Santé des Sols

2 – Soil Profile
6 – Bulk Density Test
8 – Infiltration Test
10 – Drainage System Test
12 – Compaction
15 – Tractor Balancing
16 – Occupy the soil with roots
18 – Cover crops
24 – Cover crops and crop rotation
26 – Cover Crop Characteristics Tables

Dig a little, learn a lot!

Agriculture more than ever

Québec

Soil Profile

What is the purpose of conducting a soil profile?

- An essential tool for improving profitability.
- General knowledge of the soil: physical and biological properties.
- Understanding soil fertility: physical, biological and chemical properties.
- Diagnosing problems in specific areas in a field or on the farm: low yields, low profitability.
- Identifying corrective measures: Tile drainage, leveling or cleaning of the ditches? Direct seeding or sub soiling? Changes to the crop rotation? Introduction of cover crops?

How to make a soil profile

- Dig an 80 cm deep hole in an area representative of the area to be examined.
- To conduct a diagnosis, dig 2 soil profile holes: one in poor soil conditions and the other in good soil conditions.
- Profile + field history + soil analysis.
- Can be completed in the spring or in the fall, preferably at the same time each year.
- Examine physical, biological and chemical soil properties over the whole profile.

PHYSICAL	BIOLOGICAL	CHIMICAL
Texture, pedology	Residues and decomposition	Hydrochloride (HCl) test
Structure	Roots	
Bulk density (BD)	Macropores	
Colors and mottling	Earthworms	
Water flow	Smell	

What do you see...?

1. Texture: Examine the proportion of mineral particles: sand particles (as well as proportions of gravel and pebbles), loam and clay. Sandy soils are not worked in the same way as the clayey soils.
2. Structure: Examine soil particle arrangement and organization. A good soil structure should be lumpy and friable. About a quarter of the soil volume should be occupied by aeration pores, and another quarter by waterlogged pores. Such a structure is also indicative of soil biological activity, especially in the surface soil.
3. Density: Evaluate soil density and detect compacted layers by running a knife at a 45 degrees angle along the profile.
4. Color: Color is a very good indicator of soil aeration. Good soil aeration gives a reddish hue (rust color) to the soil and poor aeration gives a grayish color. The presence of a grayish layer could indicate a compaction, or a perched water table problem. The closer the problem appears at the soil, the worse is the problem. In one case as in the other, the roots will not be able to penetrate the grayish layer. All crops should take root in a well aerated soil environment (roots breathe). It is surprising just how deep roots can go; 1.2 to 1.8 meters for corn and alfalfa and 0.9 to 1.2 meters for cereals.
5. Smell: A very foul smell indicates lack of ventilation which slows down soil decomposition processes. This could be due to soil compaction or burial of crop residues too deep in the soil profile.
6. Root development: Crops (alfalfa, corn, etc.) require at least a 60 cm rooting depth, and sometimes 100 cm rooting depth. Examine the state of the roots. Are they stunted or branched? In what directions are the roots growing? Are the roots properly nodulated?
7. Crops residues: Look at their state of decomposition. Earthworms are indicators of good soil aeration and a marker of active microbial life.
8. Machinery impact: Look for signs of frequent heavy machinery passages and intensive soil cultivation practices.
9. Crop nutrient status: The most common plant deficiency is not nitrogen, but rather… oxygen.
10. Observe soil water infiltration dynamics.
11. Look for water presence and observe its movement. See page of one side of the profile can be a flow hypodermic sign. Water seepage on only one side of the hole can be a sign of subsurface runoff (water circulates within the upper soil layers and leaches dissolves soil organic carbon and nutrients). Water seepage all around the soil profile hole indicates a perched water table. If water rises from the bottom (less than 60 cm from the soil surface), and only in this case, underground drainage should be considered.
12. Start pondering about solutions that are efficient and adapted to your farm. There are often inexpensive and very accessible such as: respecting the soil's bearing capacity, subsoiling; simplifying tillage practices; cleaning waterways or implementing waterway landscaping strategies.

Soil structure evaluation

Take a shovelful of soil to assess and separate the aggregates. A healthy soil should have a rough and porous surface as an indicator of adequate biological activity and aeration. Crush the soil clods (lumps) and rate their firmness. A dry ground will be firmer than what it actually really is and a clayey soil is friable even if it is compacted.

These two samples come from the same fields

The soil on the right has a better structure than the soil on the left which is more compacted. Compaction results of a bad long term treatment where there is less space for water, air and roots. Root growth and nutrition are therefore limited.

Aeration

- A soil in good condition is well aerated. Soil color varies from brown to yellowish brown or red.
- Following a poor plowing, the horizon under the plowing depth can develop a blue-grey color.
- The transitional area of a soil in bad condition is usually blue, grey or green and may emit a foul odour.

Lumpy soil structure, well ventilated soil, deep roots

Indirect assessment of biological activity

A soil with good structure, adequate organic matter aeration, proper biological activity and pH should be able to decompose manure that was applied in the fall or spring by the end of the following summer. Crop residues should be scarce and friable a year and half after their incorporation.

