In-field Indicators of Soil Health

A guide for producers in British Columbia

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BRITISH COLUMBIA
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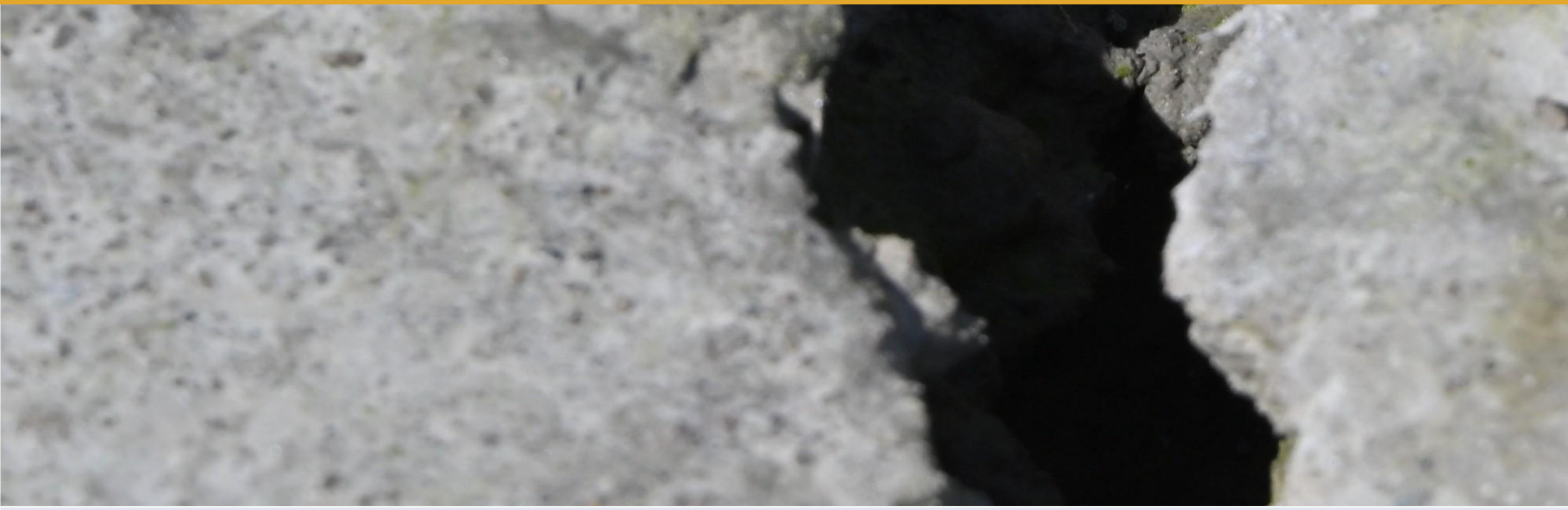
Figure credits:

All photos taken by Dieter Geesing, Soil Management Specialist



Contents

Recordkeeping pages can be found at the end of each section.

Additional Resources

Find additional resources on soil health, including the B.C. Soil Health Assessment Protocol (SHAP), on the British Columbia Ministry of Agriculture and Food Soil Health website.

How To Use This Guide

The In-Field Indicators of Soil Health Guide is designed as a resource for producers to monitor soil health in the field without the need for laboratory analysis. The indicators and their measurements in this guide were selected to be used based on their effectiveness, their ease of use, and the minimal use of complex and costly equipment.

Use of these indicators is intended for monitoring changes in soil health measurements over time due to changes in management practices and for guiding producers towards practices that improve a field's overall soil health. They are not intended to provide a soil health 'score' or provide a comparison between different fields, nor are they intended to provide a comprehensive assessment of overall soil health.

For most producers, it is not necessary to evaluate all soil health indicators contained within this guide. Instead, producers are encouraged to select the soil health indicators that they feel are appropriate based on soil, cropping system, current management practices, and particular concerns regarding soil health. However, it is strongly recommended that producers continue to monitor selected soil health indicators over time to determine the impact of changes in management practices.

Note that the measurement of each in-field soil health indicator requires different equipment, periods of time, and field conditions for optimal measurements. Please read through each soil health indictor prior to measurement to determine specific requirements.

Direct assessment of soil chemical properties, such as pH, EC, or extractable nutrients, is not contained within this guide. However, monitoring of these properties is important for both monitoring soil health and nutrient management planning and should be conducted by a reputable soil testing laboratory. Please refer to the information regarding sampling, analysis, and interpretation of these properties in the guides published on the B.C. Ministry of Agriculture and Food website or contact your local Regional Agrologist or AgriService BC.

Aggregate Stability

Importance

Aggregate stability refers to the ability of soil aggregates to resist breakdown into smaller pieces or particles when disturbed by tillage or exposed to the erosive forces of wind or rainfall. Aggregate stability is influenced by organic matter, soil texture, tillage practices, and soil biological activity.

Stable soil aggregates provide increased resistance to soil erosion, improved water infiltration and storage, enhanced soil structure, increased protection and retention of soil organic matter, and improved nutrient cycling and crop productivity.

How to Measure Aggregate Stability

Aggregate stability is typically determined by measuring the stability of soil aggregates in water, also known as slaking or slake testing. The slake test can be performed using either the jar and wire method, the strainer method, or via the SLAKES smartphone app.

Jar and wire method

Materials required:

- A 1L glass or plastic container (a regular-mouth glass mason jar works well),
- 1 wire mesh support to hold aggregates,
    - Cut the mesh to fit into the jar to a depth of about 2 in (5 cm) from the top while hung on the rim of the jar
- A stopwatch or timer, and
- Tap water

Steps:

1. Collect several soil aggregates (peds) roughly the size of a golf ball from within the top 2 inches (5 cm) of the soil surface. Allow the peds to air dry for a few hours. Do not dry in the sun or under direct heat.

2. Snugly fit the wire mesh into the mouth of the jar or container. Ensure the mesh sits about 2 inches (5 cm) deep into the jar. Fill the container with tap water to about 0.75 inches (2 cm) from the top.

3. Gently drop the soil aggregate on the wire mesh in the jar and start your stopwatch or timer. Ensure that the water fully covers the aggregate.

Figure 1. Soil aggregates prior to being measured for aggregate stability using the jar and wire method.

4. Monitor the soil aggregate for 5 minutes and observe the level of aggregate disintegration. If the aggregate breaks quickly upon immersion or the water becomes cloudy, the aggregate is less stable. In contrast, if the soil aggregate slowly breaks apart and the water remains clear, the aggregate is relatively stable.

