BRIEF OVERVIEW OF SIMILKAMEEN VALLEY SOIL HEALTH ASSESSMENT

By Julia Wagner

The results summarized here are the product of trials of a proposed soil health assessment conducted in the Similkameen Valley, in the Interior Plateau in south central British Columbia, Canada. The majority of farms in this semi-arid valley are tree fruit orchards, but there are also vineyards and ground crops, and a small number of other types of farms. According to Edwards (2002), almost half of all tree fruit production acreage in the Valley (ca.2000 acres), is certified organic ("Orcharding in an arid climate"; EcoFarm&Garden 5(4):28-30, p28).

Trials of the proposed soil health assessment were conducted on 24 benchmark plots on 15 farms between August to October 2004. All of the plots were fruit tree plots except for 2 ground crop plots and 2 tree fruit replant plots (currently in ground crops). Benchmark plots established for the trials in the Similkameen Valley were approximately 1,000m^2 (1/4 acre or 1/10 ha), square or rectangular in shape. Sampling from these benchmark plots in the future should allow producers to monitor change in soil properties over time.

The soil health assessment included on-farm assessments of some physical indicators of soil health and an earthworm count (as a biological indicator of soil health), as well as a standard laboratory analysis of soil chemical properties (0-15cm and 15-30cm soil depths). The laboratory soil analyses were conducted by Griffin Laboratories Inc., a local private soil and tissue testing laboratory company. (See Box for summary of indicators included in soil health assessment.)

As much as possible, the producers themselves were actively involved in the assessment process. Julia Wagner, the research facilitator, provided any necessary tools, participated in the assessments with the producers and ensured that consistent methods were used across farms, and recorded and compiled the results.

INDICATORS INCLUDED IN SIMILKAMEEN VALLEY SOIL HEALTH ASSESSMENT

A) Baseline Assessments

Assess One Time Only: Stable properties, do not change significantly over time

1. Rooting Medium Depth – depth to any restricting layers
2. Depth to Free Lime – soil reaction with drops of hydrochloric acid
3. Coarse Fragment Content – estimated % of rocks in 15cm x 15cm hole to 30cm depth
4. Soil Texture – hand texturing with a key[1]
5. Subsurface soil test (15-30cm) – see lab. soil analysis below

B) On-farm Soil Assessments

Monitor Annually: Dynamic properties, can change with management practices

1. Structure descriptions (Soil tilth) – using a visual assessment key[2]
2. Compaction – Dickey John compaction tester[3]
3. Water Infiltration – producer's observations
4. Earthworm Count – hand counted from 15cm x 15cm hole to 30cm depth

C) Crop Health & Other Vegetation Observations

1. Crop Quality: Size, Colour, Taste and Storage
2. Crop Yield
3. Fruit Tree Vigour
4. Weeds
5. Cover Crops or Green Manure or Orchard Floor Vegetation

D) Laboratory Soil Analysis (Surface 0-15cm)

- pH
- Electrical Conductivity (E.C. – salts)
- Extractable Nutrients: P, K, Mg, Ca, Na, SO4-S
- Micronutrients: B, Zn, Fe, Cu, Mn

E) Other Recommended Assessments

1. Tissue Analysis (Leaf and Fruitlet for tree fruit)
2. Compost Analysis
3. Water Analysis

---

[1], [2] Soil texture and soil structure keys provided by the USDA "Soil Quality Test Kit Guide" (available online: http://soils.usda.gov/sqi/soil_quality/assessment/kit2.html).

[3] Dickey-John soil compaction tester provides a measure of the soil's resistance to penetration in pounds per square inch (psi). Cost: $400 Cdn, from Candian Forestry Equipment (CFE). Most expensive equipment used in assessments, but costs may be minimal when shared among a group of producers and spread over the lifetime of the tester

SOIL HEALTH ASSESSMENT TRIALS
SUMMARY OF RESULTS

In total, Soil Health Assessments were conducted on 24 plots on 15 farms, plus one farm with a soil test only. The complete assessment for each plot included a laboratory soil analysis (0-15 cm and 15-30cm) and a series of on-farm observations and measurements.

Summary of Laboratory Soil Test Results

With 56 soil tests analysed by Griffin Labs, we were able to look for trends and issues that might be common to many growers in the Similkameen Valley. In comparing results, keep in mind that the soil test results for any plot derive from many interacting factors, including the native soil properties and the effects of a diversity of management practices over time.