Macroporosity of biological origin: earthworm galleries, spaces left by roots or visible spaces between soil aggregates are some indications of good soil biological activity.

Presence of roots in horizon A

The root system

Characteristics of roots grown in compacted soils and their causes

The more a soil is friable and well structured, the more the plant may easily develop its lateral root system ("hairy" roots). Lateral roots enable the plant to cover a greater volume of soil. In a well-structured soil, 2/3 of the roots have a diameter smaller than 0.2 mm (invisible to the naked eye). Soil researchers measure total root length in terms of kilometers of roots per cubic meter (m3) of soil. If you see large roots, which branch off at a 90 degrees angle, it is a sign of poor soil structure. The root system should be observed in detail. Solely relying on looking for large roots at the soil's surface is not sufficient for a good diagnosis.

- Superficial root growth: hard clods under the roots
- Horizontal root growth: compact and lamellar soil structure
- Root growth in biopores: only worms can penetrate the compacted area
- Rooth growth in soil cracks: presence of two compact soil clods
- Stunted taproot growth (corn) and overdevelopment of the lateral roots just over a compacted soil layer indicates that the taproot could not penetrate the compacted soil layer

Adapted from: Évaluation visuelle de l'état du sol, CRAAQ

Structural stability

Structural stability measures the ability of aggregates to resist deterioration when wet or hit by raindrops. This is an important indicator of surface sealing, lack of aeration and root penetration difficulty. An easy do-it-yourself test can be done by submerging a soil clod in water and observing how it reacts. Fast clod disaggregation indicates poor soil stability.

Bulk Density Test

Essential equipment:
Knife, hammer, piece of wood, 170 cm^3 volume stainless steel cylinder, scale, clean plastic bag, oven proof or microwave proof recipient, stopwatch

Methodology:

1. Soil bulk density (BD) must be evaluated at the soil surface and/or in a compacted area.
2. Take the stainless steel cylinder having a volume of 170 cm^3.
3. Clear the soil all of debris. In case of need, cut the vegetation close the soil surface. Insert the cylinder into the soil.

4. Remove the cylinder from the soil. Avoid losing soil in the cylinder by digging a hole all the way around the cylinder and under its base before prying the cylinder up to remove it.
5. Using a flat-bladed knife, remove excess soil at the base of the cylinder. The base must be flat and at level with the edges of the cylinder.
6. Weigh the empty plastic bag before putting the soil sample in the bag. Identify the bag and close it tightly.
7. Weigh the soil sample while it is inside the bag. Calculate the sample's weight by subtracting the empty bag's weight from the total weight. This value is referred to as the soil sample's wet mass.
8. Weigh the oven proof recipient. Transfer the soil sample in the recipient. Dry the sample is an oven heated at 100°F for a 6 hour period. Alternatively, a microwave oven can be used. If opting for the microwave, transfer the soil in a microwave proof recipient. Heat the soil sample at 30 second intervals and weigh the sample after each interval. Repeat these steps until the soil sample weight lectures are the same 3 times in a row. Do not cap the recipient in order to let water evaporate from the sample.
9. When the soil sample is completely dry, determine the soil sample's dry mass by weighing it and subtracting the recipient's weight.
10. Conduct the BD calculations shown on the next page.
11. Repeat steps 1 to 10 on 4 different areas to get a representative result.

Calculation of the MVA and the water content of soil

BD (g/cm^3) = dry mass (g)/cylinder volume (cm^3)

It is possible to measure soil water content and porosity with the data collected:

Water content (g/g) = (wet mass - dry mass)/dry mass x 100

Texture	Ideal BD (g/cm^3)	BD that may affect root growth (g/cm^3)	BD that restrains root growth (g/cm^3)
Sand, loamy sand, sandy loam	<1.6	1.7	>1.8
Loam, sandy clay loam, clay loam, silt, silt loam, silty clay	<1.4	1.6	>1.8
Sandy clay, clay, clay loam (35 45% clay)	<1.1	1.5	>1.6
Clay (> 45% clay)	<1.1	1.4	>1.5

Note :
1,0 g/cm^3 is equivalent to 1,0 ton/m^3.

Crops cope differently with soil density. Corn is less tolerant than alfafa to high density soils. Optimal BD is 1.0 g/cm^3 for corn, 1.2 g/cm^3 for soybean and cereals and 1.6 g/cm^3 for alfalfa.

Tiré de Issoufou, I. (2013) Évaluation de la qualité des sols, Trousse d'analyse

Infiltration Test

Essential equipment :
Knife, hammer, piece of wood, bottle of water, cylinder (10 cm diameter), plastics bags, stopwatch

Méthodologie :

1. Using the piece of wood and hammer, push the white cylinder in the soil at a 2.5 cm depth.

2. Pack the soil lighlty around the cylinder ***(figure 1).***

3. Completely cover the cylinder and the soil within it with the plastic bag. ***(figure 2).***

4. Pour 2.5 cm of water into the cylinder. This amounts to 200 mL of water for a 10 cm diameter cylinder. Slowly remove the plastic bag and let the water infiltrate the soil completely.