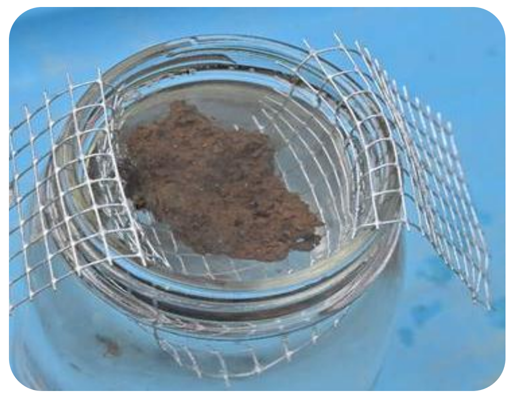


Figure 2. A soil aggregate submerged in water to determine aggregate stability using the jar

5. After 5 minutes, estimate and record the percentage of the aggregates that remains intact in the mesh. If the aggregate remains intact on the mesh after 5 minutes, remove the aggregate and break it apart. If the aggregate is wet at the centre, it indicates that the soil has good water retaining capacity and aggregation. If the aggregate is dry at the centre, it indicates that

Figure 3. A saturated soil aggregate after being removed from the jar.

the soil is highly degraded and will repel infiltration.

6. Repeat this test two to three times using aggregates from different parts of a field or management zone. Calculate and record the average percentage of aggregates remaining intact after testing for future comparison.

Figure 4. A saturated soil aggregate broken apart to determine the level of saturation.

Strainer method

Materials required:

- A 1L glass or plastic container,
- A sink strainer or wire mesh,
- A stopwatch or timer, and
- Tap water

Figure 5. Soil aggregates prior to being measured for aggregate stability using the strainer method.

Steps:

1. Collect several soil aggregates from within 0-2 inches (0-5 cm) of soil surface. Aggregates can be moist and do not require air drying (field capacity or less). Lightly crumble large aggregates so that they are approximately the size of a BB or slightly larger.

2. Place soil aggregates into the sink strainer or mesh and level it at the top. Gently lower the strainer with soil into the bowl filled with water and allow it to saturate the soil for about two minutes.

Figure 6. Soil aggregates submerged in water to determine aggregate stability using the strainer method.

3. After two minutes, carefully remove and turn the sink strainer upside down on a flat surface. Estimate and record the percentage of soil aggregates that have maintained their structure. Soils with good aggregate stability will maintain their aggregate structure, with 50% or more of the aggregates apparent after testing. Soils with poor structure will slump and have a mucky consistency. Also, water clarity in the bowl may be used as an additional indicator of soil aggregate stability, as clearer water indicates greater aggregate stability.

4. Repeat this test two to three times using aggregates from different parts of a field or management zone. Calculate and record the average percentage of aggregates remaining intact after testing for future comparison.

Figure 7. Saturated soil aggregates after being removed from the jar.

Figure 8. Saturated soil aggregates after being removed from the strainer to determine the level of aggregation.

SLAKES APP method

Materials required:

- A smartphone with the SLAKES app downloaded,
- A mount to hold your smartphone 4 – 5 inches (10-13 cm) high in a horizontal position,
  - This could be a container, such as a can or jar, or a tripod. You may also require tape to hold the smartphone in place
- 2 transparent or white containers, such as petri dishes or small plastic food storage containers,
- A sheet of blank white paper, and

- Tap water

Steps:

1. Collect 3 pea-sized (4-8 mm) soil aggregates from within 0-2 inches (0-5 cm) of the soil surface. Avoid highly asymmetrical aggregates. Do not crush aggregates. Air dry the aggregates for at least 24 hours. Do not dry in the sun or under direct heat. Keep drying temperature at a maximum temperature of 40 °C.

Figure 9. Setup for aggregate stability testing using the SLAKES smartphone app.

2. Place the 3 soil aggregates in a petri dishes or storage container in a triangular pattern, leaving space between the aggregates and not close to the container wall. If the container is transparent, place a sheet of blank white underneath to create a background.

3. If necessary, use tape to secure the smartphone horizontally to the mount. Ensure the camera is not covered. Place the container with the aggregates under the camera. Adjust the position of the phone to ensure that the camera captures all the aggregates and edges of the container but avoid capturing other objects. Zoom or resize the cropping area if necessary. Use lighting to avoid shadows around the mount, container and smartphone.

Figure 10. Defining the aggregates in the SLAKES smartphone app.

4. On your smartphone, tap "'Start Aggregate Stability Test" to enter the unique details of the soil to analyze. Tap the shutter button to capture the initial image of the soil. Adjust the

slider until the soil aggregates appear red. Then, tap the green check button.

5. Replace the container with soil aggregates with another petri dish or container filled with water deep enough to submerge the aggregates. Gently drop the three soil aggregates into the container in a triangular pattern. Keep the aggregates apart from each other and the wall of the container. Ensure all aggregates and the walls of the container can be captured by the smartphone camera.

Figure 11. The SLAKES smartphone app during the soil aggregate stability test.

6. Quickly tap the shutter button on your camera to capture a second image. The 10-minute timer will start automatically. Do not move the smartphone. Adjust the slider until the wet soil aggregates appear red. Then, tap the green check button.

7. After 10 minutes have elapsed, the final image will be taken automatically. Adjust the slider until the slaked aggregates appear red. Then, tap the green check button.

8. The aggregate stability index will be shown on the screen and saved within the app. It is calculated as the ratio area of air-dried soil (determined in the first image) to the area of soil in the image taken after ten minutes (the final image). The second image is used as a correction factor.

Figure 12. The aggregate stability index score using the SLAKES smartphone app.

9. Record the aggregate stability index for future comparison. To export the result to a computer, tap “Export Test Result” under “My Result Tab”.

Management Practices to Improve Soil Aggregate Stability

- Avoid tillage practices that disturb existing aggregates or prevent accumulation of soil organic matter and aggregate formation.
- Minimize traffic and disturbance to the soil surface, such as over-grazing, frequently using the same location for confined livestock areas, and off-road vehicular traffic.
- Maintain plant vigour and productivity through appropriate nutrient and pest management.
- Regularly add organic amendments such as compost and manure to increase soil organic matter and provide plant nutrition.
- Maintain living roots or adequate crop residue to protect soil aggregates from exposure to wind and water erosion.

Recordkeeping – Aggregate Stability (Jar and wire method and Strainer method)

Field/site name: ____

Method (circle one): Jar and wire method OR Strainer method		
Date	**% aggregates remaining intact**	**Average (% aggregates remaining intact)**

Recordkeeping – Aggregate stability (SLAKES app method)

Field/site name: ____

Date	Index value	Average index value

Biological Diversity (In-field)

Importance

Soil biota, whether microscopic or visible by the naked eye, affect every aspect of soil function, including soil aggregation, water movement and storage, nutrient cycling, and pest suppression. Creating a favourable environment for a diverse community of organisms will ensure that the soil ecosystem remains productive and resilient.

How to assess

In-field biological diversity should be assessed during the spring or fall, or when the soil is moist and growing conditions are favourable as soil organisms will be active during these conditions. During poor conditions, such as low temperatures or heavy rainfall, soil biota may not be present or difficult to observe. Make multiple observations throughout the field to determine an average assessment for the field.

Use a shovel to remove a 4 by 4 inch section of soil down to approximately 6 inches and record the number of different types of organism that you observe without using a magnification device. Be sure to look for areas where soil organisms are most active, such as on aggregate surfaces, within surface residue, along plant roots, and within soil macropores. If no soil organisms are present due to the time of the year, look for biopores for evidence of previous activity (see Biopores section of this guide).