Summary of results for 0-15cm depth soil tests

	PROPOSED DESIRED RANGE	MEAN (average)	MEDIAN (middle of all results)	MAX	MIN
*Organic Matter	stable or increasing	4.7	4.4	8.7	2.2
*pH	close to pH 7?	7.5	7.6	8.1	6.5
*Salts (E.C.)	< 4 dS/m	2.2	1.4	7.6	0.6
Nitrate NO3-N	N/A	23	16	88	7
*Phosphorus P	GC: 40-100 ug/mL TF: 20-25 ug/mL at planting	236	155	849	15
Potassium K	GC: 160-250 ug/mL TF: 100-160 ug/mL	355	327	732	142
Magnesium Mg	GC: 100-150 ug/mL TF: 50-100 ug/mL	521	513	1051	215
Calcium Ca	N/A	5398	2749	20801	1566
Sodium Na	low relative to Mg & Ca	170	158	346	105
Sulphate SO4-S	26 – 35 ug/mL	220	140	1025	25
Boron B	varies by crop: 0.4-1.0 ug/mL	1.56	1.43	3.82	0.46
Copper Cu	> 0.3 ug/mL	3.39	2.75	9.60	1.70
Iron Fe	?	49.98	21.45	591.1	10.80
Manganese Mn	?	8.19	8.05	16.10	4.80
Zinc Zn	>1.0 ug/mL	27.61	20.10	81.00	1.90

GC= ground crop TF= tree fruit

NOTE: **Bulk density (g/mL)** Your soil test also reports a "bulk density" value. Bulk density is used to convert soil test results in ug/mL to an area or volume basis (e.g. kg/ha) when accuracy in computing soil nutrient contents is required, e.g for research projects. For general farm management purposes, the soil test result is intended to be correlated to crop uptake and response to fertilizer response, and therefore accurate calculation of absolute amounts of available nutrients are not generally required. In other words, in most instances you can ignore this result.

Organic Matter: Given the semi-arid climate, the organic matter levels were in the range expected. Monitoring organic matter levels over time is recommended to ensure levels are staying stable or increasing. Further investigation is proposed *to investigate how organic matter management can be optimized* to maximize internal nutrient cycling and reduce the need for external inputs, as well as to provide important benefits to soil physical properties and water management.

pH: With very few exceptions, soil pH was between 7 and 8: alkaline as expected for the Similkameen Valley. One notable exception: a plot with pH 6.5. Was this the result of the elemental sulfur (S) application made 8 years ago? Is pH increasing or decreasing over time on this farm? *Can growers who have made applications of elemental sulfur (S) tell us about their experience with the value of this practice to nutrient management?*

Salinity: Fortunately soil test results did not indicate any concerns with elevated sodium levels which can be detrimental to soil physical properties and crop health. However, E.C. values high enough to classify soils as *saline* (E.C. >4 dS/m) were found on two plots. Eleven others plots had E.C. values between 2 to 4 dS/m that should be monitored for further increases. To what extent are various management practices contributing to elevated salt levels in soils: irrigation? compost? sulfur applications? Are any crop health effects being observed? *Continued systematic monitoring of E.C. could help identify any threats of developing salinity problems and determine if preventative management practices need to be considered.*

Nutrient Management: Overall, the soil test results generally indicated high to very high values for all nutrients, often exceeding the optimum range. There were only a few individual plot results indicating possible nutrient deficiency (below the optimum level), and these should be further evaluated for need for nutrient additions.

The high values indicate that there is little need for soil application of nutrients. However, high levels also suggest the need for improved nutrient balance. High levels of one nutrient tend to be associated with negative interactions in plant uptake of other nutrients, creating a complex situation for management. This exacerbates the difficulty of nutrient management already created by the high pH conditions of Similkameen Valley soils. *Leaf analysis and visual observations of crop health are recommended to further evaluate how soil test results are manifesting themselves in the crop.*

Of particular concern are the high soil test results for available phosphorus (P) and potassium (K). High available soil P has been associated with problems in plant uptake of other nutrients, including calcium (Ca) and zinc (Zn), copper (Cu), and iron (Fe). This negative interaction is in addition to the already poor availability of the three micronutrients (Zn, Cu and Fe) usually expected high pH soils. High soil K levels are also known to interfere with calcium (Ca) uptake, as well as with magnesium (Mg) uptake. Routine nutrient management for most organic orchardists in the Similkameen Valley currently includes foliar sprays for many of these nutrients (zinc sulphate $ZnSO_4$, Epsom salts $MgSO_4$, calcium chloride $CaCl_2$). Therefore, these soil test results for P and K suggest a need to evaluate nutrient management practices to minimize these negative interactions and potentially reduce the need for inputs.

What is contributing to the high available soil P and K levels? To some extent, these levels may be naturally occurring, characteristic of the inherent soil characteristics of the Similkameen Valley. However, to what extent is the addition of poultry manure composts increasing P and K soil levels and exacerbating any natural soil conditions? Soil P build-up has been observed in farming systems where repeated poultry manure applications have been made based on rates to meet crop nitrogen demands. *Does the value of poultry manure compost additions need to be re-evaluated in light of nutrient balance concerns? What about the use of fish pellets? Investigation of alternative means of meeting crop nitrogen requirements and building organic matter may be useful to improve nutrient management and reduce purchased inputs*.

From snapshot to trends: Because these soil test results provide a limited snapshot view*, on-going monitoring of soil test results, complemented by leaf tissue analysis (and fruitlet analysis, if available), is recommended to enable evaluation of trends* in pH, salinity and nutrient balance.