5. Repeat step 4. Pour 200 mL of water on the plastic bg. Remove the bag and start timing with the stopwatch. Stop timing when soil surface inside the cylinder gleams and when the soil has absorbed 2.5 cm of water ***(figure 3).***

6. Repeat the infiltration test to various depths and to various places in the field to have elements of comparison.

1

2

3

4

Infiltration Rate and Classification

Infiltration rate (min/2.5 cm)	Classification
< 30	Very fast to fast
30-60	Moderately fast
60-90	Medium to slow
> 90	Slow to waterproof

Take the time to contact your advisor to deepen your investigation

Interesting facts

Soil pores are excellent soil health indicators. Large and uniformly distributed pores at the soil's surface enable fast water infiltration.

The infiltration rate is very sensitive to soil surface and topsoil conditions. Water infiltration rates influence the level of biological activity and root growth. It also enables timely agricultural practices and soil management strategies.

Adapted from: Issoufou, I. (2013) Évaluation de la qualité des sols, Trousse d'analyse.

Drainage System Test

Drainage System Efficiency Test

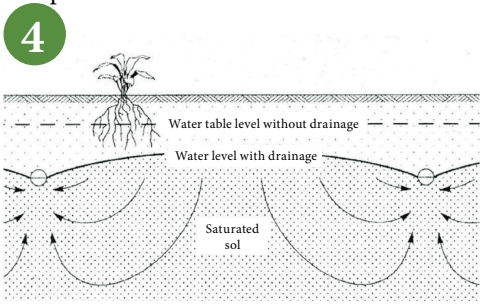
- **Compaction :** Intensive soil bed preparation, natural and deep clay, poor water infiltration or impermeable soil
- **Material :** defective drain
- Roots ***(figure 1)***, muskrats and clogged outputs
- **Drain establishment :** stone under the drain ***(figure 2)***, stretched drain, crushed drain, improper drain connexion ***(figure 3)***, drain installed on a counter slope

How to design a drainage system

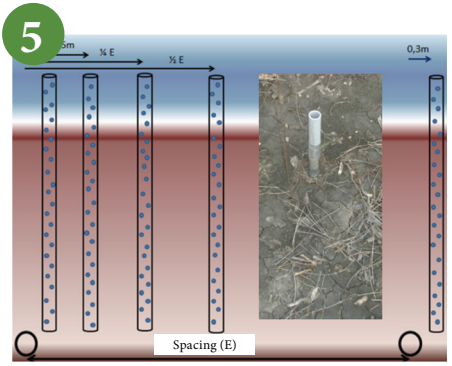
Acquire knowledge of how water flows in drained soils ***(figure 4)***. Use an infiltrometer. Install soil wells ***(figure 5)***.

Observe and understand

Conduct soil profiles and analyze soil horizons. Analyze soil macroporosity, water infiltration capacity and tillage induced soil compaction.



Photos : Jacques Robert



Before getting drains installed

Underground drainage should be installed with the sole purpose of lowering the groundwater water table. Too many fields were drained in order to remove surface water. In most cases, we find that the deeper we dig, the drier the soil, and so, even in an area where surface water accumulates (basin).

In such cases, the problem is not a high groundwater water table, but rather a slow water infiltration problem caused by:

* excessive pulverising of the soil in its upper horizon
* compaction of a lower soil layer or horizon

Soil levelling cannot correct an infiltration problem.

If you are levelling to empty your water puddles and to encourage lateral surface runoff towards the ditches, stop immediately! Vertical infiltration might simply your problem.

If this is the case, soil leveling might worsen your problem. It will further reduce water infiltration as a result of the levelling blade (and the weight of the equipment) over pulverising the soil. In addition, it could deprive the crop from water which it will probably greatly needed later on in the season.

A simple telltale test

1. **Dig.** Use a spade preferably before planting. Make one or two 75 cm deep holes, preferably before planting, with a round point shovel.

2. **Observe.** There are three (3) possibilities :
   a. No water is entering the hole;
   b. Water enters the hole and it originates from the soil's surface or the hole's walls;
   c. Water gradually fills the hole from the bottom up.

3. **Choose the right correction strategy.**
   Underground drainage should be considered only in scenario 2c, or, in previously drained fields where drains need to be unclogged or repaired. Underground drainage is justified only when water raises 60 cm or less from the soil surface. In such cases, drains will lower the water table and enable adequate root penetration.

Soil auger surveys are less reliable than those made with a round point shovel. The soil auger's narrow diameter does not enable a proper view of where the water originates from (hole walls or bottom of the hole).

