	1076a	1027a	1044A	1047	192	1877	
	O.-S.	410c	511b	438c	453B	420	16	1114	
	Mean	719B	793A	732B					
Iron (mg kg ⁻¹)	LFV	41b	45ab	55a	47A	18	0	449	
	O.-S.	4d	8cd	17c	9B	0	0	161	
	Mean	22B	26B	36A					
Copper (mg kg ⁻¹)	LFV	0.37b	0.44a	0.44ab	0.42A	0.38	0.00	2.31	
	O.-S.	0.24c	0.27c	0.29c	0.27B	0.22	0.02	4.51	
	Mean	0.30B	0.36A	0.36A					
Calcium (mg kg ⁻¹)	LFV	894b	730b	500b	708B	649	36	3704	
	O.-S.	2304a	2543a	2926a	2591A	1105	78	37499	
	Mean	1599A	1637A	1713A					
Magnesium (mg kg ⁻¹)	LFV	153b	147b	128b	143B	118	1	754	
	O.-S.	286a	273a	308a	289A	200	32	3428	
	Mean	219A	201A	228A					
Sulphur (mg kg ⁻¹)	LFV	19a	17a	16a	18B	11	0	246	
	O.-S.	56a	62a	66a	61A	9	0	4571	
	Mean	37A	39A	42A					
Sodium (mg kg ⁻¹)	LFV	34bc	39abc	57ab	43A	19	0	904	
	O.-S.	32c	48abc	58a	46A	16	0	1610	
	Mean	33B	44AB	58A					

^z Area, depth or area x depth means in bold were different (P<0.05) according to analysis of variance; individual interaction means for each measurement followed by the same lower case letter, or area or depth means followed by the same upper case letter were not different (P<0.00) according to Least Significant Difference test.

Table 3. Median phosphorus and pH values for Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia or for samples of low (<7.2) and high (>7.2) pH.

Depth (cm)	Extract/measurement	Area		pH	
		LFV	O.-S.	<7.2	>7.2
0-15	Kelowna (mg P kg ⁻¹)	83	52	81	38
	Bray-1 (mg P kg ⁻¹)	129	61	111	39
	Mehlich-3 (mg P kg ⁻¹)	120	70	110	54
	Kelowna-95 (mg P kg ⁻¹)	78	39	69	25
	Bicarbonate (mg P kg ⁻¹)	101	46	90	30
	Amm. acetate (mg P kg ⁻¹)	4	7	5	9
	Water (mg PO ₄ -P kg ⁻¹)	4	8	6	7
	Unbound P (%)	12	61	23	61
	pH	5.6	7.2	5.8	7.6
	Number	162	168	242	88
15-30	Kelowna (mg P kg ⁻¹)	62	23	58	16
	Bray-1 (mg P kg ⁻¹)	88	27	74	20
	Mehlich-3 (mg P kg ⁻¹)	83	35	78	26
	Kelowna-95 (mg P kg ⁻¹)	55	15	50	9
	Bicarbonate (mg P kg ⁻¹)	74	18	65	12
	Amm. acetate (mg P kg ⁻¹)	3	2	3	3
	Water (mg PO ₄ -P kg ⁻¹)	3	3	3	2
	Unbound P (%)	10	58	18	55
	pH	5.8	7.5	5.8	7.8
	Number	162	168	226	104
30-60	Kelowna (mg P kg ⁻¹)	14	11	15	8
	Bray-1 (mg P kg ⁻¹)	18	11	21	7
	Mehlich-3 (mg P kg ⁻¹)	19	18	21	14
	Kelowna-95 (mg P kg ⁻¹)	15	7	15	5
	Bicarbonate (mg P kg ⁻¹)	19	9	19	6
	Amm. acetate (mg P kg ⁻¹)	1	2	1	2
	Water (mg PO ₄ -P kg ⁻¹)	1	2	1	1
	Unbound P (%)	9	56	16	53
	pH	5.8	7.8	6.0	8.0
	Number	162	168	205	126

Table 4. Summary of regression equation results of phosphorus extracted by various soil test solutions with phosphorus extracted by Kelowna solution (considered dependent variable) for soil samples in Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia and at three depth increments with comparison of all data with separation into samples of low (<7.2) and high (>7.2) standard soil water pH measurements.