Summary of On-Farm Assessments

The on-farm assessments provided an opportunity *to systematically record some basic information about the soils on your farm*: the 'baseline' soil properties (texture, depth of restricting layers, coarse fragment content) might better be described as 'inherent' soil properties, characteristics that are not expected to change over time and therefore are only assessed once. When you want to compare soil management with other growers, this basic information can help to determine if you have similar soil types and can expect similar results.

The on-farm assessments also provided an opportunity to make some observations of soil health for *soil properties which are more subject to change as a result of management practices. The results we recorded this year can serve as a benchmark for future evaluations.* Is rotovating changing soil structure? Is compaction increasing in the tree rooting zone with repeated weed cultivation? If you had earthworms at one point, and then you don't see them anymore, what has changed? You can also use these assessments to help evaluate new management practices that you adopt in the future.

Although the greatest value of the on-farm assessments may be in evaluating soil health on the individual farm, *an overview of the results across farms does give some sense of issues possibly requiring further, more systematic investigation*: for example further investigation of the presence of a compacted layer in the tree rooting zone. What is the cause of this compacted layer? Is it recent or historical? Is it related to soil cultivation practices? How is it impinging on crop health? What does it mean in terms of management?

One important beneficial aspect of the on-farm assessments was the *learning opportunity* provided: to test the 'science' in the 'field', to evaluate the usefulness of available techniques for use by you the practitioners, and to identify the need for new or improved approaches, information, and/or support resources. *We need to continue to improve our ability to communicate about soils in common terms, and thereby improve our understanding of soil health and sustainable soil management.*

DID ANY OF THE ON-FARM ASSESSMENTS STAND OUT FOR YOU AS MORE INFORMATIVE OR USEFUL?

Laboratory Soil Test Results

The following sections provide a summary of the results for each main component of the laboratory soil test, including proposed optimum levels, some description of the significance of the results and recommendations where appropriate.

Organic Matter

Organic matter includes living organisms, dead roots and fresh residues, and well-decomposed residues (humus). Organic matter influences soil properties, plant productivity and environmental quality in many ways: it is generally recognized as benefiting agricultural systems in terms of nutrient cycling, water holding capacity, and soil tilth.

Griffin Labs categorizes organic matter as Low (<2.5% organic matter), Medium (3-6%) or High (>6%). However, organic matter levels of native soils vary, and hence some soils will have inherently ('naturally') higher organic matter levels than others: **this means that different soil types should not be compared.**

I recommend two approaches to evaluating soil organic matter levels:

1) compare your organic matter level to a native soil of similar type (texture and topographic position, or named soil series based on soil survey maps/reports)
2) monitor the trends in organic matter levels over time.

Without any systematically collected historical soil test records, it is difficult at this time to interpret the soil organic matter levels. However it is a positive sign that the soil test organic matter levels results are generally within the ranges expected for the Similkameen Valley.

Given the semi-arid climate which makes organic matter build-up difficult, and the many benefits of organic matter, continued efforts to maintain or build organic matter are recommended for all growers. Further investigation into organic matter management practices to optimize nutrient management and water management may be beneficial.

pH

Soil pH is a measure of the hydrogen ion (H+) activity in the soil, and indicates the acidity or alkalinity of the soil. Soil pH is of interest in agricultural systems primarily because of its influence on element availability and toxicity to plants and microorganisms.

Results:

As expected for this region, the soil pH results were relatively high (alkaline, pH 7-8). Results for individual plots are probably most influenced by native soil pH, and by historical additions of elemental sulfur (S). Two of the lower pH values were from modified planting holes where S has been applied every year since 1998. Another plot had a pH of 6.5, low for this region, and further investigation of this low pH is warranted: Is the pH decreasing over time? Have there been any observed effects on crop health? Should management be modified to adapt to changing pH levels?

Interpretation/Recommendations:
Most nutrients are optimally available between pH 6 to 7. As you likely already know from experience growing in the Similkameen Valley, higher pHs reduce the availability of some nutrients to plants, especially micronutrients (boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn)). Phosphorus (P) availability is usually also limited by high soil pH.

Elemental sulfur (S) has been added to some orchard soils in an effort to decrease soil pH. The soil test results suggest that on average the soil pH of these plots is lower than those without S additions. However, with a lack of systematically collected historical soil test records, there is insufficient data to evaluate how effective S additions have been in lowering pH and improving nutrient availability. If efforts are going to be made to lower pH, it would be worthwhile to use soil tests to monitor changes in pH and nutrient availability over time to evaluate the value of such practices.

Salinity and Sodicity Concerns: EC & pH & Na:Ca&Mg

At the field day, we discussed the possibility of soil salinity problems developing in the Similkameen Valley. Soil salinity problems are common in many arid and semi-arid agricultural systems around the world, and are often related to irrigation and/or fertilizer or soil amendment applications.