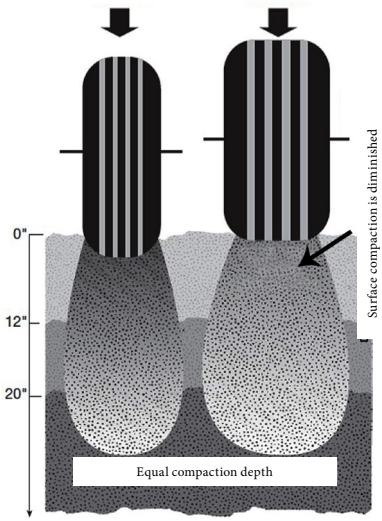
Compaction

Water puddles persist on the soil's surface? Alfalfa stands are found solely where the drains are buried? Low yields are measured especially in damp places? These are signs of surface water infiltration problems most likely caused by compaction.

What to do? There is no shortcut. Soil profiles must be carried out at 75 to 80 cm depths in areas of the field where hard pans are likely to be found. Monitor compaction presence by identifying its location and depth. Your agronomist can be very useful with this investigation.

Compaction symptoms:

- Density: A small knife is an irreplaceable instrument for assessing a more compact soil horizon. Apply small taps with the knife on a 45 degrees angle along the entire soil profile wall. Doing so will help you identify hard pans (if applicable). Note the depths at which you found the hard pans.
- Structure: The soil will disintegrate in large blocks under hand pressure. If the sol is really compacted, then it will not disintegrate at all.
- Color: All soils, regardless of their texture (clay, loam, sand) develop a greyish hue when they are deprived of oxygen. Properly aerated soils develop a rust-brown hue.
  The presence of rust spots ("mottling") in a greyish layer is indicative of slow water infiltration capacity.
- Presence of water: A profile hole dug in a compacted soil will have water seeping from its sides in wet soil conditions. When a profile is dug in a soil with underground drainage problems (undrained or clogged drains), water will gradually fill the hole from the bottom up.
  In severe compaction problem, soil will be moist at the surface and dry at the bottom.
- Root development: Compaction inhibits root growth, even in the case of alfalfa and forage radish.



The figure below shows the tire mark against the ground surface according to the tire's surface area. Note that compaction occurs at the same depth, even at equal weight per axle. This explains how tire pressure affects surface compaction, while axle weight affects compaction depth.

What does compaction look like?

It is important to remember that the axle weight determines compaction depth.

Compaction type	Average depth (cm)	Most common causes	Corrective measures
Surface	0-18	Excessive soil pulverization when preparing soil bed, stubble mulch tiller	Harrowing, soil structure improvement, cover crops
Tillage pan	18-30	Tillage in wet conditions	Area-till, strip-till, chisel
Deep	30 - 75	Heavy machinery passages, wet soil conditions	Subsoiling , crop rotation, cover crops, preventive measures
Natural	Endless, gradual	Shallow soil, waterproof subsoil	Subsoiling, crop rotation, cover crops, preventive measures, with limited effects

Compacting soil is easier to do than ameliorating soil structure. For example, a severely compacted soil will require a much longer period without rain to enable subsoiling operations.

The deeper the hard pan is, the longer the dry period will have to last before subsoiling can be done. In such cases: i) subsoiling can only be conducted in August or early September; ii) sacrificing a crop production for one year could therefore be more realistic than hoping for a profitable harvest; and iii) cover crops are advisable to improve soil structure and increase subsoiling efficiency.

Such a sacrifice is counterbalanced by average yield improvement in the long run. When subsoiling in dry soil conditions, the machinery operator will feel a marked difference in soil resistance when transitioning between compacted and non compacted areas in the field. The soil between the subsoiler shanks (legs) should raise about 15 to 20 cm above the non compacted soil or that not yet worked.

Preventive measures

- Avoid any traffic on wet soil; otherwise limit ruts (tire tracks) to shallow depths (< 5 cm).
- Reduce machinery traffic in the field and adopt the reduced tillage or no till systems.
- Limit ground pressure exerted by farm equipment by opting for: radial tires, low tire pressure (103 kPa or 15 psi max., according to manufacturer's specifications), wide wheels with a large diameter and usage of dual wheels as needed.
- Limit the load per axle to 6 tons or less and always work in good soil conditions.
- Maximize all timeframes for manure spreading by prioritizing the most suitable depending on manure characteristics.
- Integrate cover crops and winter cereals in your crop rotations to lengthen the period were the soil is occupied by living root systems.

The ideal subsoiler

- Subsoiler shanks: 1, 3 or 5 at most, straight shanks or oblique shanks leaning towards the front, 75 cm spacing between the shanks, or adjust spacing at 1.5 to 2 times the working depth.
- Flat points: as narrow as possible, neither crown, nor chisel, nor flanged sweeps.
- **Working depth: must be at least 10 cm below hard pan.**
- Safety mechanism: safety bolt or spring on each shank to prevent breakage following a major shock.

Subsoiling is not a cure-all: the results are not always immediate. When well done, results are durable as long as compaction is not repeated. Subsoiling is a corrective measure that should be seen as a "patch" and not a recurrent tillage method.

Conditions for efficient subsoiling:

- 1st step: examine the soil profile many places.
- Soil condition: DRY soil at the full working depth.
- Working depth: 10 cm below hard pan.
- Work direction according to field slope and drainage system orientation: this aspect is of little importance. The exceptions are when you are working in a steep slope, or when the shanks cannot reach the entire hard pan. In such cases, work diagonally to the slope or drains.