Area	Depth (cm)	Statistic	Bray-1			Mehlich-3			Kelowna-95			Bicarbonate		
			All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2
Both	All	r ²	0.888	0.915	0.791	0.968	0.971	0.952	0.929	0.933	0.894	0.702	0.639	0.941
Both	All	Slope	0.74 ^z	0.73*	1.02*	0.73*	0.72*	0.78*	1.23*	1.23*	1.31*	1.01*	1.00*	1.18*
Both	All	Constant	3.07*	1.69 ^{ns}	-1.15 ^{ns}	-0.78 ^{ns}	0.55 ^{ns}	-4.00*	0.88 ^{ns}	-0.88 ^{ns}	2.59*	0.85 ^{ns}	-1.71 ^{ns}	2.35*
Both	All	n	990	673	318	990	673	318	990	673	318	989	673	317
LFV	All	r ²	0.935	0.934	N.A. ^x	0.973	0.973	N.A.	0.941	0.941	N.A.	0.641	0.640	N.A.
O.-S.	All	r ²	0.917	0.971	N.A.	0.970	0.975	N.A.	0.926	0.931	N.A.	0.862	0.815	N.A.
LFV	All	Slope	0.66*	0.66*	0.66*	0.69*	0.69*	0.72 ^{ns}	1.22 ^{ns}	1.22 ^{ns}	0.98*	0.89*	0.89*	0.84*
O.-S.	All	Slope	0.93	0.92	1.03	0.77	0.77	0.78	1.26	1.24	1.32	1.35	1.50	1.19
LFV	All	Constant	2.75*	2.78*	0.86*	2.64 ^{ns}	2.64*	1.88 ^{ns}	-3.50*	-3.53*	1.87*	-1.38*	-1.36*	-1.70*
O.-S.	All	Constant	0.03	-1.68	-1.43	-3.70	-3.35	-4.08	4.08	6.18	2.56	-1.60	-9.42	2.35
LFV	All	n	486	481	5	486	481	5	486	481	5	486	481	5
O.-S.	All	n	504	192	313	504	192	313	504	192	313	503	192	312
Both	0-15	r ²	0.862	0.900	0.782	0.970	0.968	0.990	0.935	0.946	0.892	0.654	0.580	0.954
Both	15-30	r ²	0.868	0.888	0.722	0.943	0.954	0.852	0.905	0.893	0.898	0.601	0.479	0.925
Both	30-60	r ²	0.867	0.906	0.727	0.949	0.970	0.894	0.899	0.918	0.846	0.702	0.704	0.763
Both	0-15	Slope	0.74*	0.74*	1.08*	0.73*	0.72*	0.82*	1.30*	1.31*	1.40*	1.09*	1.12*	1.18 ^{ns}
Both	15-30	Slope	0.69	0.68	0.94	0.70	0.69	0.69	1.17	1.21	1.08	0.82	0.76	1.12
Both	30-60	Slope	0.86	0.90	0.75	0.78	0.80	0.67	0.90	0.87	1.20	0.91	0.91	1.27
Both	0-15	Constant	5.47 ^{ns}	0.50 ^{ns}	-1.59*	0.21 ^{ns}	1.14 ^{ns}	-5.35*	-1.87*	-5.81 ^{ns}	2.22*	-2.78*	-9.22 ^{ns}	3.49 ^{ns}
Both	15-30	Constant	5.05	5.77	-0.94	0.42	2.34	-1.67	2.39	-0.55	5.80	9.21	13.22	2.57
Both	30-60	Constant	-0.62	-2.73	2.76	-2.47	-2.19	-1.64	4.92	5.34	2.18	1.29	-0.96	1.39
Both	0-15	n	330	242	88	330	242	88	330	242	88	330	242	88
Both	15-30	n	330	226	104	330	226	104	330	226	104	330	226	104
Both	30-60	n	330	205	126	330	205	126	330	205	126	329	205	125
Summary of linear stepwise regressions showing first and second non-forced variable added after phosphorus ^y .														
Both	All	First var.	Al	N.D.	N.D.	Fe	N.D.	N.D.	Al	N.D.	N.D.	Al	N.D.	N.D.
Both	All	r ²	0.913	N.D.	N.D.	0.970	N.D.	N.D.	0.941	N.D.	N.D.	0.752	N.D.	N.D.
Both	All	Sec. var.	Fe	N.D.	N.D.	pH	N.D.	N.D.	Ca	N.D.	N.D.	Fe	N.D.	N.D.
Both	All	r ²	0.917	N.D.	N.D.	0.971	N.D.	N.D.	0.947	N.D.	N.D.	0.786	N.D.	N.D.

