Best Management Practices

SUBSURFACE COMPACTION

Subsurface compaction occurs in the subsoil at a depth of more than 10 cm (4 in.). It is the compression of subsoil aggregates and particles into a smaller volume by the actions of tillage, traffic, or both.

Soil compaction is a form of soil degradation. Compacted soils have a higher bulk density, lower porosity, and lower proportion of macropores. Compaction affects air and water exchange in the soil profile and restricts root growth.

Reduced porosity means reduced air and water movement in the soil. This leads to saturated soils and anaerobic conditions at the soil surface. Saturated soils are more susceptible to denitrification and runoff.

This infosheet presents a set of diagnostic tools used to describe the type, nature and extent of subsurface compaction of Ontario soils. Proper diagnosis is essential to identify the most suitable best management practices (BMPs) for a given field.

THE ROLE OF HEALTHY SOIL IN A CHANGING CLIMATE

Agriculture and climate are directly linked – anything that has a significant effect on our climate will influence farm production. Greenhouse gas (GHG) emissions and climate change are global concerns, and agriculture can be part of the solution.

BMPs that improve soil health can also help lower GHG emissions, reduce phosphorus loss from fields to surface water, and improve resilience to drought or excessively wet conditions. Healthy soil – an essential component of a healthy environment – is the foundation upon which a sustainable agriculture production system is built.

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Understanding subsurface compaction

There are several types of subsurface compaction. Mostly these can be grouped as compaction caused by:

- tillage (plow pan)
- traffic from farm equipment (number of passes, tire pressure, axle load, etc.), or
- natural means (how soil materials were deposited)

Anaerobic conditions from compacted and saturated surface soils can lead to denitrification, i.e., loss of nitrogen gas (N_2), or partial denitrification, i.e., loss of nitrous oxide (N_2O), to the atmosphere. N_2O is a potent greenhouse gas.

SUBSURFACE COMPACTION AND SOIL HEALTH

Compacted soils:

- are less porous
- have higher bulk densities
- are prone to other forms of soil degradation (e.g., higher erosion rates)
- are at greater risk of prolonged anaerobic (saturated) conditions.

In compacted soils, crop roots:

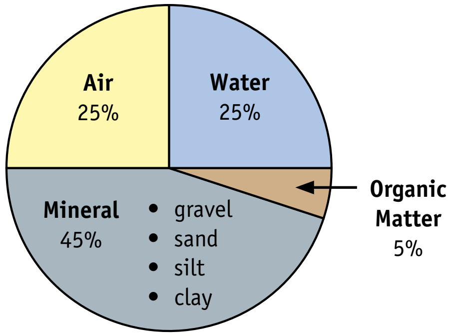
- will not readily exploit the rooting zone
- may suffocate
- are at a greater risk of root disease and suffering from nutrient deficiency.

Soil compaction increases soil strength, which means plant roots must exert greater force to penetrate the compacted layer. Often the roots are not able to break through compacted layers, leading to crop performance issues.

Reduced percolation due to compacted subsoils will result in ponding, concentrated flow, channelized in-field erosion, cropland runoff, and deposition of sediment, nutrients and organic matter into adjacent surface waters, causing sedimentation or pollution.

POROSITY AND BULK DENSITY

To understand compaction, you need a basic understanding of some of soil's physical properties.



For a simple introduction to soil physical properties, look at a handful of topsoil: it contains 50% solids and 50% space. The solids include soil minerals – made of sand, silt and clay particle sizes – as well as organic matter.