Straight subsoiler shanks without sweeps can work down to a 70 cm depth.

- Cover crops: it is advised to use cover crops to improve soil structure and increase subsoiling efficiency. If a crop season is sacrificed, a winning strategy is to replace it with sorghum-Sudan grass. Otherwise, sow before subsoiling operations (at least several days) to stimulate microbial life and active root system development as soon as possible.
- Do not enter the field until the following spring.

Tractor Balancing

Ground adhesion goals :

- Obtain a tractor power/weight ratio for an optimal energy transfer from the engine the ground.
- The ratio takes into account: soil type, soil moisture and ground speed.
- The following formula is used:

Ratio lb/HP = 625/speed (mph)

Source : A theoretical basis for tractor ballasting recommendations

The following table shows the optimal values:

Speed (mph)	< 4,5	5	>5,5
Tractor type	lb/HP		
Two wheel drive (front wheel drive)	130	120	110
Four wheel drive	110	100	90

Adjusting tire pressure

Tractor weight adjustment
Optimal measurements are essential when adjusting tire pressure to limit soil compaction. The table below presents values that limit soil compaction:

Tractor type	Hitched front/rear	Semi-mounted front/rear	Mounted front/rear
Two-wheel drive	25/75 %	30/70 %	35/65 %
2 + 2	35/65 %	35/65 %	40/60 %
Four wheel drive	55/45 %	55/45 %	60/40 %

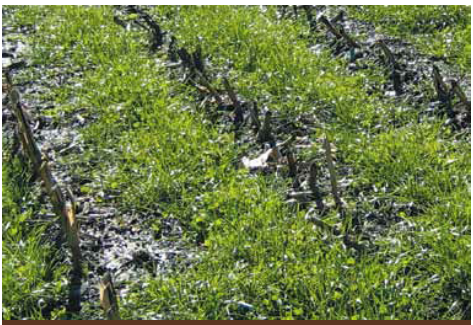
Source : Vincent Lamarre, Choix et utilisation des pneus de tracteurs, impacts sur la compaction et la consommation de diesel.

Occupy the soil with roots

No-till soybean crop grown on a rye cover crop

Cover crops are used with the goal of maintaining a living root system for as long as possible in the ground.

A cover crop is a plant (or a mixture of plants) sowed after or during the main crop's growth. The main goal is for the cover crop to actually cover the ground. This crop will not be harvested. It will be returned to the soil for the leftover nutrients captured by the crop to be returned to the soil.



Ryegrass and clover stand after a corn crop

The cover crop will be destroyed :

- either by winterkill where plants will be flattened and form a mulch;
- either by rolling or burning it down before or after planting the main crop in the spring.

Mustard and barley stand

Goals

1. Create a physical barrier to deter weed growth.
2. Produce and restore consistent biomass (whole plant) to the soil.
3. Allow the recirculation of soil nutrients.
4. Limit water and wind erosion.
5. Reduce temperature fluctuations at ground level and protect soils organisms against UV rays.
6. Reduce machinery passage impacts (improve soil bearing capacity).
7. Use taproot plants (radish) as they have good decompacting properties.
8. Build the soil: fibrous roots (grasses) can help improve surface soil structure.
9. Increase biodiversity in the crop rotation by including plants that are not related to the main field crops (different plant family).
10. Break disease and pest cycles.
11. Increase soil organic matter and biological life; the soil system's productivity.
12. Reduce chemical inputs (fertilizers, herbicides, fungicides, insecticides) and, thus, production costs.

Clover used as a cover crop in wheat

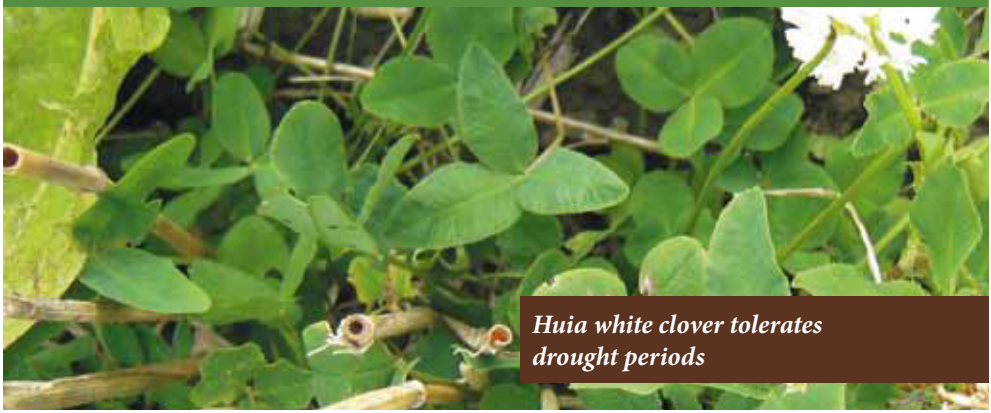
Cover crops: the broad principles

The idea is to maintain complete plant coverage in a continuous manner.