^z * shows significance at P>95% and ^{ns} not significant for slopes and constants.

^y The stepwise regression used P as a forced variable and Al, Fe, Ca and Mg in the extraction solution or standard soil pH as unforced variables.

^x N.A. = not applicable due to distribution of data, N.D. = not determined.

^w Equation is P_Kel = 15.43 + 0.77*P_Bray1 - 0.02*Al_Bray1.

^v Equation is P_Kel = 6.60 + 1.11*P_Bicarb - 0.49*Al_Bicarb.

Table 5. Regression coefficients of extraction of various elements in six soil test solutions compared to Kelowna solution for Lower Fraser Valley and Okanagan-Similkameen areas of British Columbia.

Element	Bray-1	Mehlich-3	Kelowna-95	Bicarbonate
		r^2		
Al	0.785	0.942	0.740	0.399
Fe	0.874	0.420	0.149	0.027
Mn	0.165	0.166	0.699	0.186
Ca	0.194	0.914	0.841	0.000
Mg	0.466	0.802	0.786	0.450

Table 6. Relationship of various soil test extractions of phosphorus with water extracted phosphate-phosphorus in all samples in Lower Fraser (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia and samples of low (<7.2) versus high (>7.2) standard soil water pH measurements.

Area	Depth (cm)	Statis-tic ^z	Kelowna			Bray-1			Mehlich-3			Kelowna-95			Bicarbonate		
			All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2
Both	All	r ²	0.447	0.402	0.856	0.289	0.259	0.757	0.406	0.363	0.815	0.450	0.428	0.738	0.274	0.230	0.776
Both	All	Slope	0.12 ^y	0.12*	0.14*	0.08*	0.07*	0.15*	0.09*	0.08*	0.11*	0.15*	0.16*	0.18*	0.11*	0.12*	0.17*
Both	All	Const	-0.32 ^{ns}	-1.15*	0.65*	1.00*	0.35 ^{ns}	0.21 ^{ns}	-0.20 ^{ns}	-0.79 ^{ns}	0.08 ^{ns}	-0.48 ^{ns}	-1.82*	1.10*	0.22 ^{ns}	-0.89 ^{ns}	1.06*
Both	All	n	990	673	318	990	673	318	990	673	318	990	673	318	989	673	317
LFV	All	r ²	0.752	0.753	0.711	0.658	0.657	0.709	0.819	0.819	0.843	0.631	0.631	0.825	0.397	0.395	0.926
O.-S.	All	r ²	0.597	0.526	0.866	0.554	0.471	0.791	0.557	0.479	0.825	0.704	0.690	0.758	0.668	0.712	0.801
LFV	All	Slope	0.06*	0.06*	0.05*	0.04*	0.04*	0.03*	0.05*	0.05*	0.04*	0.07*	0.07*	0.05*	0.05*	0.05*	0.05*
O.-S.	All	Slope	0.18	0.19	0.14	0.17	0.17	0.16	0.14	0.14	0.11	0.26	0.28	0.19	0.28	0.37	0.17
LFV	All	Const	-0.15*	-0.15*	-0.02*	0.16*	0.16*	0.02*	-0.21*	-0.21*	-0.12*	-0.13*	-0.13*	-0.09*	0.15*	0.16*	-0.49*
O.-S.	All	Const	0.07	0.09	0.68	0.02	0.36	0.12	-0.41	-0.04	0.08	-0.24	-1.25	1.10	-1.50	-6.54	1.06
LFV	All	n	486	481	5	486	481	5	486	481	5	486	481	5	486	481	5
O.-S.	All	n	504	192	313	504	192	313	504	192	313	504	192	313	503	192	312
Both	0-15	r ²	0.514	0.474	0.848	0.331	0.325	0.809	0.495	0.433	0.840	0.410	0.392	0.720	0.257	0.197	0.797
Both	15-30	r ²	0.335	0.283	0.818	0.174	0.140	0.576	0.286	0.238	0.693	0.289	0.244	0.698	0.139	0.088	0.682
Both	30-60	r ²	0.752	0.806	0.841	0.530	0.587	0.616	0.659	0.724	0.740	0.850	0.891	0.700	0.572	0.620	0.680
Both	0-15	Slope	0.10*	0.10*	0.14*	0.07*	0.07*	0.16*	0.08*	0.07*	0.11*	0.12*	0.12*	0.19*	0.10*	0.10*	0.16*
Both	15-30	Slope	0.11	0.11	0.14	0.06	0.06	0.13	0.07	0.07	0.10	0.13	0.13	0.15	0.07	0.07	0.15
Both	30-60	Slope	0.37	0.43	0.19	0.29	0.35	0.14	0.29	0.33	0.13	0.38	0.41	0.22	0.36	0.41	0.24
Both	0-15	Const	0.39*	-0.41*	1.06 ^{ns}	2.22 ^{ns}	1.00 ^{ns}	-0.10 ^{ns}	0.45*	-0.37*	0.32 ^{ns}	0.96*	-0.25*	1.57 ^{ns}	1.37 ^{ns}	0.45 ^{ns}	1.60 ^{ns}
Both	15-30	Const	-0.11	-0.89	0.43	1.69	1.54	0.35	0.22	-0.19	0.21	0.29	-0.83	1.31	1.75	1.77	0.97
Both	30-60	Const	-4.39	-6.59	0.16	-3.84	-6.57	0.66	-4.99	-7.10	-0.12	-3.25	-5.09	0.58	-4.22	-7.48	0.33
Both	0-15	n	330	242	88	330	242	88	330	242	88	330	242	88	330	242	88
Both	15-30	n	330	226	104	330	226	104	330	226	104	330	226	104	330	226	104
Both	30-60	n	330	205	126	330	205	126	330	205	126	330	205	126	329	205	125