Use the following to classify your observations:

- **Numerous** living organisms in the soil: 6 or more different types of organisms observed
- **Many** living organisms in the soil: 4-5 different types of organisms observed
- **Few** living organisms in the soil: 1-3 different types of organisms observed
- **None:** No living organisms found in the soil

To guide your observations, you may encounter the following soil biota:

- Mycorrhizae covering plant root
- Fungi on plant residue
- Nodules formed on legume roots
- Woodlice/pill bug
- Dung beetle
- Mite
- Springtail
- Centipede
- Millipede
- Anecic earthworm
- Endogeic earthworm
- Earthworm cocoon
- Earthworm midden

Figure 1. Centipede

Figure 2. Dung beetle

Figure 3. Earthworm

Figure 4. Millipede

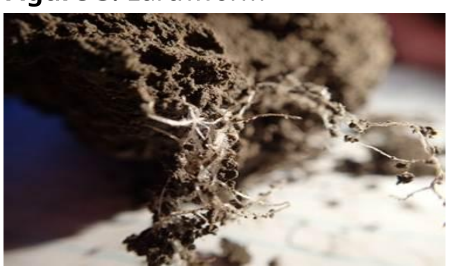


Figure 5. Root mycorrhiza

Figure 6. Root nodule on a clover plant

Figure 7. Pill bug

Management Practices to improve in-field biological diversity:

- Maximize the amount of time that there are living roots in the soil through crop rotation, cover cropping, or perennial grass/forage stands.
- Increase plant diversity through diversified crop rotations and cover crop mixes of multiple plant species to stimulate soil biological activity.
- Increase soil organic matter by regularly adding organic amendments, such as compost or manure.
- Keep soil disturbance to a minimum, such as reducing tillage and preventing compacting from farm equipment or frequent traffic, to protect soil aggregates, soil organic matter, and soil habitat.
- Manage grazing frequency, length, and amount of vegetation removed for optimal plant regrowth and addition of manure from grazing animals.

Recordkeeping – Biological diversity

Field/site name: ____

Date	Number of different types of organisms observed	Classification • Numerous (6+) • Many (4-5) • Few (1-3) • None (0)

Biopores

Importance

Biopores are large soil pores or channels formed through plant root growth and earthworm activity. They provide improved access to water and nutrients for plants and allow for rapid air and water exchange in the soil. Biopores created by earthworm activity are typically enriched in organic matter, nutrients, and microbial activity, leading to improved soil biodiversity. Older biopores will also provide easily accessible pathways for establishing plant roots and movement of soil organisms.

How to assess

Biopore development can be assessed at dry to moist soil conditions, but is easiest when soil is moist but not saturated.

Figure 1. Soil removed for assessing biopore development.

Use a shovel to remove a 4 by 4 inch section of soil down to two depths: 0-6 inches and 6-12 inches. On both the removed soil and within the newly created hole, look for intact biopores that are approximately 2 to 10 mm in width. Biopores will appear as visible soil channels that are often connected to the soil surface. Older biopores may appear darker than the surrounding soil due to accumulation of organic matter deposited through movement of plant roots and soil organisms.

Record the number of biopores that you observe for each depth. Make multiple observations throughout the field to determine an average assessment for the field.

Figure 2. Close-up of soil biopores.

Management practices to improve biopore formation and retention

- Prevent soil organism habitat loss or degradation by reducing soil disturbances, such as tillage or frequent traffic of equipment or livestock.
- Incorporate management practices that improve soil biodiversity, such as increasing the amount of time that living roots are in the soil and increasing plant diversity.
- Promote and improve aggregate stability by increasing soil cover, increasing soil organic matter through organic amendments, and appropriate water and nutrient management.

Recordkeeping – Biopores

Field/site name: ____

Date	Number of biopores (0 – 6 inch depth)	Number of biopores (6 – 12 inch depth)

Infiltration

Importance

Soils with good infiltration have an increased water use efficiency and a reduced risk of water and soil loss by runoff and erosion. Soils with frequent ponding, however, have reduced nutrient cycling, water quality, and air exchange. How quickly water enters the soil depends on several factors, including:

- Soil texture - coarser (sandy) soils allow water to infiltrate faster than soils with large amounts of fine particles (clay)
- Soil structure and aggregation - well-formed soil aggregates help water move)
- Organic matter - can improve infiltration by boosting biological activity which creates aggregates and pores, but high amounts may slow it down at first like a sponge
- Soil moisture level - dry soils may take in water faster at first, but very dry soils can repel water)
- Vegetation - roots help create pores for water
- Crusting from broken aggregates or sodium buildup and compaction (fewer large pores) both slow down infiltration
- Tillage can have mixed effects. It may improve infiltration in crusted soils by loosening the surface, but it can also destroy larger and longer pores and reduce water flow.

Materials required

- A beveled 6-inch wide ring or clean, open-ended tin or steel can,
  - Larger rings or cans may be used, but will affect the amount of water used during the assessment to be equivalent to 1 inch (25 mm) of water
  - Ensure that your ring or can is at least 6 inches long to prevent water overflowing
- Plastic wrap,
- Water and water bottle,

- Use a graduated cylinder to measure out the following volumes of water (equivalent to 1 inch or 25 mm) based on the size of your ring or can:
    - 6 inch: 444 mL (or 444 grams)
    - 6.5 inch: 544 mL (or 544 grams)
    - 7 inch: 630 mL (or 630 grams)
    - 7.5 inch: 724 mL (or 724 grams)
    - 8 inch: 824 mL (or 824 grams)
- If you don't have a graduated cylinder, put the empty bottle on a kitchen scale, set the scale to zero, and add the appropriate mass of water shown above. Then mark the water level with a marker.

- A stopwatch or timer,
- A hammer or hand sledge, and
- A block of wood

How to assess

Infiltration is assessed by measuring the rate at which 1 inch (25 mm) of water infiltrates into the soil. The current moisture contents will affect the infiltration rate. For best results, perform infiltration tests when soil is moist but not wet (about 48 hours after soaking rain or irrigation), it has been at least 4 weeks after tillage, and ideally in early spring before field work begins.

If rainfall or irrigation has not occurred recently and the soil is very dry, you may:

- **Option 1** (easier): Perform the test twice. Use the result from the second test, since the first one just wets the soil.
- **Option 2** (more effective, but takes more time): Go to the spot a few hours before (or the day before) and soak the soil well. Mark the spot with a small flag so you can find it again.

Step 1: Choose a spot that represents the whole field. Avoid areas with tire tracks, used for storage piles, low spots (depressions), or raised bumps, etc.

Step 2: Insert the Ring into the Soil

- Clear away any residues, sticks or stones from the area.
- If there's vegetation, cut it as close to the soil as possible.
- Put the ring (beveled edge down) on the ground.
- Use a hammer or hand sledge and a block of wood to gently tap the ring or can into the soil. Try to drive the ring or can 3 inches deep into the soil if possible.
- Use your finger to gently press down the soil just along the inside edge of the ring or can. This helps stop water from leaking out the sides. Try not to disturb the rest of the soil inside the ring.

