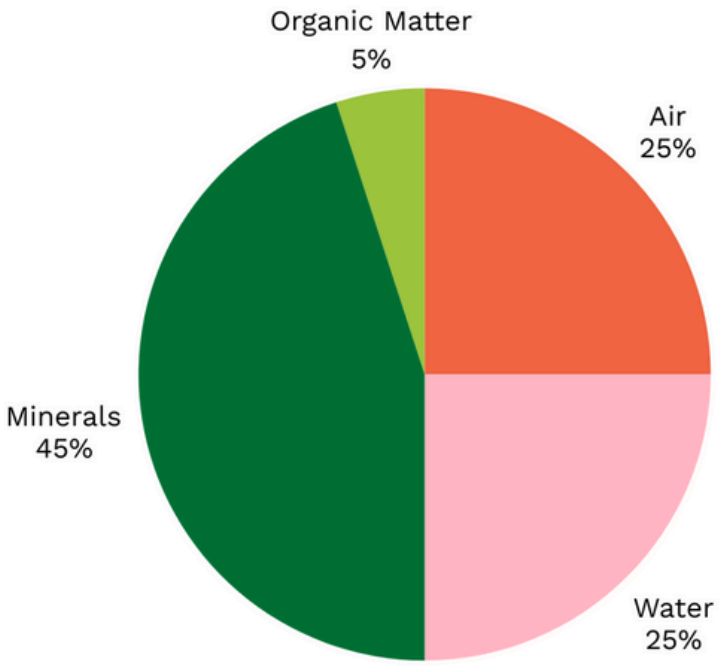
Learning Journey: Soil Compaction

This learning journey is a curated collection of educational resources, designed to help you acquire knowledge and skills on soil compaction.

What is Soil Compaction?

Soil compaction is a measure of the amount of space that exists between the physical parts of the soil. This space is filled by water or air and is where plant roots and the soil food web exist. When soil is acted upon by external forces (for example, when heavy machinery passes over the surface or when aggregates break down after cultivation), the structure that holds the physical parts of the soil in place collapses in on itself eliminating much of the space between the particles and leaving less room for water, air, roots and microbes. The more compact the soil is, the harder it is for the soil food web and our crops to thrive because they literally have less space available to live in!



Did you know that only half (50%) of a healthy soil is minerals and organic matter?! The other half (and arguably the more important half from a biological point of view) is made up of pore space filled with water and air. This is where the soil microbiology lives. It's also where plant roots grow and life abounds!

Soil compaction occurs when the pore space between soil particles is lost as the physical components (mineral and organic) squash tightly together due to the various forces being applied on them (ie heavy machinery moving across a field).

The loss of this space can be imagined to be akin to having a giant stomp on your apartment complex or house. Technically, there may still be some room left for you to shelter in the rubble but the functionality of your home, and your ability to remain a productive member of society has been seriously compromised! Same goes for soil microbes!

If you're interested in assessing soil compaction in your fields there are two monitoring techniques that are readily at your disposal: the penetrometer and bulk density. If you want to address compaction ASAP, put a plant in the ground. Or better yet, plant a diverse cover crop and watch if flourish!

Compaction Assessment

Ecological Process:

- Water Cycle: Soil compaction primarily affects the small water cycle by reducing infiltration rates. This leads to increased surface runoff, erosion, and impacts on water availability for plants and groundwater recharge.
- Nutrient Cycle: Compaction alters soil structure, impacting root growth, microbial activity, and nutrient availability. This affects soil fertility and nutrient cycling processes.
- Community Dynamics: Changes in soil conditions due to compaction can influence plant growth, biodiversity, species composition, and overall ecosystem stability.

Why Perform This Test:
To assess soil compaction levels which impact water infiltration, nutrient availability, and overall ecosystem health.

Tools and Materials:

- Penetrometer
- Field flags
- Measuring tape
- Datasheets
- Clipboard
- Pencil/Pen/Marker
- Phone with geolocation

Selecting Samples:
Identify 10 sub-sampling sites within a 30m x 30m area, avoiding edges and roadways to ensure representative sampling.

Preparing the Penetrometer:

1. Select Penetrometer Tip: Choose the appropriate tip based on soil conditions:
    - Larger Cone (0.798 inches base diameter): Use for softer soils to distribute force effectively and avoid excessive penetration.
    - Smaller Cone (0.505 inches base diameter): Use for compacted or harder soils to penetrate without disturbing the soil structure excessively.
2. When reading the penetrometer - make sure you're reading the appropriate (inner or outer) gauge depending on which tip you are using.