^z Const = Constant

^y * shows significance at P>95% and ^{ns} not significant for slopes and constants.

Table 7. Relationship of various soil test extractions of phosphorus with proportion of phosphorus not bound by the soil during equilibration with 50 mg PO₄-P kg⁻¹ in all samples in Lower Fraser (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia and samples of low (<7.2) versus high (>7.2) standard soil water pH measurements.

Area	Depth (cm)	Statistic ^z	Kelowna			Bray-1			Mehlich-3			Kelowna-95			Bicarbonate		
			All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2	All	pH <7.2	pH >7.2
Both	All	r ²	0.005	0.042	0.036	0.001	0.009	0.104	0.008	0.049	0.055	0.001	0.012	0.007	0.040	0.009	0.012
Both	All	Slope	0.03 ^y	0.07*	0.08*	-0.01 ^{ns}	0.02*	0.16*	0.03*	0.05*	0.08*	-0.02 ^{ns}	0.05*	0.05 ^{ns}	-0.09 [†]	-0.04*	0.06 ^{ns}
Both	All	Const	34.39*	23.36*	50.01*	36.53*	25.87*	47.44*	33.91*	22.96*	48.90*	36.70*	25.47*	51.53*	41.08*	30.98*	51.36*
Both	All	n	990	673	318	990	673	318	990	673	318	990	673	318	989	673	317
Both	All	-	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear	not linear
LFV	All	r ²	0.056	0.056	0.007	0.034	0.034	0.001	0.091	0.090	0.005	0.014	0.013	0.007	0.003	0.003	0.000
O.-S.	All	r ²	0.050	0.050	0.042	0.074	0.042	0.131	0.055	0.042	0.062	0.034	0.054	0.011	0.030	0.028	0.018
LFV	All	Slope	0.06 ^{ns}	0.06 ^{ns}	0.01 ^{ns}	0.03 [†]	0.03 ^{ns}	0.00 ^{ns}	0.05 ^{ns}	0.05 ^{ns}	0.01 ^{ns}	0.04 ^{ns}	0.04 ^{ns}	0.01 ^{ns}	-0.02*	-0.02*	0.00 ^{ns}
O.-S.	All	Slope	0.06	0.04	0.09	0.07	0.04	0.18	0.05	0.03	0.03	0.07	0.06	0.06	0.07	0.05	0.07
LFV	All	Const	12.31*	12.36*	9.17*	13.15*	13.21*	9.45*	11.44*	11.49*	9.25*	14.05*	14.12*	9.19*	17.14*	17.26*	9.48
O.-S.	All	Const	52.14	54.90	50.61	51.33	55.04	47.63	51.70	55.00	49.49	52.80	54.92	51.99	52.64	55.15	51.75
LFV	All	n	486	481	5	486	481	5	486	481	5	486	481	5	486	481	5
O.-S.	All	n	504	192	313	504	192	313	504	192	313	504	192	313	503	192	312
Both	0-15	r ²	0.001	0.022	0.019	0.012	0.000	0.116	0.002	0.028	0.028	0.009	0.001	0.002	0.094	0.057	0.011
Both	15-30	r ²	0.000	0.044	0.005	0.013	0.003	0.032	0.001	0.057	0.013	0.021	0.004	0.005	0.122	0.003	0.002