Conventional cropping systems quickly mineralize a small amount of biomass and produce little humus. Whereas systems under permanent plant coverage slowly mineralize a large amount of biomass and produce much more humus. To increase soil organic matter, it is necessary to bring more biomass in the soil than the amount which was mineralized.

It is thus necessary to choose the type of plants to be incorporated into the crop rotation according to the: i) desired specific effects; ii) actual and upcoming crop; and iii) available means to control or eliminate the cover crop.

Cover crops



Huia white clover tolerates drought periods

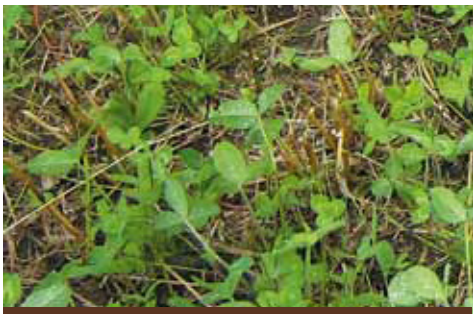
Legume Family

White clover

It has 4 times more seeds than the same weight of red clover seeds. 3kg/ha are enough. It tolerates drought periods and is very resistant to trampling, thus ideal in access roads. Prefer the Huia to Ladino cultivar. The Ladino cultivar becomes too high.

Red clover

Sow 10 to 12 kg/ha when cereals are at the tillering stage or 5kg/ha if clover is sown at the same time as the cereal. Red clover should be preferred in clay soil because it tolerates humidity better than the other clover cultivars. On the other hand, it is sensitive to drought.



Red clover is best suited in clayey soils because it tolerates wet conditions

Wait until August 1st when sowing in a mix with forage radish for the seeds to benefit from ideal cool and wet establishment conditions. Slow establishment will leave an opportunity for weeds to grow.

Crimson clover

Benefits: tolerates shade, excellent intercrop option in: spring and winter cereals, canola and corn. Produces small biomass volumes (does not interfere with main crop harvest). Contributes 60 to 70 kg N/ha to the following crop. In most cases, herbicide treatment is not required to destroy the cover crop, as it cannot survive the winter. Sow 12 to 15 kg/ha when sowing with a spring cereal, or in spring when sowing in winter cereals. It can be sown after post emergence herbicide application in cereals or corn.

Vetch

Grows very well in fall when the other plant growth has stopped and has a rapid growth in spring. It can be sowed in association with 60 kg/ha of rye or oats in spring or 4-6 weeks after main crop emergence. When sown with cereals in spring, cereals will act as a support for the vetch and compete against weeds (vetch is not very competitive in its early developmental stages).

Vetch provides large volumes of organic matter or forage. Plant it on hills, where organic matter is scarcer and soil is drier. Hairy vetch does not survive in areas where wet soil conditions persist. It can be destroyed with a pre-crop emergent herbicide application in corn.

Hairy vetch is a biennial plant which can occasionally survive to winter.

Common vetch is an annual plant which does not survive to winter.

Austrian winter peas

During a cool and wet year, plant coverage nitrogen turnover can reach up to 200 kg/ha and plants can grow 90 cm high. It will survive winter if it is sown in July.

After an early soybean harvest, peas can be sown with oats or oilseed radish which will protect them from the frost. A 6-week growth period is necessary to ensure good plant coverage. Pea growth will be vigorous until late autumn. In muck soils, peas will produce a lot of biomass without generating many pods. Peas are sensitive to mold. Plant residues degrade rapidly in spring. Therefore, do not rely on peas to create mulch in order to suppress weeds.

Austrian winter peas can be sown with oats or oilseed radish

Microbial peak activity phenomenon

When a cover crop is destroyed just before sowing the main crop, decomposition processes are activated. This multiplies the microbial population which, in turn, releases big quantities of soluble sugars in the soil. Microbes have a hard time making the distinction between sugars released by the decomposing cover crop and those released by the germinating corn seed. They will therefore attack the corn seed and its radicules. This phenomenon is sometimes wrongly interpreted as nitrogen immobilization for residue decomposition.

To avoid this phenomenon, destroy the cover crop three weeks before sowing the main crop or right after having it has been sown. Microbial activity will therefore have time to return to its normal level. Rye can also be harvested as forage feed.

To maximize plant coverage an ensure winter survival, rye must be sown before the end of September. Rye seed can even be mixed directly in the liquid manure tank. Seeding rate will not be uniform but young plants will benefit from readily available nutrients. Winter rye will not head out if it is sown as an intercrop in spring (rye requires frost [vernalization] in order to complete its life cycle). Such intercrop trials were conducted in soybeans and gave good results.

Grass Family

Cereal regrowth

Cereal regrowth is desirable after combining. Just make sure crop residues are uniformly distributed throughout the field. Add some diversity to this regrowth by seeding some crucifers, legumes or seed mixtures containing cover crops that come from different plant families.

