Learning Series:
Interpreting the CARA Soil Health Lab Report

Introduction

This session aimed to build a foundational understanding of what reports from the CARA Soil Health Lab in Alberta offer, especially the biological insights that go beyond a simple “snapshot” of soil chemistry or structure. Biology reflects the long-term systems at work in a field and helps farmers understand how microbial communities shape soil function and crop outcomes.

Why Soil Health Matters

Soil is a living system filled with billions of organisms. Tens of thousands of species, even in a single teaspoon, form the key to biological resilience. Traditional views of soil focused mainly on sand, silt, and clay, but much of soil is actually living organisms, organic matter, and the pore spaces they create. These pores hold air and water, which microbes and plant roots depend on. All in all, the biological community is built in the rhizosphere.

CARA’s scoring system is based on Cornell’s Comprehensive Assessment of Soil Health, and these documents reveal how the metrics and assessments are derived. It can be found on the Regenerative Organic Hub.

Soil Type

The first major part of the report includes soil type (percentages of sand, silt, and clay, which should total about 100) and sampling depth. If the percentages do not add up to 100% (or very close to 100%), there is an error in the lab report. If compaction was detected, the samples would have been split into two, measuring at 0-3" and 3-6".

Physical Metrics

The physical metrics section includes indicators such as aggregate stability, water infiltration rate, bulk density, and compaction. Each metric shows the measured result, a texture-adjusted score, and (on one page) constraints or (on the next page) management suggestions.

Wet Aggregate Stability
Wet aggregate stability shows how well soil aggregates hold together in water. Higher stability is

better, because when aggregates fall apart, the fine particles wash down and clog pore spaces, which reduces habitats for microbes, airflow and water within the soil; and root growth. 100% wet aggregate stability is the maximum stability that an aggregate can achieve, and the most ideal score. Soil texture also affects ag stability.

Water Infiltration Rate
Water infiltration rates measure how long it takes soil to absorb the equivalent of one inch of rainfall. Effective precipitation is arguably more important than total rainfall, since water that runs off is not doing anything for the crop or the soil food web. Ideally, you want the water to infiltrate as fast as possible; this means that there is plenty of pore space within the soil for the water to enter, thereby maximizing the accessibility for plant roots to access water. A few minutes of infiltrating is also fine, but if the water is taking longer than a few minutes, you need to look at why.

Bulk Density
Bulk density is the mass of soil of a known volume. It quantifies the physical component of soil (primarily the 45% mineral component plus organic matter, which is lighter). If there are more minerals (in a given space), there is less room for air and water/pore space. Therefore, a low bulk density measurement is desired.

Soil Compaction
Penetrometers are very tactile and can help feel changes in soil, such as where compacted layers are located. It is important to consider that using a tool like a penetrometer can be very context-based, and results may differ depending on many factors. For example, soil moisture has a big effect on compaction. If the soil is dry, it is going to be hard. That is why it is important to assess the situation with a holistic approach. If you get an undesirable compaction reading, the first step is to ask why. Do not take one measurement and assume the whole field is compacted. Repeat measurements through the season to see if it is caused by low moisture, seasonal conditions, or an actual compaction layer before deciding on a fix.

When compaction hits 200 psi, plants will need to expend more energy to navigate the soil profile with their roots in order to grow. When compaction hits 300 psi, that is when it gets concerning. Most crop roots cannot push through that, so they start growing sideways at 90 degrees. Another thing to remember: if roots cannot penetrate, they are limited to the soil above the compaction layer. Instead of having access to the whole profile, you only have the top 3-6 inches to work with.

Tillage
For those interested in mechanical loosening of the soil, tillage can be useful, but it is important to understand what it does. Tillage will temporarily fluff up the soil, but it also breaks down aggregates. Eventually the soil settles again. So if you rely on tillage alone, the compaction tends to return.

What works best is pairing tillage (if you choose to use it) with practices that rebuild aggregation. That means planting something right away and adding organic matter. Adding plenty of organic

matter alongside tillage gives soil microbes and roots what they need to rebuild the soil structure. Tillage is a strong tool, but not a standalone solution.

Biological Metrics

The biological metrics section includes organic matter, active carbon, the carbon-to-nitrogen ratio, and microbial respiration. The layout is the same as before: results, scores, and the mean biological health score.

Organic Matter
Organic matter includes anything alive, formerly alive, or a by-product of something that lived. Organic matter is typically carbon-rich, constituted by about 58% carbon. It acts as a sponge, improving water infiltration and water-holding capacity. Nutrients bind to organic matter, which helps prevent leaching. And importantly, organic matter is both the home and food supply for the soil food web.

More organic matter is better. The absolute minimum is often listed as 3%, but in many Prairie systems, it can be higher. That said, if you see extremely high numbers (close to 20%), be cautious. That could be the result of sampling leaf litter, fresh compost, or even peat, rather than the field soil itself. Also remember: organic matter does not change overnight. Management can increase it over time, but it is a slow-moving indicator.