What to Measure:

1. Identify Sampling Points by walking through the sampling area in a zig-zag pattern, randomly stopping at 10 locations (sub-sample sites) within the designated 30m x 30m area.
2. At each sub-sample site:
    a. Measure compaction, noting/recording:
        i. Depth 200 psi was reached.
        ii. Depth 300 psi was reached.
        iii. Whether or not 300 psi was reached within the top 6 inches.
        iv. If the soil is impenetrable, make a note of this on the data sheet. Ideally, you will relocate to a different field or location within that field. If not possible, proceed with observational metrics. You may also consider using alternative tools for sampling (i.e., step in sampler or spade).
    b. Place a flag to mark the sub-sample site.
    c. IMPORTANT: all sub-sample sites in a field should have a compaction of:
        i. < 300 psi by 6" OR > 300 psi by 6". NOT A COMBINATION OF BOTH.
    d. If you encounter an "anomalous" compaction reading, relocate your sub-sample site. Do not mix compaction categories within the same site; if the measurement does not fit the category, move to another location.
    e. Take a picture to geolocate the sub-sample site.

How to Measure:

- Measure Soil Compaction by inserting the penetrometer vertically into the soil at each sampling point.
- Gently apply downward pressure until the tip reaches the desired depth or until maximum resistance (300 psi) is reached.

Post-Field GPS Recording:

- After completing the fieldwork, return to your home or office.
- Use the photographs taken with geolocation enabled to pinpoint the exact locations of each sampling site on a digital map (e.g., Google Maps, GIS software).
- Record these coordinates on the data sheet.
- Enter or confirm the GPS coordinates for each site based on the photographs and any additional notes taken during the fieldwork.

Bulk Density

All About Bulk Density

Bulk density is a measurement of the weight of soil of a known volume. It can help us understand soil compaction and the amount of pore space in the soil.

How to Calculate Bulk Density

Bulk density is measured by taking the oven dried weight of a known volume of soil and dividing it by its volume. The measurement is recorded in grams per centimeter cubed (g/cm^3) or kg/m^3 (if you receive a report in kg/m^3 you can convert to g/cm^3 by dividing by 1000 or moving the decimal 3 places to the left). The higher the value – the more compacted the soil, and the harder it is for roots to penetrate. The following slide is a short table of bulk density values to look for based on soil texture:

Soil Texture	Ideal Bulk Density for Plant Growth	Bulk Density that Affects Plant Growth	Bulk Density That Restricts Plant Growth
Sand, Loamy Sand	<1.60g/cm³	1.63g/cm³	>1.80g/cm³
Sandy Loam, Loam	<1.40g/cm³	1.63g/cm³	>1.80g/cm³
Sandy Clay Loam, Clay Loam	<1.40g/cm³	1.60g/cm³	>1.75g/cm³
Silt, Silt Loam	<1.40g/cm³	1.60g/cm³	>1.75g/cm³
Silt Loam, Silty Clay Loam	<1.40g/cm³	1.55g/cm³	>1.65g/cm³
Sandy Clay, Silty Clay, Clay Loam	<1.10g/cm³	1.49g/cm³	>1.58g/cm³
Clay (<45% clay)	<1.10g/cm³	1.39g/cm³	>1.47g/cm³
Source: USDA			

In an Ideal Situation, What Is the Makeup of Soil?
Ideal soil is roughly half pore spaces (mix of air, available water and unavailable water) and half soil (majority of minerals and organic material). This type of soil has good gas exchange (good aggregate of the soil).

Why Is Bulk Density Important?
It is of vital importance to understand the bulk density of the soil into which you are planting. This will give you an idea of:

- How easily the plants can penetrate the ground
- The soil's ability to hold moisture and soil biology
- Whether or not anaerobic conditions are likely to exist/occur

Calculating Bulk Density at Home

Bulk Density Overview
Soil bulk density is a measure of the mass of soil particles in a known volume of space and can be impacted by a number of factors including compaction, particle size and field management. When you're delineating the area that you're going to sample, make sure that it appears homogenous (i.e. the same throughout). Within a single field, there may be different areas that should be investigated independently (i.e. the tops of knolls vs. two low areas between knolls). When measuring bulk density, we recommend taking a minimum of three separate samples in each area of interest. This will help account for variability.

Measuring Bulk Density with a Penetrometer
Use your penetrometer to determine compaction in your field of interest. When taking readings, ensure you are using the correct gauge (inner or outer) based on the tip you are using.

- Larger cone: best for softer soils to distribute force effectively.
- Smaller cone: best for harder or compacted soils to penetrate without excessive disturbance.