Soils can be classified as *normal* (low salts and low sodium, pH not high), *saline* (high salts, pH not high), *saline-sodic* (high salts with high sodium levels and high pH) or *sodic* (low salts but high sodium levels and high pH).

Interpretation of Soil Test Results:

- No soils were found to be saline-sodic or sodic (based on an estimated Sodium Absorption Ratio calculation[4]).
- Three plots had E.C. levels that would classify the soils as *saline*: E.C.>4dS/m. These three also have high sulfate-sulfur (SO_4.S) levels: SO_4-S is a negatively charged salt (SO_4^{2-}).
- All other plots would classify as normal. However, there were 11 plots with soils in the 2 to 4 dS/m range – to keep an eye on and see if they are increasing over time.
- E.C. results from two 'native' soils (non-cultivated and non-irrigated) were in the 0.5 to 0.6 dS/m range, much lower than most of the cropped soils.

[4] Sodium Adsorption Ration (SAR) = [Na+] / square root (1/2 ([Mg^{2+}] + [Ca^{2+}])) , where [Na^{+}], [Mg^{2+}] and [Ca^{2+}] are the concentrations of these ions in the soil solution, measured in $mmol_c$/L

Nitrate (NO_3-N)

As Griffin Labs states in its soil test report interpretation leaflet: "The analysis for nitrogen is not a good indicator of the fertilizer required."

The nitrogen measured by Griffin Lab's soil analysis is nitrate-nitrogen (NO_3-N): the inorganic, soluble form of nitrogen most readily taken up by plants. Nitrate levels change significantly throughout the year, and may even change significantly within a few days.

Nitrogen in the soil is categorized into two main forms: organic and inorganic. Nitrogen in the soil is transformed from organic forms to plant-available inorganic forms (ammonium, NH_4^+ and nitrate, NO_3^-) by microorganisms: this is termed *mineralization*. The opposing process is the conversion of inorganic forms (ammonium, NH_4^+ and nitrate, NO_3^-) to organic forms as a result of uptake by microorganisms and roots: this is termed *immobilization*. The result of these two processes is that nitrate levels are not readily measured as an indicator of plant-available nitrogen: **"Since mineralization and immobilization occur simultaneously, plants may have an adequate supply of available N, even though soil tests indicate little N is available at a given instant"** (Foth and Ellis 1997: *Soil Fertility, 2nd Edition*. Lewis Publishers: New York.)

For most crops, there is no reliable soil test to predict fertilizer requirements for nitrogen. However, it has been suggested that a late season nitrate-nitrogen test may serve as a 'report card' for potential environmental risk of leaching into the groundwater. This is particularly a concern on highly irrigated, coarse-textured soils.

Nitrogen management therefore must rely on other approaches than soil test nitrate-nitrogen results. You are probably already using some of these approaches: adapting your nitrogen-containing soil amendment application rates based on observations of crop health. For fruit tree growers[5] this includes observations of vegetative growth versus crop load, annual terminal growth, fruit colouring, and fruit storage quality. Leaf tissue analysis and fruitlet analysis can also contribute to nitrogen management decisions.

Calculations can be made to estimate the amount of nitrogen to apply to your crop to meet (and not exceed) its nutrient requirements. Different estimation calculations have been devised by researchers, but common considerations include: typical annual nitrogen uptake for the crop, expected yields, levels of organic nitrogen in the soil that can be expected to mineralize to plant available forms during the growing season (related to soil organic nitrogen levels and past applications of organic nitrogen sources such as manure or compost), and available nitrogen already in the soil at the beginning of the growing season (i.e. your soil test nitrate nitrogen results). Local research can contribute to the development of more reliable estimation calculations for your soil type and growing conditions.

[5] Refer to the Organic Tree Fruit Management handbook (Edwards, L. 1998: COABC, BC) for more details.

Phosphorus (P)

Optimum Levels:
For ground crops, the optimum range is 40 to 100ug/mL (Griffin Labs rating of M+ to H+). For tree fruit, phosphorus recommendations are only made for new plantings, in which case the optimum range for soil test results is 20-25 ug/mL.

Results:
In high pH soils, phosphorus availability is generally expected to be low. However, the majority of the soil test results were in the high to very high range, particularly for tree fruit. These high results are of concern because:
1) high P may interfere with plant uptake of calcium (Ca), copper (Cu), iron (Fe) and zinc (Zn). This exacerbates difficult nutrient management conditions already created by high soil pH.
2) high P poses an environmental risk of runoff or leaching into groundwater.

Interpretation/Recommendations:
Maximum soil P levels have been published in some places because of concerns of environmental risk. The new BC Environmental Farm Plan process recommends a Nutrient Management Plan when soil test P levels are greater than 80 ug/mL: all but 6 plots exceeded this level.

The high soil test phosphorus levels suggest a need to reconsider the use of phosphorus-containing soil amendments, including poultry manure compost. Application of poultry manure compost to meet crop nitrogen needs may be contributing to a build-up of soil phosphorus.

Leaf analysis (and fruitlet analysis where available) may contribute to evaluation of this potential nutrient management inefficiency.