Active Carbon
Active carbon (sometimes called POXC) is the carbon that is readily available to microbes. It responds quickly to changes in biological activity, making it a leading indicator. Organic matter is more of a lagging indicator. Both reflect similar processes, just on different timelines.

Carbon-to-Nitrogen Ratio (C:N)
Think of ratios as narrow (low numbers) or wide (high numbers). A narrow ratio means carbon and nitrogen are relatively balanced; a wide ratio means you have a lot more carbon than nitrogen. Why does this matter? For a few reasons: it affects decomposition, nutrient cycling, and whether microbes immobilize or mineralize nitrogen.

A low C:N (narrow) ratio means that microbes break down residue quickly. This is great for nutrient cycling, but it can leave soil bare and vulnerable to erosion and overheating. A high C:N (wide) ratio means that microbes do not have enough nitrogen in the residue itself, so they pull nitrogen from the soil, thereby immobilizing it and making it temporarily unavailable to crops.

Every organism has a C:N ratio; bacteria are narrow (around 5:1), while something like a spruce tree can be around 500:1. The wider the organism's ratio, the more carbon it needs relative to nitrogen. Microbes have to get enough carbon to fuel their biological processes, and if there is an excess of nitrogen in the food that they consume, then it is excreted. The microbe poop is then taken up by plants or other microbes in a usable form.

"Total Nitrogen" in the CARA Soil Health Lab report includes nitrogen sources like nitrate and ammonium. "Total Carbon" includes organic and inorganic carbon. "Total Carbon" should always be greater than or equal to "Total Organic Carbon" (often referred to as TOC, or Soil Organic Carbon). A low pH typically means that organic carbon dominates, whereas a pH above 7.2 means that inorganic carbon is dominant. Remember to always flag issues and ask questions, since reports can present incorrect data.

How do you obtain your carbon to nitrogen ratio? Simply divide the value for total carbon by the value for total nitrogen.

Microbial Respiration
Microbial respiration measures how much carbon dioxide is released by the soil, essentially, how much the soil is "breathing." The more CO_2 comes off of the soil, the more microbial activity you can assume is happening beneath the surface. It is a great indicator of biological activity, but there is an important nuance here.

Because bacteria release excess carbon as CO_2 while fungi tend to store their excess carbon in their hyphae, microbial respiration often reflects bacterial activity more than fungal activity. That means a conifer forest, or a perennial field with a strong fungal community, can have an incredibly healthy soil food web while still showing relatively low respiration values. In contrast, a freshly tilled field where bacteria explode in response to disturbance will show high respiration, even if the system is less stable overall.

Chemical Metrics

The chemical metrics section is an overview of the chemical indicators: pH, extractable phosphorus, extractable potassium, and magnesium.

pH
pH is on a logarithmic scale. A shift of one full pH point represents a tenfold change, so these are not small adjustments. pH matters because it influences biology, nutrient availability, and the micro-environment right around the plant roots. Plants and microbes can also modify pH locally through exudates and biological processes, meaning the chemistry at the root surface can differ from the chemistry in the bulk soil.

Extractable Phosphorus
Phosphorus plays major roles in photosynthesis, respiration, energy transfer, cell division, and more. Its importance comes down to energy: plants use phosphorus atoms to release or store energy within molecules. Without adequate phosphorus, those fundamental processes slow down.

Extractable Potassium
Potassium is also essential and is measured as extractable K, which is what is available to the crop. It is easily leached, especially from sandy soils. Potassium influences photosynthesis,

respiration, water regulation, and the opening and closing of leaf stomata. These tiny pores on the underside of a plant's leaves let CO_2 in and water out; managing them properly keeps plants cool and hydrated while still allowing photosynthesis. Without potassium, stomata will malfunction, leading to wilting or reduced growth.

Stomata are on the underside of leaves, right where CO_2 released by soil microbes rises. A living plant canopy can take advantage of this CO_2 "micro-climate", boosting photosynthesis and feeding more carbon to the soil as root exudates. It is a lovely example of how plants and microbes support one another.

Magnesium
Magnesium also matters for enzyme activity, photosynthesis, and general plant health, but its headline role is that it is the central atom in chlorophyll. Without magnesium, you cannot capture sunlight efficiently.

CARA Total Soil Health Score

When everything across the biological, chemical, and physical sections gets combined, you land at an overall soil health score that ranges from 0-100. That wraps up the first major section of the report.

The Soil Food Web Analysis
CARA Labs directly measures the numbers for bacteria, fungi, protozoa, and nematodes within a sample of soil. These are the organisms that drive nutrient cycling, carbon flow, residue decomposition, and ecosystem functioning.

When interpreting their presence, the key is not "good guys vs. bad guys," but whether the organisms present are the ones best suited to the environment you have built. Agriculture is all about shaping conditions to grow what we need; the soil biology responds accordingly. This section helps decipher whether the life in the soil aligns with the system that you are trying to create.