Both	30-60	r ²	0.050	0.113	0.099	0.038	0.084	0.183	0.085	0.139	0.165	0.008	0.040	0.020	0.004	0.005	0.012
Both	0-15	Slope	0.01 [†]	0.04 [†]	0.03 [†]	-0.03 [†]	0.00 [†]	0.10 [†]	0.01 [†]	0.03 [†]	0.03 [†]	-0.04 [†]	0.01 ^{ns}	0.01 ^{ns}	-0.12 ^{ns}	-0.10 [†]	0.03 ^{ns}
Both	15-30	Slope	-0.00	0.09	0.04	-0.04	0.02	0.11	0.01	0.08	0.05	-0.09	0.04	-0.04	-0.18	-0.11	-0.03
Both	30-60	Slope	0.20	0.25	0.34	0.16	0.20	0.41	0.21	0.23	0.32	0.07	0.14	0.20	-0.06	0.06	0.17
Both	0-15	Const	37.57 ^{ns}	26.81 ^{ns}	56.50 ^{ns}	41.63 [†]	30.79 ^{ns}	52.67 ^{ns}	37.34 ^{ns}	26.28 ^{ns}	55.84 ^{ns}	41.35*	30.10 ^{ns}	57.97*	49.43*	41.11*	57.08*
Both	15-30	Const	34.61	20.52	50.00	37.51	25.22	47.73	33.56	19.75	49.03	38.41	24.86	51.94	44.59	34.77	51.72
Both	30-60	Const	30.72	19.79	44.65	30.84	19.74	43.03	28.65	18.41	41.96	33.53	22.86	47.72	36.22	24.23	48.25
Both	0-15	n	330	242	88	330	242	88	330	242	88	330	242	88	330	242	88
Both	15-30	n	330	226	104	330	226	104	330	226	104	330	226	104	330	226	104
Both	30-60	n	330	205	126	330	205	126	330	205	126	330	205	126	329	205	125

^z Const = Constant

^y * shows significance at P>95% and ^{ns} not significant for slopes and constants.

Table 8. Median potassium values for Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia or for samples of low (<7.2) and high (>7.2) standard soil water pH measurements.

Depth (cm)	Extract/measurement	Area		pH	
		LFV	O.-S.	<7.2	>7.2
0-15	Kelowna (mg K kg ⁻¹)	105	251	144	255
	Amm. acetate (mg K kg ⁻¹)	140	285	178	281
	Mehlich-3 (mg K kg ⁻¹)	150	309	188	306
	Kelowna-95 (mg K kg ⁻¹)	152	305	192	295
	Bicarbonate (mg K kg ⁻¹)	138	299	165	320
	Bray-1 (mg K kg ⁻¹)	118	245	149	245
	Number	162	168	242	88
15-30	Kelowna (mg K kg ⁻¹)	69	126	87	120
	Amm. acetate (mg K kg ⁻¹)	93	161	115	136
	Mehlich-3 (mg K kg ⁻¹)	92	175	118	153
	Kelowna-95 (mg K kg ⁻¹)	100	168	126	146
	Bicarbonate (mg K kg ⁻¹)	85	170	107	169
	Bray-1 (mg K kg ⁻¹)	74	143	91	134
	Number	162	168	226	104
30-60	Kelowna (mg K kg ⁻¹)	44	91	51	89
	Amm. acetate (mg K kg ⁻¹)	65	104	74	99
	Mehlich-3 (mg K kg ⁻¹)	60	115	65	113
	Kelowna-95 (mg K kg ⁻¹)	72	113	80	113
	Bicarbonate (mg K kg ⁻¹)	56	118	67	112
	Bray-1 (mg K kg ⁻¹)	51	97	60	95
	Number	162	168	205	126