Calcium (Ca), Magnesium (Mg), and Potassium (K)

Because of the interactions between soil Ca, K and Mg in plant uptake, these three elements should be considered in relation to one another.

Optimum Levels:

	OPTIMUM RANGE (ug/mL)	
CROP TYPE	**Potassium (K)**	**Magnesium (Mg)**
Tree Fruit	100 to 160	51 to100
Ground Crops*	160 to 250	101 to150

*Ground Crops: melons, cucumbers, squash, tomatoes, peppers.

Results:
- All tree fruit plot soil test K results were in the very high range (>190 ug/mL), with two in the high range. One ground crop farm was in the optimum range, while the other was in the very high range.
- All soil test Mg results were very high, beyond the optimum range.

- No recommendations are made for calcium levels, as soil calcium is generally considered adequate as long soil pH is high enough for crop production. Similkameen Valley soils are expected to have high calcium levels, and these were reflected in the soil test results.

Interpretation/Recommendations:
These high soil test Ca, K and Mg results are as expected for the region. Although the soil test results for these three elements are high, your experience probably already tells you that plant uptake of all three is generally not optimum. Tree fruit uptake of magnesium and calcium tends to be problematic: this is generally attributed to a negative interaction caused by high soil potassium levels.

Given these high levels of potassium, and negative interference with plant uptake of magnesium and calcium, this suggests that further potassium additions to your soil are neither necessary nor desirable. As with phosphorus, this suggests a need to re-evaluate the use of potassium-containing soil amendments, including poultry manure compost. Research from Delta indicates that poultry compost provides 13 to 30 kg of available potassium per tonne of compost applied (unpubl., pers. comm. W. Temple).

Leaf analysis (and fruitlet analysis, if available) are recommended to complement the soil test and evaluate the plant uptake of calcium, magnesium and potassium.

Sodium (Na)

See "Salinity-Sodicity Concerns" section for more information.

Sodium levels are evaluated in relation to magnesium and calcium levels: high relative sodium levels are problematic because of disruption of soil physical properties, interference with plant nutrition and increase in soil pH. The soil test results indicate that, at this time, relative sodium levels do not appear to be overly high. Continued application of soil amendments such as manure composts, with potentially high levels of sodium, warrants continued monitoring of soil sodium levels.

Sulfate-Sulfur (SO_4-S)

Optimum Levels:
The optimum range for soil test sulfate-sulfur (SO_4-S) for all crops is 26 to 35 ug/mL (Griffin Labs "High" rating: no immediate response to fertilizer expected).

Results:
Although there was a wide range of results, from 25 to 1025 ug/mL, all but three plots exceeded the optimum. The three plots within the optimum range included one ground crop plot and two tree fruit plots.

The highest result was from a plot currently in ground crops, but previously and in the future to be growing tree fruit. The second highest was from a modified planting hole. Elemental sulfur (S) has been applied to both of these plots.

The soil test results for two native soils were 20 to 31 ug/mL and therefore considered low to optimum.

Interpretation/Recommendations:
- SO_4-S soil test results are difficult to interpret because this nutrient is subject to fluctuations, similar to nitrate-nitrogen (NO_3-N).
- High levels of sulfur are not considered to have any toxic effects, however SO_4-S can contribute to high salts levels and may damage roots. Plots with high SO_4-S levels also have high E.C. results.
- It is also possible for SO_4-S to have a negative effect on plant nitrogen nutrition by competing with nitrate-nitrogen (NO_3-N) for plant uptake.
- There are a number of sulfur containing inputs to tree fruit systems which may be having an influence on the sulfate-sulfur results: foliar sprays (Kumulus, Lime Sulfur, Epsom Salts ($MgSO_4$), zinc sulphate ($ZnSO_4$)), elemental S, irrigation water, and possibly compost.
- The three plots at the bottom of the optimum range can monitor any possible effects on crop health by watching for any visual signs of deficiency and performing leaf tissue analysis, as well as monitoring soil test level trends.

Copper (Cu), Iron (Fe), Manganese (Mn), and Zinc (Zn)

Reviews of Cu, Fe, Mn and Zn status of BC Interior soils and soil test analysis methods for these micronutrients used in BC, conducted by Agriculture and Agri-Food Canada research scientists Dr. Grant Kowalenko and Dr. Gerry Neilsen (1992) and Dr. Denise Neilsen (1992), have indicated that minimal local research has been conducted. Therefore, we generally lack knowledge to reliably interpret Cu, Fe, Mn and Zn soil test results. However, the following interpretations are made to the best of our currently available knowledge.

Optimum Levels:

Micronutrient	Optimum Level (below which fertilizer recommended)
Copper (Cu)	0.3 ug/mL
Iron (Fe)	rarely if ever deficient: deficiency may occur due to imbalances
Manganese (Mn)	rarely deficient
Zinc (Zn)	1.0 ug/mL

Results and Interpretation/Recommendations:

Copper (Cu): All soil test results were well above 0.3 ug/mL, including those for the two native soils. High phosphorus and zinc levels may interfere with plant uptake of Cu.