Figure 1. An infiltration ring being inserted into the soil.

Step 3: Place a sheet of plastic wrap inside the ring or can so it fully covers the soil and touches the inside of the ring.

Step 4: Carefully pour the water (corresponding to a 1-inch depth as described above) into the ring or can that is lined with plastic wrap. Pour slowly to ensure that no water escapes around the plastic wrap.

Figure 2. Water being poured into an infiltration ring lined with plastic wrap.

Step 5: Remove Plastic Wrap and Time the Infiltration.

- Get your stopwatch or timer ready.
- Gently pull out the plastic wrap, leaving the water in the ring.
- Start timing right away.
- Watch the water and stop the timer when the soil surface is just starting to shine (glistening).
- If the surface is uneven, stop timing when about half the soil is showing and glistening (see Figure 3).
- Record the time it took in minutes. You may repeat this procedure several times throughout the field to determine an average infiltration rate for the entire field.

Figure 3. The infiltration ring when the infiltration test is completed and the soil surface is glistening.

Interpreting infiltration

The table below shows typical infiltration rates based on soil texture, which is an important factor — but not the only one: in fact, many factors affect how fast water soaks into the soil. Infiltration can be faster in soils with good structure (like well-aggregated or cracked soils), or slower if there is a crust on the surface.

For comparison purposes, divide 60 by the infiltration rate (in minutes) determined using the method above to convert to inches/hour shown in the table below. For example, 60 divided by 27.5 minutes equals an infiltration rate of 2.18 inches (55 mm) per hour. Multiply the rate (in inches/hour) by 25 to convert to mm/hour.

Only compare results between soils that are similar (e.g., texture, slope, vegetation). However, this test works best to track changes over time in the same field.

Table 1. Steady infiltration rate for different soil textures.

Soil texture	Steady Infiltration Rate* (inches per hour)	Steady Infiltration Rate* (mm per hour)
Sands	> 0.8	> 20
Sandy or silty soils	0.4 – 0.8	10 - 20
Loams	0.2 – 0.4	5 - 10
Clayey soils	0.04 – 0.2	1 - 5
Clayey soils with high sodium content (causing crusts)	< 0.04	< 1
* *After the soil has been wet for a long time, the infiltration rate usually stays steady — as long as excess water can drain away.*		

Management practices to improve infiltration rate

- Break up tillage pans in frequently tilled, heavily compacted soils.
- Prevent compaction by avoiding intensive grazing, using heavy equipment on saturated or nearly-saturated soils, and frequently tilling to the same depth.
- Improve soil aggregation by increasing the amount of soil organic matter through additions of organic materials and promoting plant root growth.
- Maintain a soil cover through cover cropping or retaining crop residue to reduce erosion and prevent surface crusting.

Recordkeeping – Infiltration

Field/site name: ____

Date	Time (minutes)	Rate (inches/hour) [60/time]	Rate (mm/hour) [rate*25]	Average rate

Penetration Resistance

Importance

Soil compaction in agricultural systems occurs when repeated wheel or hoof traffic, or repeated tillage at the same depth, compresses soil particles and reduces pore space. This loss of soil porosity limits water infiltration and restricts the movement of air through the soil profile. Plant roots face greater resistance to growth, making it more difficult for them to access moisture or nutrients. Beneficial soil organisms, such as earthworms, bacteria, and fungi, lose the habitats they need to break down organic matter and cycle nutrients effectively. As a result, nutrient availability declines, plant health suffers, and overall crop productivity is reduced, while the risk of greenhouse gas emissions increases considerably.

Materials required

- A wire flag, or
- A penetrometer, also called compaction meter.

How to assess

Penetration resistance is a method for detecting and assessing soil compaction, which can be done using either the wire flag method or with a penetrometer.

Penetration resistance increases significantly as soil dries.

This assessment should be conducted when the soil is at *field capacity* - meaning the soil has been saturated and allowed to drain so that it is not waterlogged, which is usually more than 48 hours after heavy rainfall or irrigation. The best time is usually early spring, before you begin any field work. Compaction from machinery or animals most often happens 2–8 inches below the soil surface, but it can be deeper on some soils or due to certain soil management practices.

Using either method, assess soil compaction at 8–10 random spots in the field that are the same soil type.

Wire flag method

Hold the wire flag by its end and insert it with consistent speed into the soil, observing the resistance encountered as it is pushed in. Note the **resistance** (easy, noticeable, tough) and **depth** wire penetrates without bending. Use Table 1 below (and the relevant recordkeeping table at the end of this guide) to help guide and record your observations by adding a tally mark for the observed resistance at each depth. Within the same field, compare the frequency of each measured resistance over time at each depth (for example, the number of tally marks for 'Easy' increases every year for the 0 – 5 cm depth).

Figure 1. A wire flag being inserted into the soil to determine penetration resistance.

Figure 2. A penetrometer being inserted into the soil to determine penetration resistance.

Table 1. Recordkeeping table for determining penetration resistance using the wire flag method.

	Depth		
Resistance	**0 – 5 cm**	**5 - 20 cm**	**> 20 cm**
Easy Flag slides in smoothly			
Noticeable A gentle push-back			
Tough Force needs to be applied			

Using this method, you can also compare the resistance with that measured in a known noncompacted area, such as along a fence row or another undisturbed field border, to see how management practices have potentially affected compaction.

Penetrometer method

Select the appropriate tip for the penetrometer based on the field's soil texture: the 0.5-inch cone for silty, clayey, and loamy soils, and the 0.75-inch cone for sandy soils.

Apply slow, steady downward pressure so the penetrometer rod sinks at about 1 inch per second, watching the pressure gauge as it moves. Record the maximum pressure (in psi: pounds per square inch) and the corresponding depth observed while you apply pressure. Additionally, note the depth where resistance increases sharply and record the corresponding pressure, as this may indicate the presence of restrictive layers.

Many crops will begin to experience root growth restriction when penetrometer readings are at approximately 200 psi. Penetrometer readings above approximately 300 psi typically indicate a compacted layer. At this level of compaction, root growth will be severely impeded.

Management practices to decrease penetration resistance

- Prevent compaction by avoiding intensive grazing, using heavy equipment on saturated or nearly-saturated soils, and frequently tilling to the same depth.
- Break up tillage pans in frequently tilled, heavily compacted soils, and reduce the frequency and breadth of tillage to prevent further formation of tillage pans.
- Regularly add organic materials, such as compost and manure, to the soil to increase soil organic matter, improve soil aggregation, and reduce soil bulk density.
- Keep a living crop growing in the soil (e.g. cover crops and perennials) to allow plant roots to create soil pores and promote soil aggregation.