These solid constituents combine to form aggregates. In between larger soil particles and aggregates are pores, ranging from large to small, also known as macropores and micropores. The pores contain air or water. For crop growth, it's ideal to have an even number of macropores and micropores. The distribution of pore sizes and the connectivity of soil pores have a profound effect on soil functionality. Large, interconnected soil pore spaces enhance several functions:

- air exchange from the soil to the atmosphere
- water infiltration into the soil surface
- water percolation into the root zone and subsoil

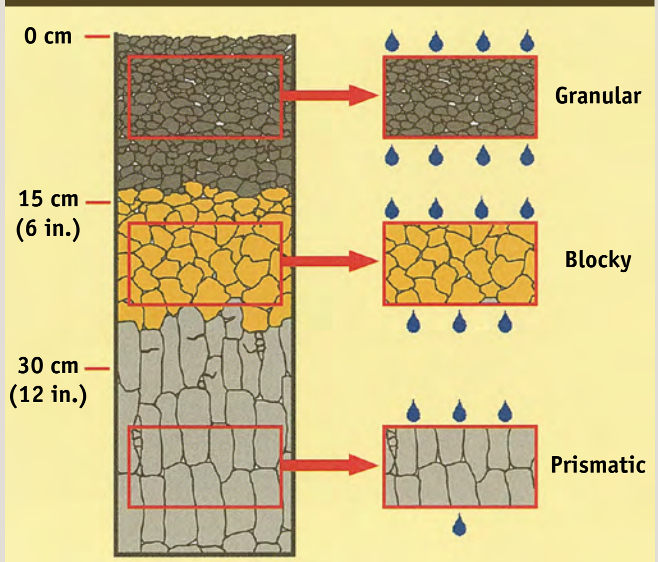
The presence of large continuous macropores and an even distribution of pore sizes help soils to provide sufficient moisture for crop growth and air for roots to grow. Further, there are several important biological and chemical processes taking place within soil pores that require both water and air, such as the cycling and release of plant-available nutrients. Reduced pore size and number will affect these processes as well.

COMPACTION, BULK DENSITY, AND SOIL STRENGTH

Compaction changes the space, size, and distribution of pores in the soil, which increases soil bulk density. Soil bulk density is the dry weight of soil divided by the volume of the soil. It is usually expressed in grams per cubic centimeter (g/cm^3).

In a compacted soil, porosity decreases and bulk density increases. Normally, loam to clay loam soils have a bulk density of about 1.3–1.4 g/cm^3, and sandy loam to loamy sand soils have a bulk density of 1.4–1.6 g/cm^3. Soils loosened by tillage will have bulk densities in the range of 1.0–1.2 g/cm^3. Compacted soils have bulk densities that exceed 1.6 g/cm^3.

STRUCTURAL FORMS – WITH DEPTH AND DRAINAGE



Heavily compacted subsoils contain few large pores and have a reduced rate of water penetration through the compacted layer. As shown in the illustration above, the subsurface blocky and prismatic forms of soil structure have become compacted, reducing pore size. Large soil pores are the most effective in moving water through the soil. When large pores are compacted, percolation rates of water through the soil drop. In addition, the exchange of gases in soil with the atmosphere slows down in compacted soils, causing an increase in the likelihood of aeration-related problems.