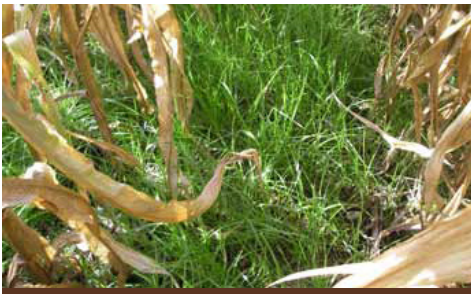
Annual ryegrass

Annual ryegrass (and crimson clover) is one of the few species that can tolerate being sown in corn. Ryegrass seed can be broadcast between each row at a 15 kg/ha rate when the corn reaches the 6-8 leaves stage. Ryegrass greatly improves soil structure and soil bearing capacity at harvest. It protects the soil against erosion. However, it is harder to destroy chemically and can become a problem when it's not properly controlled.

Ryegrass can be sown when manure is spread in the fall. It will survive to winter and can easily be destroyed afterwards. If ryegrass is not fertilized properly, most of the plant stand will die out before winter and the remaining plants will be harder to destroy. Apply a herbicide when ryegrass plants reach 5 to 12 cm high or, at the latest, during heading, to have proper ryegrass control.

Scouting is essential afterwards to ensure that the herbicide application was efficient.

Burndown applications are most efficient when days are cool and nights are warm. It's better to stop the spraying before 3 or 4PM. After that, plant stomas close and spraying is less effective.



Ray-grass : between corn rows, it improves the bearing capacity of the field during harvesting.

Fall rye

Very versatile, we can use only it as a cover crop and destroy it in spring, or let it grow until the end of May to be harvested as forage (before heading out), or even leave it until maturity, (July) and harvest it as a cereal with a good straw yield. Rye is one of the hardiest species; the only species that we can plant after corn and before soybean. It contributes to weed control, as well as all the others benefits of a cover crop. It will survive winter and regrow in spring

Warning

Corn after rye can be risky because the decomposition of rye takes a lot of nitrogen and can cause deficiencies in corn. Only a soil with an excellent health and with high organic matter content can counteract this phenomenon.

The next crop, soybean preferentially, will be seeded trough the standing rye coverage. The rye can be destroyed chemically right away after seeding with glyphosate or later after crop emergence if the crop is glyphosate tolerant. It's not recommended to destroy rye in the days previous to seeding the main crop because it will flatten, retain ground moisture and harm the crop emergence. It is suggested to wait three weeks after a burn down before seeding the next crop. Spreading liquid manure on rye that was already burned down before seeding allows for a faster breakdown.

Rye destroyed after heading will yield the best results. It's two or two and a half months after burning where there is the highest point of nitrogen release. Rye helps to decrease soybean cyst nematode impact and soybean sudden death syndrome. It creates an important amount of roots that can reach 75 cm deep in the ground.

It is well adapted to wet and acidic soil, also to cool conditions but doesn't survive in water puddles that can freeze during winter. Rye can transmit blight to the following wheat crop.

Rye destroyed after heading will yield the best results.

Tillage radish : The roots goes out the ground, when it reaches a hard pan.

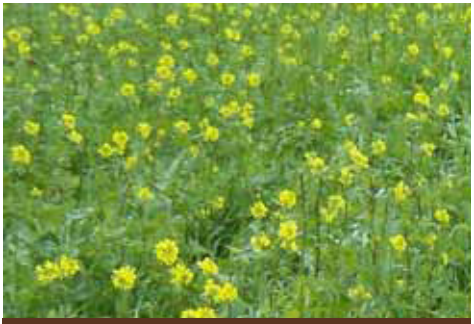
Brassica Family

Forage radish
A forage radish variety was selected for its swivel root, long and straight (Tillage Radish). In common oil or forage radishes, the roots change to bulb or develop two stems when it reaches a hard pan.

The forage radish will keep its single and straight root, but it lifts the ground while it grows and the aboveground part is 20-30 cm high when it reaches the hard pan. The tuber can go to a depth of 35 cm and the root can reach 75 cm in depth. Seed before the second week of September (it needs a growing period of 6 weeks before frost for a good coverage). It gives less results if it sown in spring.

Winterkill. A "natural herbicide" is released during the decaying of the radish that destroys weeds around the root.

Radish and mustard
Brassica plants (radish, mustard) are goods covers crops to introduce before wheat and oat.



Mustard: grows quickly in cold seasons, can reach 60 cm in height

When decaying, radishes give off a bad smell like natural gas. Radishes cause a flushing effect in the spring, because the snow melts very quickly into the holes left from the large roots after decomposition, allowing the soil to warm up quickly.

Sow forage radish after cereals with manure for an optimal growth. It can be sown with a precision seeder equipped with a beet seed plate, at 37.5 cm with companion crops like peas or barley, or at 75 cm, near future corn rows. It provides excellent control for winter annuals because of its quick growth. It suppresses nematodes and to increase yields in the future crop by, in spring, providing good quantities of nitrogen, calcium and phosphorus recovered from the ground. It increases yield when seeded (2kg/ha) with winter wheat.