Recordkeeping – Penetration resistance (Wire flag method)

Field/site name: ____________________ Date: ________________________

	Depth		
Resistance	**0 – 5 cm**	**5 - 20 cm**	**> 20 cm**
Easy Flag slides in smoothly			
Noticeable A gentle push-back			
Tough Force needs to be applied			

Field/site name: ____________________ Date: ________________________

	Depth		
Resistance	**0 – 5 cm**	**5 - 20 cm**	**> 20 cm**
Easy Flag slides in smoothly			
Noticeable A gentle push-back			
Tough Force needs to be applied			

Recordkeeping – Penetration resistance (Penetrometer method)

Field/site name: ____

Date	Penetration resistance (psi)	Average penetration resistance (psi)

Plant Roots

Importance

Plant roots are essential for soil health – microbes use simple and complex sugars secreted by plants roots as a food source, leading to the formation of soil aggregates. Well-aggregated soil protects organic matter from decomposition, resists compaction and erosion, and improves infiltration and soil water storage. As plant roots grow and die, they will also contribute to soil fertility by providing nutrients to subsequent crops.

How to assess

Assess plant root development during periods of active plant growth and sufficient soil moisture. For a whole-field observation, select an area in the field that looks representative of the current crop's growth. Alternatively, assess multiple areas within each field to compare and determine areas of concern.

Use a shovel or trowel to remove a small section of soil and roots, from the soil surface to approximately 12 inches deep or further depending on the plant's rooting depth. Use the root sample to make observations on plant root growth.

What to look for

- Roots are distributed throughout the soil, deep, well-branched, and appear healthy.
- There are no indications of a hardpan or compacted soil, such as sideways root growth or "J" shaped roots.
- The presence of numerous fine root hairs. The lack of root hairs may indicate oxygen deprivation in the root zone.
- Soil aggregates and plant roots are intertwined, with plant roots growing through and around soil aggregates; roots and aggregates form a complex interwoven system with roots contributing to aggregate development and stability.

Use the table below to assess plant root development and monitor changes over time. Assign a score for each item in the table below based on your observations and the associated score shown at the top of each column. Add the scores together to determine an average score for each sampled area. Determine an average score for the field if you sample multiple areas, or use the scores to compare different areas within the field.

Table 1. In-field assessment of plant root development.

Item	High (3)	Moderate (2)	Low (1)
Root distribution, depth, branching, and health	Roots are well distributed throughout the soil, grow deeply, and have many branches; roots are alive and healthy in appearance	Roots have grown below the soil surface but not to a sufficient depth; areas of patchy root growth with some branching; some dead roots are present	Poor root establishment that does not grow far below the soil surface; little to no branching; a large proportion of dead roots are present
Restricted growth	No sign of restricted root growth; majority of roots grow vertically into the soil profile	Some signs of restricted root growth, though some root growth appears unrestricted; some roots grow sideways or have "J" shapes	Majority of roots have signs of restriction, such as sideways growth; many "J" shaped roots growing along compaction layer
Root hairs	Numerous root hairs; soil is clearly well-aerated with no visible ponding, drainage, or compaction issues	Some root hairs are present; potential issue with ponding, drainage, or compaction	Root hairs not present; area is clearly frequently waterlogged or heavily compacted
Soil aggregates	A large portion of roots are intertwined with soil aggregates; roots clearly contributing to aggregate development and stability	Some plant roots are intertwined with soil aggregates; roots contributing to a moderate level of aggregate development and stability	Little to no interaction between roots and soil aggregates; soil aggregates present are not associated with current root growth

Figure 1. A close-up of plant roots that may be observed

Management Practices to improve plant rooting

- Use soil testing to detect and correct any soil pH or nutrient deficiencies that may be limiting plant and root growth.
- Break up tillage pans in frequently tilled, heavily compacted soils.
- Prevent compaction by avoiding intensive grazing, using heavy equipment on saturated or nearly-saturated soils, and frequently tilling to the same depth.
- Improve soil aggregation through regular additions of organic matter, maintaining a soil cover, and promoting plant growth through appropriate nutrient and water management.

Recordkeeping – Plant roots

Field/site name: ______________________________

Date	Score	Average score

Residue Breakdown

Importance

Residue breakdown is the biological decomposition, fragmenting, and cycling of crop residues after harvest by soil biota and can be indicative of a soil's current level of biological activity. Residue breakdown also releases nutrients in residual biomass for subsequent crops and supports further biological activity. The rate of residue breakdown is primarily influenced by management practices, type and size of residue, residue quality (carbon to nitrogen ratio, lignin and cellulose content, etc.), and environmental conditions.

Materials required

- Flags or markers,
- Quadrat (optional; if assessing via visual estimation),
- A smartphone or camera for taking photos (if assessing by visual estimation), and
- A decomposition or mesh bag with a mesh size of 1-2 mm (if using the mass balance approach)

How to assess residue breakdown

Residue breakdown can be assessed either by visual estimation or by using a mass balance approach.

Assess via visual estimation

After crop harvest, identify 5-10 areas of the field that are representative of crop residue in the field. Use a flag or marker to mark each location. For each area, take a photo of approximately 1 ft by 1 ft (30 by 30 cm) square of the current crop residue. A quadrat (a frame made of metal, plastic, or wood) may be used outline a specific area.

Return to each area periodically and take a photo of crop residue as it decomposes. Compare each new photo with the photo of crop residue taken when monitoring began and estimate the amount of residue remaining, expressed as a percentage. To assess the level of residue breakdown, look for signs of decomposition, shredding, and incorporation by soil organisms. Additionally, residue will become darker in colour as it decomposes.

Figure 1. A quadrat outlining a section of plant residue.

Once you have assessed each location, calculate and record the average amount of residue remaining for the field. Additionally, save your photos to ensure estimation consistency between assessment periods.

Assess via mass balance approach

After crop harvest, take a sample of crop residue from 5-10 locations throughout the field. Allow the residue to air-dry for 48 hours (or oven-dry at 60°C for 48 hours if available) and then place into a decomposition or mesh bag. Use a scale to determine and record the mass of the crop residue and bag separately.

Figure 2. A mesh bag with plant residue prior to being buried in the field.

Select locations that are representative of the field and place the bags either on the soil surface or bury just below the soil surface, based on your tillage practices after harvest. Retrieve the bags at regular intervals, such as every 30 days, and gently remove any soil or insects. Air-dry or oven-dry the residue for 48 hours and then determine and record the mass.

Remove the mass of the decomposition or mesh bag from your measurements and determine the residue breakdown rate (%) using the following equation:

$$Residue\ breakdown\ rate\ (\%) = \frac{Initial\ dry\ mass - Remaining\ dry\ mass\ at\ a\ given\ time}{Initial\ dry\ mass} \times 100$$

Record the residue breakdown rate and return the crop residue bags to the field. Repeat the above procedure until no significant amount of residue remains.

Management practices to improve soil biological activity

- Regularly add organic materials, such as manure and compost, to build soil organic matter.
- Promote plant diversity through diversified crop rotations and cover crop mixes of multiple plant species.
- Maintain optimum levels of soil moisture and nutrients to promote plant growth and productivity.
- Avoid soil disturbances and compaction, such as frequent tillage, equipment or livestock traffic, and over-grazing.
- Maintain a soil cover through growth or living roots or retaining crop residue on the soil surface.