Iron (Fe): Iron deficiency has been observed in the Similkameen Valley. Iron deficiency in plants tends to be caused by chemical soil conditions rather than low total iron content. Iron deficiency is associated with high pH, low moisture, and low organic matter and removal of surface soil which exposes calcareous subsoils. High phosphorus levels may also negatively influence plant uptake of iron.

Manganese (Mn): Insufficient information to evaluate. High pH and cool spring conditions can cause Mn deficiency. Also plant uptake influenced by negative interaction with iron.

Zinc (Zn): All cultivated soils were above the optimum level. Ground crop soil test results ranged from 1.9 to 3.9 ug/mL and therefore were lower than tree fruit levels of 3.7 to 81 ug/mL (median 20.1 ug/mL). Soil test results for the two native soils were 0.6 to 0.8 ug/mL, below the optimum level.

These high available Zn levels were surprising: according to general principles of soil fertility, soil Zn availability is generally expected to be low in high pH soils. The low available zinc results from the native soil samples suggest that agricultural management practices may be contributing to the build-up of soil Zn levels.

However, despite high available soil Zn levels, plant uptake may be negatively affected by high soil P levels

The need for foliar applications of zinc in tree fruit systems has been questioned by some researchers. These authors have proposed that improved capacity to evaluate orchard zinc status, soil zinc applications at planting time and management of soil conditions (including P levels, organic matter levels and compaction) may minimize the need for foliar sprays. However, further research is needed.

Leaf Analysis: Because of the limited information to evaluate the soil test results for these micronutrients, soil test results are best complemented by monitoring leaf tissue analysis results and watching for visual signs of deficiency or excess.

Boron (B)

The optimum level for soil test born (B) is crop dependent. Five crop groups are recognized in the interpretation of soil test results by Griffin Labs. For crops of importance in the Similkameen Valley, the following are the optimum levels (below which fertilizer recommended) and critical levels at which toxicity becomes a concern:

Optimum Levels:

CROP	OPTIMUM LEVEL	CRITICAL TOXICITY LEVEL
Apples & Pears	1.0 ug/mL	3 ug/mL
Soft tree fruit	0.60 ug/mL	1.0 ug/mL
Onions, Tomatoes, Peppers	0.80 ug/mL	
Squash	0.4 ug/mL	

Results:
For tree fruit plots, 6 soil test results were in the optimum range (0.8 to 1.2 ug/mL) while 13 were considerably higher than the optimum but below the critical level of 3 ug/mL for apples and pears. One plot with apple trees exceeded the critical level of 3 ug/mL and a peach plot exceeded the critical level of 1.0 ug/mL.

Ground crop plots had soil test B levels of 0.46 to 1.28 ug/mL. Because of the different B requirements of different ground crops, results should be checked for the crops intended. For example, all results were adequate for squash but some were deficient for onions, tomatoes and peppers.

Interpretation/Recommendations:
With many soil test results greater than the sufficiency level, soil test and leaf tissue analysis results should be used to monitor trends over time and evaluate need for foliar applications. As well, crop health should be monitored for visual symptoms of deficiency or toxicity.

ON-FARM ASSESSMENTS

The following will summarize the results for each indicator included in the on-farm assessments of soil health. You will notice some blank spots in your records for the on-farm assessments:

- Either we didn't complete this assessment due to time
- Or due to complexity/inadequate expertise to evaluate any further
- Modifications were also made in the process of trialling the proposed assessment, in particular:
  - soil structure (assessed 'type' only)
  - rooting depth (focused on 0-30cm),
  - compaction (fewer # of assessments: focus on tree row, between tree row and wheel track, wheel track, and mid-alley).

A) Baseline Assessments (one-time only, not expected to change significantly over time):

1. **Rooting Zone Depth**: This was not assessed. Instead we focused on the 0-30cm depth as the 'literature based' rooting zone

2. **Rooting Medium Depth:** No true restricting layers were found. Gravelly layers were the main type of 'restricting' layer, which made digging difficult but these do not necessarily restrict root growth. However, such gravelly layers may be important in terms of nutrient availability (less soil in the rooting zone) and water movement in the soil. Some layers of higher clay content were also observed: again these will affect water movement in the soil.

3. **Depth to Free Lime**: The presence of free lime (calcium carbonate, $CaCO_3$) in the surface soil, as indicated by the 'fizzing' of hydrocholoric acid (HCl) in reaction with the soil, indicates that efforts to reduce the pH of the soil will likely require large amounts of acidifying materials. If the acid test identified the presence of free lime, more quantitative analysis to determine the amount of free lime can be conducted if planning soil acidifying amendment applications. Each 1% free lime ($CaCO_3$), requires approximately 13 tonnes/ha (~13000 lbs/acre) elemental sulfur (S) simply to be neutralized, which means even more is required to lower the pH.