Types of subsurface compaction

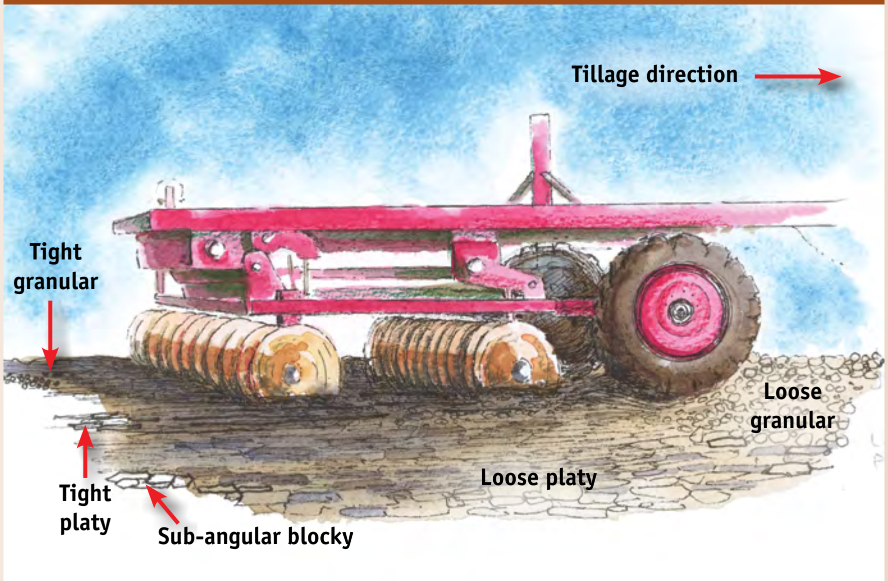
PLOW PAN – ALSO KNOWN AS TILLAGE COMPACTION

A plow pan is a compacted layer just below cultivated depth, i.e., 10–25 cm (4–10 in.) and usually 5–8 cm (2–3 in.) thick.

Original seedbed soil structure consists of granular in the topsoil and sub-angular blocky in the subsoil just below it. The aggregates and soil particles are routinely smeared at depth by plows, disks and other tillage implements when soils are moist to wet.

This forms a platy structure, which is in-filled by smaller particles to form a sealed bulk soil structure called a plow pan or hard pan. This layer restricts air, water, and root movement to deeper in the soil profile.

COMPACTION BY TILLAGE



Tillage conducted at the same depth year after year will accelerate compaction problems. In these zones, porosity drops, density increases, and pores become sealed. The smeared aggregates form platy structures, which further reduce percolation, thereby increasing the moisture content of the surrounding soil. After several wetting and drying cycles, a thick dense layer of soil forms below the tillage depth called a plow pan or hard pan. The layer can affect air and water movement through the soil profile as well as affect crop growth.

Tillage at the same depth year after year without significant additions of organic amendments results in an increase of finer, less stable soil aggregates. These finer aggregates are smeared against the lower soil layer with each tillage pass to form a tillage hard pan.

Not all forms of tillage compaction form at furrow-depth. Disking or cultivating moist to wet soils will cause smearing and compaction at shallower depths of 5–10 cm (2–4 in.) from the soil surface. These pans can hinder root development, water movement, and the availability of certain crop nutrients. Note the lateral pattern of the roots in this photograph.

COMPACTION FROM FARM EQUIPMENT TRAFFIC AND WEIGHT

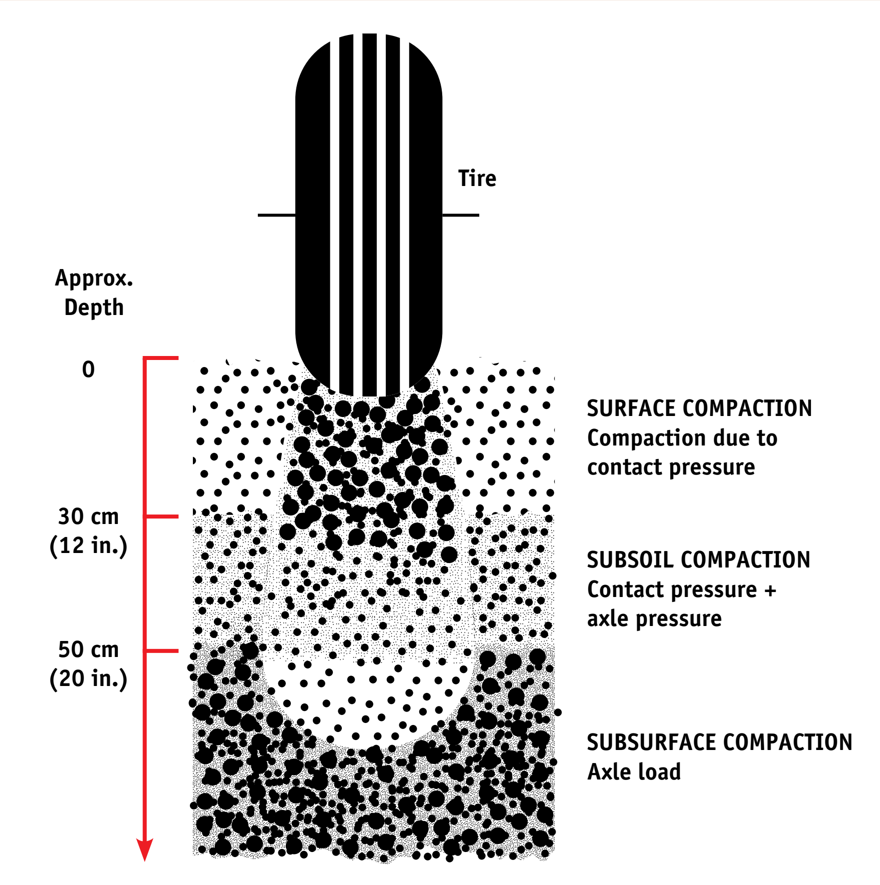
Pressure and weight from farm equipment traffic on cropland compress soil particles and reduce pore space. The severity of compaction increases with greater:

- Soil moisture (up to field capacity)
- Surface contact pressure
- Axle load
- Number of passes
- Soil type and condition

Researchers throughout Europe and North America have discovered that:

- **Surface compaction** is caused by contact pressure (pressure exerted by ground contact with track or tire)
- **Subsoil compaction,** i.e., shallow (25–50 cm or 10–20 in.) subsurface compaction, is caused by high axle loads and contact pressure
- **Subsurface compaction** (soil parent material) compaction (>50 cm or 20 in.) is caused by high axle loads – not contact pressure.

The illustration below shows three types of compaction.



SURFACE COMPACTION

In most conventional tillage systems, surface compaction is partially alleviated by cultivation and, to a lesser extent, freeze-thaw and wet-dry cycles, provided the soil is in relatively good condition. In no-till systems where there is minimal soil disturbance, surface compaction can be more problematic in the first few years: note the platy structure at the top of the spadeful of soil. However, with time, surface conditions in no-till systems will loosen up. The rate of improvement can be accelerated with the proper crop rotation, cover crops and additions of organic amendments.

Overworked soils in poor (structurally unstable) condition are at risk of consolidating – otherwise referred to as setting-up – from the combined effects of heavy rains, soil aggregate dispersions, and drying. The impact is compounded if a series of such events take place after the soil has been finely worked.

SHALLOW SUBSURFACE COMPACTION (25–50 cm or 10–20 in. depth)

Shallow subsurface (subsoil) compaction is caused by high axle loads and contact pressure. Contact pressure, or the pressure exerted by cropland equipment tires or tracks, is higher when exerted by narrow tires at higher pressures.

Lower axle loads (i.e., 5 tons/axle) will impact this zone and the topsoil. Higher axle loads (>10 tons/axle) will impact the entire soil profile. Compaction at this depth lasts longer and is more difficult to alleviate than surface compaction.

Frost and deep tillage do not solve the problem. Deep-rooted forages help; prevention or avoidance works best.

Subsoiling is not recommended to alleviate shallow subsurface compaction. Smearing moist soils at or below the depth of subsoiling may cause even greater compaction problems at this depth.

DEEP SUBSURFACE COMPACTION (DEEP COMPACTION)

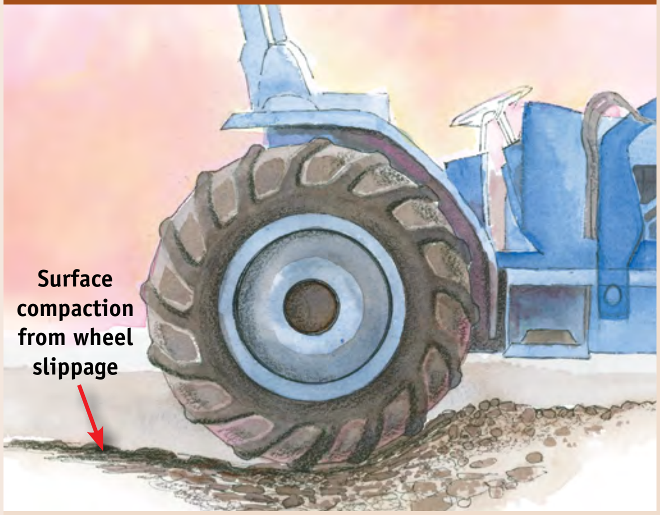
Deep compaction is a layer of high density well below tillage depth (>50 cm or 20 in.) and is usually 15–25 cm (6–10 in.) thick.