Recordkeeping – Residue breakdown (Visual estimation method)

Field/site name:___________________________ Date: __________________________________

Measurement location	% crop residue remaining	Average % crop residue remaining

Recordkeeping – Residue breakdown (Mass balance approach)

Field/site name: ___________________________ Date: ___________________________________

Measurement location or Bag ID	Bag mass (g)	Initial dry mass (g)	Remaining dry mass (g)	Residue breakdown rate (%)	Average residue breakdown rate (%)

Soil Colour

Importance

Soil colour can be used as an indicator of accumulation or loss of soil organic matter. Over time, accumulation of soil organic matter generally results in a darker soil colour while loss of soil organic matter results in a lighter soil colour. Along with soil organic matter, soil parent material, mineral reactions with air and water, and salt accumulation also have major influence over soil colour.

Materials required

- A soil colour book (Munsell or Globe) or soil colour smartphone app (LandPKS),
- A shovel or trowel,
- Water, and
- A reference material (such as a sheet of white printer paper or yellow sticky note) if determining soil colour via smartphone app.

How to assess

In the field, soil colour can be assessed using either a colour chart, such as the Munsell or Globe colour charts, or via a smartphone app, such as LandPKS.

Both methods require taking a small soil sample to determine the soil colour. Perform this test on soil collected several spots on the field (do not mix).

First, dig a small scoop of soil from the depth that you're interested in. Gently crush or rub the soil to remove big clumps, stones, and plant residue. If the soil has two or more distinct colours, do not mix them together but assess colours separately. As soil colour changes based on moisture, assess soil colour first when it is dry or has been air-dried, then assess soil colour after moistening the soil sample with a small amount of water. Make sure the soil is not saturated and instead it appears glistening.

Figure 1. A handful of soil at three different moistures for the purposes of determining soil colour: dry, moist, and wet

Assess via Munsell colour chart

Hold your soil next to the chart's coloured squares on each page. Look for the **hue** that "blends" into your soil best. On that page, find the row of numbers (2.5 – 8) that most closely matches the lightness or darkness of your soil. This is the **value** of the colour. Next, across the value row, find the column of numbers (1 – 8) that best matches how vivid or dull the colour is. This is the **chroma** of the colour.

Combine hue, value, and chroma into one code, for example: **10YR 4/3**. On the opposite side of the color chips, you can find the colour's English name. Record the soil colour code to monitor changes in soil organic matter over time.

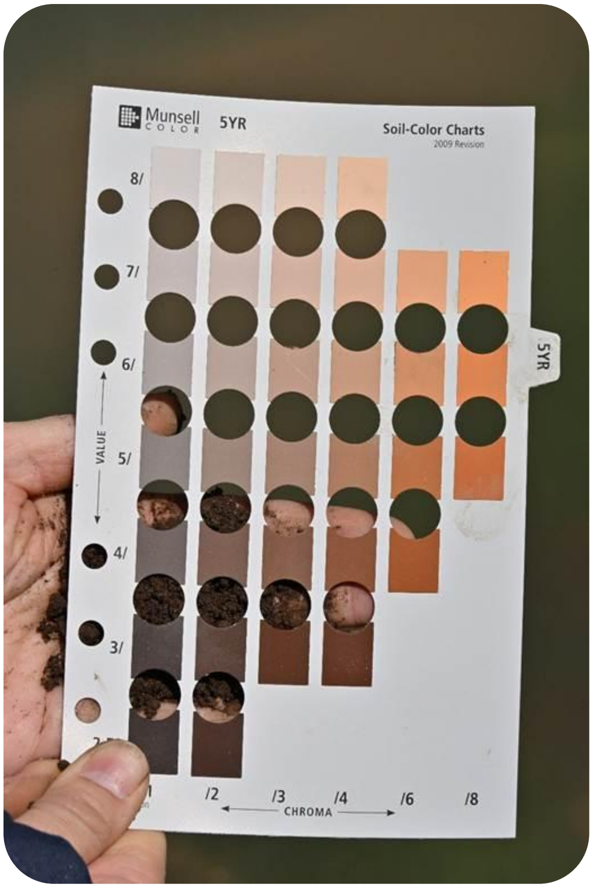


Figure 2. Soil being compared to Munsell colour chips.

Figure 3. Soil being compared to Globe colour chips.

Assess via Globe colour chart

Unlike the Munsell colour chart, the Globe chart uses a single fan of common soil-color chips with all the three parts (hue value/chroma). Flip through the chart's pages with colour chips, holding each chip beside your moist or dry soil until you find the most similar colour, and then record that chip's colour code.

Assess via Smartphone app

Use a smartphone app, such as LandPKS to determine soil colour. Many smartphone apps require you to use a reference material to determine colour, such as a sheet of white printer paper or yellow sticky note. Record the soil colour code determined by the app for future comparison.

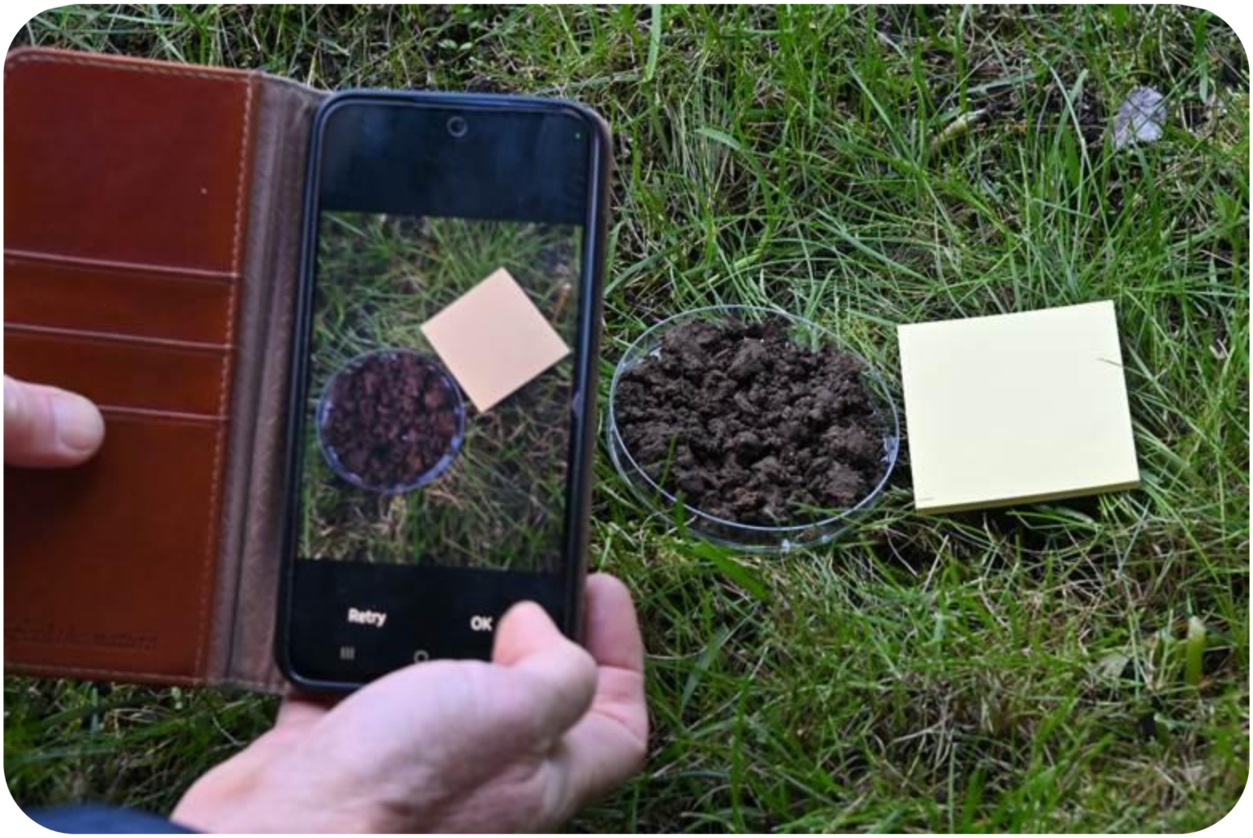


Figure 4. Soil and reference material photographed for determining soil colour using the LandPKS smartphone app