Table 9. Summary of regression equation results of potassium extracted by various soil test solutions with potassium extracted by Kelowna solution (considered dependent variable) for soil samples in Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas of British Columbia and at three depth increments with comparison of all data with separation into samples of low (<7.2) and high (>7.2) standard soil water pH measurements.

Area	Depth (cm)	Statistic ^z	Ammonium acetate			Mehlich-3			Kelowna-95			Bicarbonate			Bray-1		
			All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2	All	pH<7.2	pH>7.2
Both	All	r ²	0.964	0.951	0.980	0.978	0.977	0.983	0.953	0.939	0.965	0.952	0.962	0.951	0.935	0.928	0.939
Both	All	Slope	0.82 ^y	0.77*	0.84*	0.76*	0.72*	0.79*	0.77*	0.74*	0.78*	0.92*	0.85*	0.99*	0.99*	0.95*	1.02*
Both	All	Const	-5.36*	-3.93*	1.75 ^{ns}	-2.80*	1.44 ^{ns}	-3.62 ^{ns}	-5.34*	-6.35*	4.48 ^{ns}	-14.81*	-4.91*	-28.27*	-5.54*	-2.09 ^{ns}	-6.61 ^{ns}
Both	All	n	990	673	318	990	673	318	990	673	318	989	673	317	990	673	318
LFV	All	r ²	0.940	0.940	N.A. ^w	0.981	0.981	N.A.	0.965	0.966	N.A.	0.956	0.956	N.A.	0.849	0.848	N.A.
O.-S.	All	r ²	0.968	0.947	N.A.	0.976	0.968	N.A.	0.948	0.910	N.A.	0.951	0.962	N.A.	0.945	0.962	N.A.
LFV	All	Slope	0.72*	0.73*	0.73 ^{ns}	0.70*	0.70*	0.67 ^{ns}	0.70*	0.70*	0.67 ^{ns}	0.78*	0.78*	0.75 ^{ns}	0.85*	0.85*	1.00 ^{ns}
O.-S.	All	Slope	0.82	0.78	0.84	0.77	0.72	0.80	0.77	0.75	0.78	0.96	0.88	0.99	1.01	0.99	1.02
LFV	All	Const	-0.66*	-0.63*	-3.88 ^{ns}	3.16*	3.17 ^{ns}	3.19 ^{ns}	-3.86*	-3.82*	-6.27*	1.07 ^{ns}	1.15*	-6.36 ^{ns}	5.83*	5.84*	-0.16 ^{ns}
O.-S.	All	Const	0.05	-1.24	2.14	-2.69	1.40	-3.50	2.27	-0.78	4.99	-21.09	-5.91	-28.25	-7.16	-6.77	-6.75
LFV	All	N	486	481	5	486	481	5	486	481	5	486	481	5	486	481	5
O.-S.	All	N	504	192	313	504	192	313	504	192	313	503	192	312	504	192	313
Both	0-15	r ²	0.979	0.974	0.990	0.982	0.981	0.989	0.960	0.949	0.974	0.958	0.964	0.959	0.940	0.909	0.968
Both	15-30	r ²	0.949	0.910	0.983	0.974	0.972	0.981	0.947	0.919	0.969	0.933	0.950	0.927	0.905	0.953	0.867
Both	30-60	r ²	0.906	0.880	0.932	0.946	0.941	0.954	0.913	0.855	0.926	0.924	0.933	0.943	0.933	0.884	0.973
Both	0-15	Slope	0.84*	0.80*	0.85 ^{ns}	0.77*	0.73*	0.80 ^{ns}	0.80*	0.77*	0.80*	0.94 ^{ns}	0.87*	1.04 ^{ns}	1.01*	0.94*	1.08*
Both	15-30	Slope	0.78	0.71	0.82	0.75	0.69	0.78	0.74	0.70	0.75	0.91	0.83	0.98	0.93	0.96	0.92
Both	30-60	Slope	0.77	0.68	0.82	0.74	0.67	0.78	0.69	0.67	0.71	0.92	0.76	1.00	1.00	0.85	1.07
Both	0-15	Const	-7.60*	-6.31*	8.46*	-3.08 ^{ns}	1.36*	2.78*	-7.14*	-7.61*	13.75*	21.84 ^{ns}	-6.79 ^{ns}	-53.96 [†]	-9.52 ^{ns}	1.37 ^{ns}	-24.56 ^{ns}
Both	15-30	Const	-0.55	4.26	4.95	-1.53	4.38	-2.67	-1.01	-0.66	9.79	-13.07	-1.22	-31.69	0.60	-2.62	4.85
Both	30-60	Const	-2.39	1.05	0.72	-0.79	4.33	-3.93	0.72	-1.19	6.91	-11.14	0.49	-17.99	-6.84	1.34	-8.29
Both	0-15	n	330	242	88	330	242	88	330	242	88	330	242	88	330	242	88
Both	15-30	n	330	226	104	330	226	104	330	226	104	330	226	104	330	226	104
Both	30-60	n	330	205	126	330	205	126	330	205	126	329	205	125	330	205	126
Summary of linear stepwise regressions showing first and second non-forced variable added after potassium ^x .																	
Both	All	1 st var	Mg	N.D.	N.D.	Mg	N.D.	N.D.	Mg	N.D.	N.D.	Ca	N.D.	N.D.	Mn	N.D.	N.D.
Both	All	r ²	0.975	N.D.	N.D.	0.982	N.D.	N.D.	0.968	N.D.	N.D.	0.953	N.D.	N.D.	0.944	N.D.	N.D.
Both	All	2 nd var	pH	N.D.	N.D.	Ca	N.D.	N.D.	Al	N.D.	N.D.	Ca	N.D.	N.D.	Al	N.D.	N.D.
Both	All	r ²	0.978	N.D.	N.D.	0.986	N.D.	N.D.	0.973	N.D.	N.D.	0.954	N.D.	N.D.	0.947	N.D.	N.D.