High axle weight (>10 tons/axle) exerts pressure on moist to wet soil aggregates. Heavy traffic when soils are moist to wet at this depth compounds the compaction problem.

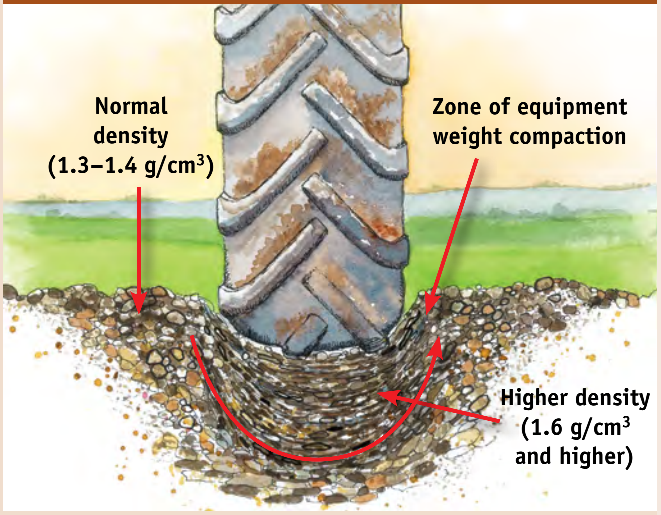
However, if the entire soil profile is dry, the risk of deep subsurface compaction is much lower, even with higher axle loads.

Deep compaction is very hard to remediate since it is so deep in the profile. Some researchers consider deep subsurface compaction to be permanent.

COMPACTION BY WHEEL SLIPPAGE



COMPACTION BY WEIGHT



Compression from farm equipment can cause soil particles to become compacted from wheel slippage (left illustration) or weight (right illustration) into a smaller volume. As particles are compressed together, the space between particles (pore space) is reduced, thereby reducing the space available in the soil for air and water.

Soil texture can also affect the potential for subsurface compaction. Some soil minerals are more prone to compaction. Fine textures (clayey and silty soils as shown here) are easily compacted. But very fine sand can compact as well if there is a lack of organic matter to act as a buffer.

Conditions where subsurface compaction is likely

SOIL CHARACTERISTICS

Soil texture

- Soils that are 10–35% clay and less than 2% organic matter (sandy loams to clay loams) are more prone to compaction.

Soil structure and aggregate stability

- Fine, weak aggregates are prone to compaction.

Bulk density and porosity

- Soils with low porosity or a low proportion of macropores will reduce infiltration rates and permeability, which will accelerate saturation of the subsoil and make soils more prone to compaction.
- Poorly drained soils or soil/site positions where subsurface drainage systems are less effective at removing excess soil moisture are more prone to compaction.

NATURALLY COMPACTED SOILS

Some soils are naturally compacted at depth. Soil parent materials (>60 cm or 2 ft depth) may have higher bulk densities if they were deposited thousands of years ago by advancing glaciers or under the weight of deep water (e.g., post-glacial lakes). These soils often have massive (shown here) or platy soil structures that will restrict rooting depth and internal drainage. For the most part, this should be considered a permanent condition.

Soils with unstable aggregates caused by excessive tillage and low organic matter levels are prone to tillage and subsoil compaction.

WATER TABLE AND TILE CHARACTERISTICS

Water table

- Fluctuating water tables may cause saturated conditions near the tillage depth, which results in smearing and compaction of the soil in the vicinity.