Interpreting soil colour as an indicator for soil organic matter

Soil colour is described using a hue value/chroma notation, for example 10YR 3/4. The hue describes the soil's basic colour, such as 10R for red, 5YR for yellow-red, or 2.5Y for yellow.

The **value** describes how light or dark or dark a soil is, on a scale from about 2 (very dark) to 8 (very light). This number should be used to monitor for changes in soil organic matter over time, as darker soil typically contains a greater amount of soil organic matter. If a soil's colour value gets lower over time it indicates a darkening of soil and an increase in soil organic matter, whereas if a soil's colour value gets larger over time it indicates a lightening of soil and a decrease in soil organic matter.

Management practices to improve soil organic matter

- Regularly add organic amendments such as compost and manure.
- If possible, reduce the frequency, depth, or breadth of tillage to protect existing soil organic matter from microbial decomposition.
- Provide year-round soil cover through perennial cropping systems, growing cover crops, or leaving surface residue from high-residue crops in place.
- Promote crop growth and root turnover through adequate supplemental nutrition and irrigation.
- In grazing systems, manage rotation time and intensity to ensure forages are not over-grazed and have adequate regrowth before grazing again.

Recordkeeping – Soil colour

Field/site name: ____

Date	Method (Book, App)	Colour (Hue Value/Chroma)

Soil Cover

Importance

Keeping the soil surface covered is an important factor in supporting healthy soil. This could be with cover crops, residues, or mulches. Soil cover protects the soil from erosion, conserves soil moisture by reducing evaporation, reduces nutrient losses, prevents soil degradation, and supports weed suppression.

Materials required

- Quadrat (optional; if assessing via visual estimation),
- Smartphone or camera for pictures (if assessing via visual estimation), and
- 25-foot, 50-foot, or 100-foot measuring tape with material to anchor it in the ground (if assessing via line-transect method)

How to assess

Soil cover can be assessed either by visual estimation or the line-transect method. It can be assessed at any time but is ideally assessed prior to planting the main crop. It may also be beneficial to assess soil cover during fallow or crop establishment periods.

Assess via visual estimation

In 10-15 randomly selected areas of the field, take a photo of an approximately 1 ft by 1 ft (30 by 30 cm) square of the soil surface. A quadrat (a frame made of metal, plastic, or wood) may be used to outline a specific area. Using the reference photos below, estimate the percentage of soil cover for each photo and then calculate an average of the estimates. Record the average soil cover that you calculated for long-term monitoring and comparison. Additionally, save your photos to ensure estimation consistency between assessment periods.

Figure 1a. Approximately 25% soil cover.

Figure 1b. Approximately 50% soil cover.

Figure 1c. Approximately 75% soil cover.

Figure 1d. Approximately 90% soil cover.

Assess via line-transect method

First, select an area that is representative of the whole field. Anchor one end of your measuring tape into the ground and extend it at a 45° angle so that it is neither parallel nor perpendicular to current or previous crop rows. Once the measuring tape has been fully extended, check for residue at the top end of every 1-foot mark. Ensure that you are looking straight down at the measuring tape, as standing away from the measuring tape and looking at an angle may lead to an overestimation. Count the number of marks on the measuring tape that have residue exactly under them. Do not count any marks where the presence of soil cover is questionable.

Once you have counted every point on the measuring tape, determine the percent soil cover based on the length of your measuring tape. For example, a 50-foot measuring tape that has soil cover under 17 of the 50 measuring points has 34% soil cover.

Figure 2. Soil cover being measured using the line-transect method.

Record the percent soil cover and then repeat this method two to five times depending on the length of your measuring tape. A shorter measuring tape will require more measurements for an accurate assessment while a longer measuring tape will require fewer. Once you have finished, determine the average of your measurements to determine the percent soil cover of the entire field.

Management practices to improve soil cover

- In annual systems, plant cover crops species suited to local conditions and management practices.
- Retain straws and crops residues on the field after harvest to protect the soil surface from erosion.

- Apply organic or synthetic mulches to provide cover to bare soil; consider the C:N ratio of organic materials to compare their relative decomposition rates.
- Avoid soil disturbance by adopting zero-till, conservation tillage, or reduced tillage practices.
- Monitor grazing time, frequency, and amount of vegetation removed to avoid over-grazing and exposure of the soil surface.

Recordkeeping – Soil cover

Field/site name: ____

Method (circle one): Visual estimation OR Line-transect method

Date	**% soil cover**

Soil Structure

Importance

Soil structure is the way that soil particles are arranged into aggregates. Soils with good structure and aggregation allow water to infiltrate quickly, holds moisture, and allows for air exchange. It also provides a good environment for root growth, supports biological activity and nutrient cycling, and protects soil organic matter from decomposition.

Soil structure is influenced by inherent factors, such as soil texture and climate, and management factors, such as tillage and cropping practices.

Materials required

- A shovel, and
- A tarp, tray, or plastic sheet

How to assess

Soil structure can be assessed at any time, but late autumn or early spring is ideal. Soil should be moist but not saturated, when it is easy to dig and crumble aggregates by hand. Avoid assessment during prolonged dry or wet periods. Also avoid assessment for three to four weeks after tillage, as aggregation and structure will be weak.

Choose a location that is representative of the field or management area. Avoid wheel tracks, animal pens, fresh tillage, or other disturbed places.

Using your shovel, cut three sides of a square to a depth of 1ft (30 cm). Leave one side of the square intact and avoid stepping on the intact side. Opposite the intact side, use your shovel to pull up a cube of soil. Lay the cube with the undisturbed side facing up on a tarp, tray, or plastic sheet.

Use Table 1 below to determine the structure of your soil. If multiple soil layers are present, determine their soil structure separately. If the sampled soil has multiple structures present, estimate the percentage of each soil structure within the sample.

Repeat the assessment in multiple locations and record the percentage of each soil structure observed at each location. Determine the average percentage of each soil structure in the field or management zone for long-term comparison.

Table 1. Observations for determining soil structure.