^z Const = constant; var = variable

^y * shows significance at P>95% and ^{ns} not significant for slopes and constants.

^x The stepwise regression used P as a forced variable and Mg, Ca, Mn and Al in the extraction solution or standard soil pH as unforced variables.

^w N.A. = not applicable due to distribution of data, N.D. = not determined.

Table 10. Simplified multiplier factors (re-calculated by forcing the regression through zero, i.e., constant set to zero) for converting phosphorus in various extractants to phosphorus in Kelowna extracts for British Columbia soils based on 990 values from samples collected in the Lower Fraser Valley (LFV) and Okanagan-Similkameen (O.-S.) areas at three depths (0-15, 15-30 and 30-60 cm).

Element	Extractant	General	pH		Area	
			<7.2	>7.2	LFV	O.-S.
Phosphorus	Bray-1	0.76 (0.93) ^z	0.74 (0.96)	1.00 (0.85)	0.68 (0.97)	0.94 (0.94)
	Bicarbonate	1.01 (0.82)	0.99 (0.99)	1.21 (0.96)	0.88 (0.81)	1.34 (0.91)
	Mehlich-3	0.72 (0.98)	---	---	---	---
	Kelowna-95	1.24 (0.96)	---	---	---	---
Potassium	Amm. acetate	0.80 (0.98)	---	---	---	---
	Mehlich-3	0.75 (0.99)	---	---	---	---
	Kelowna-95	0.76 (0.97)	---	---	---	---
	Bicarbonate	0.88 (0.97)	---	---	---	---
	Bray-1	0.97 (0.97)	---	---	---	---

^z Numbers in brackets = r^2 values.