   Free lime was identified in all but 5 plots, indicating the high-buffering capacity (resistance to pH change) of the soils in the region and the large amounts of acidifying materials that would likely be necessary to reduce pH. One of the plots without free lime was also the plot with the lowest pH and where S has been applied in the past: this suggests that either the native soil had minimal free lime to neutralize or the S additions were large enough to neutralize any free lime present and pH was effectively lowered.

   If you are concentrating on changing the properties of the rooting zone, free lime at depths below this zone will be less of a concern. Most plots with free lime had free lime at the surface, however in a few plots the depth of free lime was 30cm or greater.

4. **Coarse Fragment Content (c.f.%):** Coarse fragment content – the gravel and small rocks in your soil - influences the water- and nutrient- holding capacity of soil. The higher the coarse fragment content, the less volume of soil your crop roots have to obtain nutrients and water. If you have coarse fragment content of 25% or greater, this should be kept in mind when interpreting soil test values: a low value or a value at the lower end of the optimum range will be of more concern. Coarse fragment content of the plots assessed varied from none to up to 75% of soil volume.

5. **Soil Texture**: Soil texture, the relative amounts of sand, silt and clay in your soil, influences soil fertility and soil water and air relations. The hand-texturing estimation of soil texture indicated higher levels of clay than expected based on soil survey reports. The soil survey in the Similkameen Valley identified medium to coarse-textured soils: loamy sand, sandy loam, silt loam and loam. Our assessments identified textures ranging from coarse-texture to fine-textured: loamy sand, sandy loam, loam, silt loam, sandy clay loam, clay loam, silty clay loam, clay and silty clay.

   This reflects the subjective nature of interpretation of the soil texturing key, and a certain level of experience that may be needed to apply the key reliably. For more accurate determinations of soil texture, a lab analysis is recommended (Cost: $25, Griffin Labs).

6. **Subsurface Soil Test (15-30cm):** Sampling from as much of the crop rooting zone as possible is important for a more complete understanding of the nutrient supplying capacity of the soil. With soil management activities concentrated in the surface 0-15cm soil zone, nutrient deficiencies or toxicities at greater depths are easily overlooked, but could affect crop health.

   The soil test results indicate that soil management activities (e.g. cultivation, soil amendment applications) concentrated in the surface 0-15cm zone have changed the soil chemical properties relative to the less intensively managed 15-30cm zone. However, for management purposes, soil properties are fairly uniform throughout the rooting zone.

B) On-Farm Assessments for on-going monitoring (expected to change over time):

7. **Structure:** Structure is related to the degree of "clumping together" of soil particles which influences soil aeration and water supply. The terms soil tilth and soil structure can probably be used interchangeably.

   The soil structure assessment key allows identification of structure type, size and grade. These three characteristics can then be combined to calculate an index value used to evaluate the quality of the soil structure. However, we focused mainly on the soil structure type, as defining structure at the size and grade level were found to be too difficult without more expertise or a clearer identification key.

   The key we used distinguished among five main types of soil structure type: granular, blocky, platy, single grain and massive (the latter two actually indicating 'no structure').

Almost all soils were identified as being somewhere along the continuum from granular to blocky. This is a good sign, generally indicating 1) good physical soil condition with no extreme compaction that has compressed soil particles and pore space and 2) adequate organic matter to create structure in coarse-textured (sandy) soils.

Soils with blocky soil structure may have some loss of aeration and water movement: look for continuous pores/channels (cracks and burrows) and rooting patterns to further evaluate the effect of structure on these important functions.

Platy soil structure indicates some damage to soil structure: particles have been compressed and water, air and nutrient supply may be affected. Observe crop health for any signs of stress, minimize soil disturbance and promote good structure with organic matter building practices.

8. **Compaction**: In some plots, we had problems with the proper functioning of the Dicky-John compaction tester being used for this assessment, however we were able to use the tester to evaluate relative zones of more or less resistance. The compaction tester could also not be used in rocky soils. Measurements of compaction are affected by soil moisture: some plots were too dry to even use the tester, and in others we made the measurements but the results can be expected to be higher than they would be with better soil moisture.

   The compaction tester measures "penetration resistance" in pounds per square inch (psi): a general guideline is that roots cannot grow in soils with penetration resistance >300 psi. A common trend among all tree fruit plots was a compacted layer (>300 psi or relative evaluation of increased resistance) between 15 to 30cm (6 to 12 inches) in the tree row. Could this be a compacted layer caused by repeated cultivation for weed control and amendment incorporation? Or related to soil disturbance at planting? Or historical compaction that has never been alleviated because all soil management activities have been above this level of compaction. Since this is within the main active rooting zone of tree fruit crops, possible effects on crop health should be considered.

   Further evaluation of this compacted layer may be desirable: digging a hole and using visual observation of any restricting layers, soil structure, root growth patterns. This visual observation is recommended as a substitute for the compaction tester in rocky soils, and as a complement to the compaction tester in all soils.