If most readings are less than 300 psi within the first 6″ of soil, collect a single 6″ deep soil sample at each of your three replicate areas within the field. To do this, pound a 2×6″ metal sleeve (or any cylinder with a known volume) into the soil. Ensure the top of the cylinder is flush with the soil surface before carefully excavating it with a trowel. Take care not to lose any soil from within the cylinder, as this could affect your results.

If compaction reaches 300 psi or higher within the first 6″, collect soil in two separate depth increments. Use a 2×3″ sleeve to collect two samples from the same hole: the first at a depth of 0–3″ and the second at 3–6″. If you note a clear change in compaction while using the penetrometer

(e.g. you hit hardpan or suddenly the soil becomes less compact), it is practical to separate samples into “above” and “below” the transition (hardpan) area.

Measuring Bulk Density Without a Penetrometer:
At each site, collect two samples using a 2×3″ sleeve or a 2×6″ sleeve: one from 0–3″ and one from 3–6″, respectively. Make sure to bag each sample separately and label them clearly, including the depth if you collected both 0–3″ and 3–6″ samples, so you know exactly where each sample came from.

How to Calculate Bulk Density at Home

1. Prepare the Samples
    a. Spread each sample out on a piece of cardboard (the bottom of a box without holes or cracks works well) or a cookie sheet. Make sure to include a label with each sample.
2. Drying Environment
    a. Leave the samples to dry in a safe area where they’re unlikely to be knocked over and protected from wind. Let the samples air dry until there is no moisture left. This usually takes a few days.
3. Accelerate Drying (Optional)
    a. If you’re eager to speed up the process, you can place the samples on a cookie sheet in the oven at a low temperature. Just be sure to keep an eye on them!
4. Weigh the Samples
    a. Once dry, weigh each sample as precisely as possible using a kitchen scale or similar device. This will give you the soil weight. Remember to subtract the weight of the container or bag holding the soil from the total weight on the scale.
5. Calculating Bulk Density
    a. Measure Volume: To determine the volume, measure the inside diameter of the metal sleeve used for sampling and measure the height of the sleeve (i.e. 3″ or 6″).
    b. Calculate Volume: Use the formula:(Diameter/2)×3.14×Height
    c. Calculate Bulk Density (BD): Divide the weight of the sample by the volume of the container to calculate the bulk density (BD) of your sample.

Important: Ensure you are consistently using either imperial or metric units, do not mix grams with inches! To avoid confusion and to ensure consistency, it is easiest to use metric units. For example, if you are measuring height, a measurement of 3″ translates to approximately 7.6 cm.

Soil Under Pressure - Taking It Into Your Field

How Could Soil Compaction Be Influencing Your Growing Space?
Soil compaction is the compression of soil particles that reduces pore space in the soil. Soil

compaction decreases the space in which air and water can access the soil, thereby increasing the bulk density of the soil. Reducing the pore space in soil decreases the infiltration of gases and water into the soil, leading to poor water uptake, poor nutrient cycling, increased difficulty for roots to penetrate deeper soil, and an overall reduction in crop yield.

How Does Soil Compaction Affect Crops?

Imagine you are in your living room, and all of a sudden, the walls and ceiling start to close in. The room gets smaller and smaller as the couches, tables, chairs, television, and bookshelves all compress into the decreasing volume of the room. Soon, there is not enough room to move around, and it feels like there is less air around you as your living room gets smaller and smaller. This is how plants and microbes feel when there is too much soil compaction! The soil beneath our feet is susceptible to compaction by vehicles, our own bodies, and the force of rain pounding on the soil surface. The more frequently soil experiences a heavy object or strong force on the surface, the more the soil will begin to compact and close necessary pore space. This limits the amount of water that can infiltrate the soil, the amount of air space within the soil, and the accessibility for roots to navigate within the soil.

How Does Compaction Occur?

Two types of soil compaction can occur:

- Natural
- Human-induced

Natural compaction results from exposure to precipitation, livestock grazing, and gravity pulling soil particles down. Human-induced compaction results from tillage and vehicle traffic. Heavy tractors and machines can create huge compaction with their wheels, and the first pass of a vehicle over a field accounts for up to 80% of soil compaction, compared to the following passes which account for far less.

How Do You Measure Soil Compaction?

One way to measure soil compaction is with a penetrometer. The penetrometer has a pressure gauge at the top, and gradients of measuring soil depth along the rod. You can test soil compaction anywhere you are interested, and it is a simple procedure. Take the penetrometer out to a field of interest, and place it over the ground. The rod should be driven into the ground slowly, and you should watch as the gauge increases the more you press down. Record the depth at which soil compaction reaches 200 and 300 psi. At 200 psi, plant roots start having difficulty penetrating compacted soils. At 300 psi, they make almost no progress whatsoever!