Fungi-to-Bacteria Ratio
The first indicator here is the fungi-to-bacteria ratio, based on biomass. Fungal cells and bacterial cells are not comparable one-to-one, so biomass gives a more meaningful measurement than simple counts. A high ratio means that there are more fungi populating your soils, whereas a low ratio means that more bacteria are within your soils. Crops prefer a balanced ratio, especially oats who typically prefer a fungi to bacteria ratio of 1:1. Weeds like high amounts of bacteria (close to 0.1). Bacteria eat simple sugars and release nitrates that weeds love, whereas fungi release more complex nutrients.

Fungi stabilize the nutrient pool and can break down more woody material (high lignin). They release ammonium into the soil, which is nitrogen in a form usable by plants.

Average Hyphal Diameter
The fungi considered most beneficial in agricultural soils tend to have wider hyphae, while many of the pathogenic or opportunistic fungi have very narrow hyphae. Hyphal diameter gives us a quick clue about which side of that spectrum your fungal community leans toward.

You will also see actinobacteria included on the chart. They are not fungi; they are filamentous bacteria, but because they look like extremely thin fungal threads under the microscope, they get pulled into this part of the analysis. If actinobacteria dominate the “filamentous” category instead of true fungi, it suggests your soil is not offering the conditions fungi need to thrive. In other words, the ecosystem is skewed toward organisms that tolerate stress, disturbance, or lower-quality habitat.

So when you look at average hyphal diameter, you’re essentially asking:

- Do I have lots of the robust, wide-diameter fungi associated with good soil structure and nutrient cycling?
- Or are things trending toward the narrow-diameter types that signal stress, disease pressure, or other challenges?

Bacterial Biomass
Bacteria are endlessly busy; they eat constantly and reproduce at incredible speed. They play the same fundamental role as fungi at the base of the soil food web: consuming organic matter and holding nutrients within their bodies. While nutrients are tied up inside those bacterial cells, they are not prone to leaching.

Bacteria also produce sticky compounds (i.e., natural glues) that help form soil aggregates and anchor themselves in place so they aren’t flushed away every time water moves through the soil profile. That aggregation is a big part of how they help retain nutrients in the root zone.

Bacteria specialize in breaking down simple materials like sugars, and they tend to release nitrogen in the form of nitrate. Because they multiply so rapidly, they can deliver quick pulses of available nutrients. This is why you often see a dramatic flush of nitrate right after tillage: you stir things up, oxygen floods the system, bacteria explode in number, and their waste products flood the soil with fast-release nitrogen. But there is a catch: “fast food” nitrogen tends to favour weeds, not crops. Weeds are built to take advantage of short-term nutrient surges. So a very bacteria-dominated system can unintentionally give weeds the competitive edge.

The Soil Food Web
Bacteria and fungi make up the first level of the soil food web. Above them are the predators: protozoa and nematodes. Protozoa mostly feed on bacteria, and they come in three main forms:

- Flagellates: tiny swimmers with whip-like tails
- Amoebae: shapeshifting blobs that engulf prey
- Ciliates: organisms covered in fine hairs, moving like fuzzy little ovals through the soil water films

Flagellates and amoebae thrive in aerobic soils. When they are abundant, they are constantly grazing on bacteria, releasing nitrogen in plant-available forms, and keeping the nutrient cycle humming along.

Ciliates, on the other hand, prefer anaerobic or low-oxygen environments. If your sample shows a lot of ciliates, you may be looking at soils that recently experienced compaction, saturation, or flooding. They still mineralize nutrients, but they are feeding on a bacterial community that reflects stress and oxygen limitation rather than healthy, diverse activity.

This is why it is so important to note field conditions at sampling time: Had you just tilled? Was the soil waterlogged? Was it extremely dry? So much of what we see in the microscope is a snapshot of what the soil organisms were dealing with in the days before sampling.

If protozoa are absent entirely, nutrient cycling stalls. The nitrogen locked inside bacterial bodies cannot reach plants until something eats those bacteria and releases it. No predators = no nutrient release.

Moving onto nematodes, AKA the roundworms. Most people only think about the plant-parasitic ones, but nematodes occupy several feeding groups: bacterial feeders, fungal feeders, root feeders, and predators that eat other nematodes. They can be identified by their mouthparts.

For example, plant-parasitic nematodes have a distinctive spear-like stylet. You will see a pointed “needle” they use to puncture plant cells, and a muscular knob behind it that pushes that stylet through the plant tissue. That’s the classic “bad guy” structure.

Other nematodes have mouthparts adapted for scraping fungi or swallowing bacteria. These are beneficial because they are essential for releasing nutrients trapped in microbial biomass, especially fungal tissue. Without nematodes, fungal carbon and nutrients can sit locked away for extremely long periods, potentially centuries. If you want nutrients returned to crops, you need the right balance of microbial predators to make that happen. So the goal is not a nematode-free soil, it is the right mix of nematode feeding groups, and a minimal presence of the plant-parasitic types.