   The compaction assessments also indicated a highly compacted surface layer (0-3cm) in the wheel track, that often could not even be penetrated by the compaction tester. This is not a concern for crop health for most high-density tree fruit plantings since the roots are not expected to be found in this area, however it should be considered when replanting the orchard. If orchard floor vegetation is not growing well in the wheel track you may also be concerned with maintaining organic matter for future plantings, or with runoff and erosion if water does not infiltrate and you are on a slope. Efforts to reduce traffic and to avoid traffic when soils are wet will help prevent further compaction. Assessment of subsoil compaction prior to replanting provides an opportunity for remediation if there is a problem.

9. **Water Infiltration:** Few problems have been observed with water infiltration: water tends to enter the soil without any ponding. Again, this is a good sign meaning minimal problems with surface compaction and soil structure. Water infiltration is best observed after a heavy rainstorm: keep your eye out after the next one for further observations!

10. **Earthworm Count:** The presence or absence of earthworms should be evaluated in conjunction with your evaluation of other soil health properties such as soil structure/soil tilth. Generally speaking, the presence of earthworms is a positive sign for soil health. The absence of earthworms is more difficult to interpret and does not indicate poor soil health.

    The number of earthworms counted in the 15cm x 15cm hole to a depth of 30cm ranged from 0 to an astounding 47 earthworms.

    No earthworms were found in 3 plots: two were drip irrigated and one was very dry, indicating that soil moisture was an important factor in their absence.

    One plot had no earthworms in the clean cultivated tree row, but earthworms were observed in the lushly vegetated alley root zone. This may reflect the detrimental effects of soil cultivation on earthworm populations, as well as the need for a food source (organic materials such as root exudates) to support earthworms.

    In many cases there was a considerable range in the number of earthworms between the three assessment holes within each plot. This reflects the patchy distribution characteristic of earthworm populations, which can make them difficult to use as an indicator of soil health.

    Why some plots had higher numbers than other plots is difficult to interpret, as many factors influence the presence or absence of earthworms. Soil moisture (irrigation type or how recently irrigated), cultivation, soil temperature (for example, as affected by black plastic mulch), and food sources (litter/organic residue on surface, dead roots and root exudates) would all be expected to influence the presence or absence of earthworms.

    As indicated above, the presence of earthworms in almost all of the plots is a good sign for soil health: earthworms increase soil microbial activity, improve soil chemical fertility and enhance soil physical properties. Their presence supports the evaluations of soil structure and soil compaction as generally being good.

    The average number of earthworms per assessment hole was 3[*]. Literature sources have indicated that 100 earthworms per square meter would be considered good. If we were to estimate the number of equivalent worms in the 15cm x 15cm assessment hole we used, this would equate to 2.25 earthworms per hole. Given this literature value and the average number of earthworms found in the Similkameen Valley plots**, 2 to 3 earthworms per 15cm x 15cm hole is proposed as a benchmark value for your future evaluations**.

---

[*]Average calculated as follows: 1) mean # of earthworms per hole calculated for each plot; 2) median (middle value) of these mean values calculated and reported as average.

C) Crop Health and Other Vegetation Observations

11-13. Crop Quality and Crop Yield: We are lacking observations of these indicators which are best made at the time of harvest. To minimize extra work, is it possible to make use of any readily available data you collect as a part of your normal operations (e.g. information from your packing house about crop quantity and quality)? Recording any observations of crop colour, size, or yield, new shoot extension length for tree fruit, or other crop health indicators (disease, nutrient deficiency or toxicity, etc.) in your Soil Health Assessment record sheets may be useful in helping to interpret soil indicator results, and in monitoring changes over time.

14. **Weeds:** A diversity of weeds was observed on all farms. Many of the weeds are recognized as indicators of fertile soil and many are also commonly related to cultivation. Observing changes in the populations over time may indicate changes in soil properties. Further research could help to more accurately identify the weeds, investigate the relationship between weed populations and soil conditions, and investigate the timing of cultivation to optimize control. The latter relates to soil health in terms of nutrient management (soil fertility) and possibly also organic matter management.

15. **Cover Crop/Orchard Floor:** Lush orchard floor vegetation was observed in the majority of plots, except those drip irrigated or where irrigation problems were noted. Ground cover was also patchy in some wheel tracks, an indication of the effect of compaction on plant growth.

The generally lush growth of weeds and other orchard floor vegetation can be interpreted as an indication of the high soil fertility of the plots. Managing this fertility to the benefit of crop production is the challenge which likely could benefit from further research.

Combining the Laboratory Soil Test and the On-Farm Assessments

There are many interactions between the soil's chemical, physical and biological characteristics and processes. For example earthworms (our biological indicator) can improve soil chemical and physical properties, and at the same time soil physical and chemical properties such as compaction and organic matter (as a food source) can influence the presence or absence of these creatures. Or another example, your on-farm observations of physical properties can be useful in interpreting your soil test: if the chemistry of your soil test results indicate that a nutrient should be highly available, but your crop appears to be deficient – is a physical soil characteristic such as compaction causing the problem?