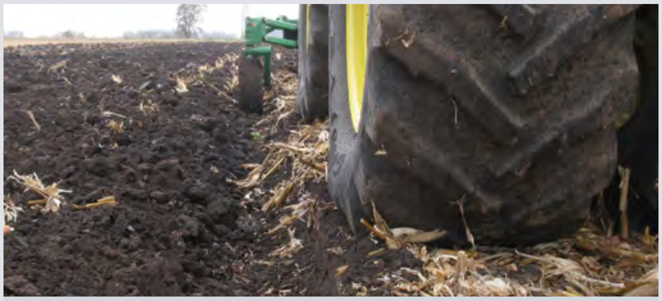
Subsurface drain depth and spacing

- Closer and deeper tiles keep the water table levels low and consistent throughout the field.
- A greater distance between lateral pipes will result in a higher water table level between laterals. These wetter soil conditions are more prone to subsurface compaction.

Tile spacing directly influences how low the water table is kept under the field. Large spacing allows for the water table to creep up between lines. Closer tiles keep the water table at a consistent lower depth across the field as indicated in this aerial image. In the image above, the subsurface drainage tiles are running north and south as can be seen from the slightly darker green lines of vegetation. Wider-spaced tiles would result in greater colour variation across the field due to a higher water table between tile runs.

PAST AND PRESENT MANAGEMENT THAT CONTRIBUTE TO COMPACTION

- Intensive and frequent tillage leading to organic matter and soil structure breakdown
- Tillage at the same depth and with the same implements year after year
- Heavy axle weights leading to deep compaction
- High-pressure narrow tires leading to surface compaction, which eventually extends deeper into the profile
- High frequency of traffic across fields
- Poorly timed field operations (too wet)
- Specialty crops with short windows for planting and harvesting, and intense seedbed preparation and harvesting procedures
- Grazing pastures when wet



Plowing and cultivating to the same depth each year, especially when soils are wet, will reduce porosity, increase density, and lead to the formation of plow pans.

A habit of conducting field operations on wet soils – as with this harvest of canning peas – is a leading cause of subsurface compaction from tillage and traffic weight.

Subsurface compaction is related to axle weight. Surface compaction is related to contact pressure at the surface when there are no tillage passes to alleviate it (as with no-till systems).

Diagnostics for subsurface compaction

Subsurface compaction is best verified by digging a soil pit and looking closely at soil structure, soil density and crop roots. However, there other indicators such as ponding in fields and stunted crops that can be a direct result of subsurface soil compaction.

Field, crop and soil diagnostics for subsurface compaction are described below. Use these to verify that you have this form of degradation in your soil.

FIELD OBSERVATIONS

- Surface ponding
- New wet spots
- Runoff and erosion
- Perched water table and waterlogged soils at depth
- Plow pan at 10–25 cm (4–10 in.) depth

Ponding after rain events is often evidence of subsurface compaction. Ponded soils are more susceptible to higher rates of greenhouse gas emissions of methane (CH_4) and nitrous oxide (N_2O).

Compacted headlands are prone to runoff.

CROP OBSERVATIONS

- Uneven, spotty emergence
- Stunted growth
- Visible crop differences in wheel tracks
- Root tips that are flattened or swollen
- Restricted or lateral root growth through and above compacted layer
- Root disease (vegetable crops)
- Nutrient deficiencies or general discoloration (such as nitrogen and potassium)
- Wilting in dry years and waterlogged in wet years
- Yield reductions of 10–20%

Use a shovel to look at roots of stunted crops. Roots that are flat or swollen in dense soil are an indicator of subsurface compaction.

Stunted growth in high traffic areas often indicates subsurface compaction. In dry years, some compaction can benefit yield. But in wet growing seasons, crop yields decline.

SOIL OBSERVATIONS

- Platy, blocky, dense, or massive layers at depth
- Increased bulk density at depth
- Few root or earth worm channels at depth
- Gleysolic (grey) soils at depth
- Mottling at depth
- Reduced soil biota

Plow pans are considered severe if dense platy or blocky structure shows evidence of a perched water table, i.e., a zone of mottles (rust-coloured blotches) and/or gley colours overtop of a zone of soil colours indicative of good drainage.