Structure	Observation	
Crumbly or granular	Soil aggregates fall into small, round crumbs usually smaller than 1 cm in diameter	 **Figure 1a.** Crumbly or granular soil structure.
Blocky	Soil aggregates break into irregular chunks or clods 1 – 5 cm in diameter; aggregates are nearly square or angular blocks	 **Figure 1b.** Blocky soil structure.

Platy	Soil peels into thin, flat plates that are parallel to the surface and stacked on one another; commonly found in compacted soil	 **Figure 1c.** Platy soil structure.
Massive	Soil remains in one dense mass	
Single grained	Individual soil particles do not cling together and show no signs of aggregation; commonly found in sandy soils	

How to interpret soil structure

- **Crumbly or granular:** Typical structure found in soils with high organic matter and good aggregation. Soils with granular structure have lots of pore space, providing good movement for water, air, and roots.
- **Blocky:** Blocky and subangular blocky structures are common in soil layers that have a high clay content. If blocky aggregates are found below the top 4 – 6 inches (10 –15 cm) and easy to break by squeezing, then the soil structure provides good drainage, air exchange, and root penetration. However, blocky aggregates near the soil surface and difficult to break apart by hand can indicate compaction and issues with soil porosity.
- **Platy:** Platy structure often occurs due to compaction or natural layering and can restrict water movement and root flow. It is commonly seen in reduced or zero-till systems as the result of machinery or animal traffic.
- **Massive:** Massive structure in soils allows for little air or water movement and is difficult roots and soil biota to penetrate. Massive structure is more

commonly seen in soils with finer textures that have been tilled or been exposed to heavy loads while wet.

- **Single grained:** Single grained structure is typically seen in sands or loamy sand soil that have no observable aggregation and no observable arrangement of soil particles. These soils appear to be loose soil particles when disturbed. Single grained soils generally have rapid water and air movement due to inherent soil textural characteristics.

Management practices to improve soil structure and aggregation

- Regularly add organic materials, such as compost or manure, to build soil organic matter.
- Avoid tillage practices that disturb or destroy soil aggregates; adopt conservation tillage practices that reduce the frequency, depth, and/or breadth of tillage.
- Maintain living roots throughout the year to aid aggregate formation or retain crop residue after harvest to protect surface aggregates.
- Break up tillage pans or heavily compacted layers.
- In grazing systems, prevent compaction and destruction of soil structure by managing traffic, grazing time, and grazing frequency.

Recordkeeping – Soil structure

Field/site name: ____

Date	Depth(s)	% of each soil structure

Surface Crusting

Importance

Surface crusting occurs when a hard and relatively thin compacted layer forms on the soil surface, causing it to become sealed. Crusting reduces water infiltration, increases runoff, impedes seedling emergence, reduces air exchange, and reduces nutrient cycling.

Surface crusting typically occurs in soils that are tilled and left uncovered so that the soil is exposed to the direct impact of water droplets from irrigation or rainfall. However, it may also be caused by high salt (sodic) or high sodium (sodic) soils.

Materials required

- A ruler,
- A trowel or shovel, and
- A penetrometer (optional)

How to assess surface crusting

After a rainfall or irrigation event, visually assess the field for crusting. Look for a shiny, smooth, hard soil surface, a cracked or sealed crust, and poor seedling emergence.

If crusting is present, carefully remove a 4 by 4 inch (10 by 10 cm) section of the crust using a trowel or shovel. Using a ruler, measure and record the thickness of the crust layer. Take several measurements to determine an average thickness of the crust layer.

Figure 1. Crusting of the soil surface.

If available, use a penetrometer to measure the penetration resistance of the soil crust. Take several measurements in the area where surface crusting is occurring to determine an average pressure (in psi: pounds per square inch) to penetrate the soil's surface crust.

Management Practices to Reduce Crusting

- Adopt zero-tillage and reduced tillage practices to prevent crust formation.
- Reduce the amount of time the soil surface is uncovered through cover cropping, perennial cropping systems, crop rotation, and retaining crop residue.
- Maintain soil organic matter to build stable soil aggregates that are resistant to disruption from rainfall and traffic.
- Break up surface crusts with light and shallow tillage.
- Monitor irrigation water for high sodium content; for soils with high sodium content, apply gypsum to promote flocculation and inhibit dispersion of soil particles.

Recordkeeping – Surface crusting

Field/site name: ______________________________

Date	Crust thickness (mm)

Ponding

Importance

When water ponds on the soil surface after rainfall or irrigation it may indicate that the soil has poor infiltration. Surface ponding can be caused by management practices, such as poor aggregate stability, crusting, tillage pans, or poor plant or residue cover. Ponding may also be caused by naturally occurring conditions, such as an impermeable layer near the soil surface.

When water ponds on the soil surface, it can lead to runoff and erosion, crop damage, poor nutrient cycling, reduced water quality, increased flood risk, and increased greenhouse gas emissions.

Materials required

- Wire flags, or other markers, and
- A ruler

How to assess

Assess surface ponding within 24 hours after rainfall or an irrigation event. Determine if ponding is occurring over the entire field, or only in patches.

Within a ponded area, place 3 to 5 wire flags or markers in a straight line through the middle of the pond. Measure and record the depth of water at each marker.

Return to the markers every day to measure and record the depth of water to monitor water infiltration. Generally, infiltration may be classified as:

- **No ponding after 1 day**: good infiltration.
- **Some ponding up to 3 days**: moderate infiltration.
- **Ponding over 3 days**: poor infiltration.

How to interpret results

If ponding occurs in multiple, smaller patches, it may indicate areas of local compaction, crusting, or naturally occurring soil layers with low permeability.

However, if ponding is widespread and remains in the field for several days, it may indicate a field-wide issue with infiltration or soil structure.

Once surface ponding is no longer present, assess the previously ponded areas for the following possible causes:

- Surface crusting
- Poor aggregate stability
- Compaction
- Clayey soil texture or other low permeability soil layers.
- Low areas that collect water
- High salts or sodium in the soil or water (this will require soil or water testing)
- Damaged or clogged drainage tiles or ditches (if present)

Additionally, you may also investigate the history of a field for potential causes, such as intensive ploughing, a history of row cropping, or animal confinement.

Management practices to reduce ponding

- Adopt practices that reduce soil surface crusting and compaction in ponded areas and throughout the field, such as breaking up crusted and compacted soil with tillage, or avoiding heavy traffic with equipment or livestock.
- Improve aggregate stability and build soil organic matter by maintaining living roots or crop residue on the soil surface, adding organic materials such as manure or compost, or increasing plant and soil biodiversity.
- Monitor irrigation water for high salts or sodium content that may disrupt flocculation of soil particles; for soils with high sodium content, apply gypsum to support soil flocculation.

Recordkeeping – Ponding

Field/site name: ____

Flag ID	Date	Ponding depth (cm)	Change in ponding depth from previous measurement (cm)

Flag ID	Date	Ponding depth (cm)	Change in ponding depth from previous measurement (cm)

Flag ID	Date	Ponding depth (cm)	Change in ponding depth from previous measurement (cm)

Flag ID	Date	Ponding depth (cm)	Change in ponding depth from previous measurement (cm)

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