Do this at multiple sites of the field, and compare soil compaction between different fields to see where soil compaction is greatest so that you can assess future management from there. To get a good feel for compaction, take time to check out areas that you'd expect high compaction, like a

driveway or the ground around your bonfire pit. Also, seek out areas with expected low compaction like a tree or fence line.

How To Assess Soil Compaction

Some key features of areas with excessive compaction can be:

- Areas with heavy foot/vehicle traffic
- Exposed soil and lack of vegetation
- Shallow plant roots
- Ponding

How to Decrease Soil Compaction

Soil compaction can be detrimental to crop yields, and it is important to make farm decisions that make sense for you in the context of your world. Here are some things you can do to reduce soil compaction:

- Limit the use of heavy machines and vehicles on wet soil
  - Wet soil compacts easier due to the pore space being occupied by water
- Create tracks in defined areas to limit traffic across the entire field and minimize compaction zones
- Add compost and other organic materials to increase organic matter in the soil
  - This increases microbial interactions that facilitate the building of soil structure
- Plant crops with deep taproots, like alfalfa and brassicas
  - Plants with taproots can penetrate deeper into the ground and take up water from deep, moist, compact soil.

Using a Penetrometer

A penetrometer is a simple yet invaluable tool for anyone looking to monitor and improve soil health. This handheld devise is manually pushed into the soil while a gauge indicates the pressure (in psi) it takes for the shaft of the penetrometer to penetrate into the soil. The more highly compacted a soil is, the greater the force that must be exerted on the penetrometer to push through it. Similarly, the more highly compacted a soil is, the greater the force that a plant root must exert on the soil to push through it. Most plants cannot exert a pressure greater than 300 psi at which point the root growth is stopped or must be diverted in a new direction in order to continue.

In healthy, non-compacted soil you'll be able to easily sink the penetrometer into the soil right up to the handles! In extreme conditions, you won't be able to sink the penetrometer in at all! Once you reach a psi of 300 grab the penetrometer's shaft at ground level before pulling it back up out of the soil. The distance between the point of the penetrometer and your hand is the depth at which you hit compaction. This is the depth at which most pant roots can't descend further.

Other Observations To Make:
Take note when you encounter resistance (and whether or not you're able to punch through it). Historical tillage depths can often be identified by the hardpan layers left in the soil!

The penetrometer can also give you hints about changes in the texture of the soil as you go deeper. Sudden scratchiness felt along the shaft can indicate sand or gravel layers. Abrupt stops can indicate rocks or large debris.

After using the penetrometer, it might be interesting to you to get out a shovel and dig down to see how roots are behaving at the level where you hit 300 psi or to look at the different layers of soil you "felt" through the penetrometer. Getting to know your soils is the first step in helping them meet their health and productivity potential.

Measuring Bulk Density At Home or In the Lab

Looking at bulk density is a great way to take your assessment of soil compaction a step further. A denser soil indicates less pore space while a lower density soil is lighter and more full of pore space.

Bulk density is a straight forward measurement that compares the dry weight of a sample of soil to it's known volume. Many labs offer analysis of bulk density for a fee however this test can easily be accomplished at home with some basic tools and a little bit of math.

To take the sample you simply drive a cylinder (plastic or metal pipe) of known height and (inside) diameter into the soil, remove the soil core (without losing any of course) and then spread it out and let it dry for a few days. Once the soil is completely dry, weigh it!

Bulk density = dry weight / volume

Learn More About Compaction with These Related Resources

- Building Soils for Better Crops: Ecological Management for Healthy Soils (Book)
- Soil Management Guide: Soil Compaction (Article)
- Understanding Soil Compaction (Article)
- Vital KPI's for Regenerative Agriculture Advisors (Article)
- 6 Best Crops for Soil Compaction (Video)
- Managing Compaction in Regenerative Cropping Systems (Video)
- Using a penetrometer to detect soil compaction (Video)
- The Penetrometer: A Simple Tool to Decrease Tillage, Labor and Improve Soil (Article)

Learn More About Bulk Density with These Related Resources

- Bulk density sampling demonstration (Video)
- Bulk Density is an Indicator of Soil Health (Article)

Find Out More. Give Us Your Feedback. Get Involved.

Thank you for participating in this Learning Journey on Canadian Organic Growers' Regenerative Organic Hub. We hope you were inspired and found practical information and tools that will support you on your regenerative organic journey.

We invite you to click below and use our contact form to ask us any questions you may have, or comment on your Hub experience. This form is also the place to let us know if you would like to get involved with COG, including as part of our next cohort of Regenerative Organic Oats (ROO) program participants.