A layer of dense blocky or platy soil structure indicates subsurface compaction.

A soil bulk density core is a cylindrical core cutter (@ 75 x 75 mm) with a bevelled end. The core is pounded (using a mallet and block of wood) into a soil profile to obtain a sample. The complete sample is weighed and divided by the known volume to determine the bulk density (weight/volume) of the sample. Results exceeding 1.6 g/cm^3 are considered compacted.

A soil penetrometer is a diagnostic tool that measures the extent and depth of subsurface compaction. It consists of a gauge, handles, shaft and tapered pressure-sensing point. The shaft of the tool is marked-off to help determine depth. A pressure gauge reads pressure in psi. Relative density can be estimated by noting pressure readings and depth as the investigator pushes the unit into the soil. Relative density can also be assessed using a tile probe, as shown in this photograph.

Best management practices (BMPs)

✓ **Avoid subsoil compaction.**

- Time field operations to stay off moist or wet soils.
- Reduce axle loads by reducing axle weight or increasing number of axles.
- Reduce the number of trips.
- Reduce the surface area of traffic by following laid-out tramlines – this will limit traffic to certain areas.

Timing field operations to avoid moist or wet conditions will help to reduce the risk of surface or subsurface compaction. Dry soils are more resilient to tillage and traffic.

✓ **Reduce the risk of surface compaction.**

- Reduce tire pressure.
- Change to flotation tires.
- Switch to radial-ply tires.
- Use larger-diameter tires to increase length of footprint.
- Use four-wheel drive tractors.
- Use tracks for poorly drained soils.
- Adjust ballasts to reduce axle load.
- Check moisture content at depth – avoid traffic on moist to wet subsoils.

Lowering tire pressures in the field increases the amount of tire touching the soil. This distributes the weight across more area, resulting in less weight and compaction.

✓ **Make soils more resilient to compaction.**

- Add organic amendments.
- Switch to conservation tillage – no-till, mulch tillage, ridge tillage to reduce structural degradation and loss of organic matter.
- Protect soils with residue management and cover crops to increase organic carbon and to cushion the soil surface.
- Reduce excess soil water by improving subsurface drainage systems.

✓ **Rehabilitate compacted soils.**

- Select cover crops with deep taproots (e.g., oilseed radish) to break up plow pans.
- Rotate crops with deep-rooted crops (legumes) to break up plow pans.

Adding 20 tonnes/ac/year of composted leaf and yard waste from urban centres will increase the organic matter level of a loamy soil by 1% in about 15 years. Soils with higher organic matter levels are more resilient to compaction.

Soils with high infiltration rates store more water for the growing season and reduce cropland runoff rates. Soil compaction reduces infiltration. Fast-growing, deep-rooting post-harvest cover crops, such as cover crop radish, have taproots that will create macropores in the soil that will penetrate and break up plow pans – improving water entry.

For more information

ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS

Many sources of supplementary information are available.

Below are some suggestions to get you started. Most can be found online at **ontario.ca/omafra** or ordered through ServiceOntario.

- *Agronomy Guide,* Publication 811
- *Cover Crops: Adaptation and Use of Cover Crops*
  omafra.gov.on.ca/english/crops/facts/cover_crops01/cover.htm
- *Cover Crops Following Cereals and Late-Summer Harvested Crops*
  omafra.gov.on.ca/english/crops/field/news/croptalk/2014/ct-0614a5.htm
- *Soil Erosion – Causes and Effects,* OMAFRA Factsheet 12-053
  omafra.gov.on.ca/english/engineer/facts/12-053.htm

Best Management Practices Series

- *Controlling Soil Erosion on the Farm*
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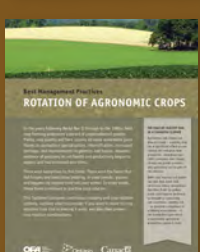

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- #15, *Soil Management*

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