Radish Seeds

Radish seeds mixed in a liquid manure tank (bag of 25 kg/tank) and spread will not be eaten by the birds. Fertilizing radishes this way will allow them to reach their full potential.

Mustard

The plant grows quickly during the cool season. It can reach 60 cm in height when mature and can resist early frosts. It doesn't leave much aboveground residue in spring which allows for a no-till follow-up. It can transmit clubrot (not recommended for fields traded with cabbage and broccoli producers). Less expensive, but needs manure to develop well. It can smother legumes. It can suppress soil nematodes when it's chopped and buried. White mustard incorporated in the crop rotation after wheat and before potatoes, has fungicidal properties and can reduce the potato verticillium wilt incidence. Brassica family plants generally like well drained fields.

Hydrophyllaceae family

Phacelia

Honeyplant used as forage crop or nectar plant that prefers light soils. Emerging in 20 days, you have to use the seeder because it's a photosensitive plant, that won't germinate if expose to light.

Slow starting, so not very competitive at beginning. It germinates at around 15°C. Once well established, its abundant canopy can control adventitious plants, even couch grass.

Phacelia: absorbs potash in the soil and liberates it when it decays

Can be intercropped with corn or can be a catch crop after cereals. It can help to build up soil structure with its root system and be very useful on soil prone to crusting.

You can seed it until mid-August, at the latest, to have a good crop (it needs 3-4 months to complete its cycle). It can be seeded as a winter cover crop in orchards and vines, even if it is destroyed by frost. When mature, it can reach heights of 1.20 m and flattens itself on the ground. Phacelia mulch is not enough to control weeds in spring. This crop absorbs potash and liberates it when it decays. It can be seeded in a mix: 8kg/ha with 40 kg/ha of buckwheat. Phacelia flowers in 50 days. When intercropped, we have to be sure that the main crop won't flower at the same time, because pollinator's insects can prefer phacelia. Its flowers also attract aphid predators. It produce a biomass of 1.2 to 4.5 t/ha and suppresses nematodes. There's no known parasitic species for this crop.

Polygonaceae Family

Buckwheat
Usually seeded at a rate of 50-70 kg/ha. Sparse populations give a chance to the crop plants to branch and provide good weed control. Buckwheat creates a good canopy and generates a good root network that helps to build good surface structure. It absorbs a lot of phosphorus that cannot be absorbed by other crops and after, releases it. You have to be careful, because it is destroyed at first frost, so seed it early enough (after winter wheat for example) to give it a chance to grow well.

It is an attractive honeyplant to bees and aphids predators. Flowering can start 3 weeks after seeding and can spread out to 10 weeks. Don't let it go to seed because it can be a weed in the following crop.

Has a good allelopathic effect and can be used to "clean" a field full of weeds. It grows quickly. Well adapted to poor fields, but doesn't like soils that are compacted, too dry or too wet.

Remarks

Legume association in cereals and cereals in legumes work very well.

Allelopathic effect is the production of substances by the plant that can interfere with the germination and growth of others plants. They are natural herbicide liberated either by the living or decaying plant.

Legumes recycle calcium and all minerals.

Rye smothers weeds and volunteer corn in Roundup Ready soybean field.

Buckwheat:creates a good plant coverage and generates a network of important roots

Cover crops and crop rotation

Intercrop

Cover crops seeded after the main crop, during the main crop's growing season or just before its harvesting.

Catch crop

Cover crops seeded after main crop harvesting.

Crop	Intercrop Crop Possibilities
Wheat	Clover and Ryegrass;
	Living hay field slightly damaged by a half dose of herbicide in spring;
	Broadcasted seeding of peas + vetch before harvest.
Grain corn	Mustard + Forage peas + buckwheat;
	Vetch;
	Living hay field slightly damaged by a half dose of herbicide in spring;
	Ryegrass.
Soya	Oats + Mustard + Buckwheat seeded in soya when it has lost 20% of its leaves.

Crop	Catch Crop Possibilities
Wheat	Phacelia;
	Buckwheat + Hairy vetch + Sunflowers; (Forage radish can be added is a "flushing effect" is desired in spring)
	Ryegrass;
	Rye + Forage radish;
	Rye;
	Tillage radish
Corn	Rye.
Soya	Oats + Vetch;
	Ryegrass;
	Rye.

Buckwheat, peas and vetch: creates a large biomass

Seed Mix Example

Mixes are interesting to do, because they increase the biodiversity, helping to increase biomass and bringing different root systems to the soil:

- Sunflower + phacelia + peas + vetch;
- Rye + hairy vetch + peas;
- Rye + forage radish;
- Buckwheat + hairy vetch + peas + white clover + mustard + sunflower.

Practical advice

1 Choose cover crop depending on the required needs

- Good nutrient management, N source
- Soil stabilizer
- Erosion control
- Helps reduce compaction
- Weeds control
- Pest control
- Increases soil bearing capacity, better traction
- Mulch retains soil moisture
- Improves biodiversity

2 Crop rotation analyzed to see best opportunities for covers crops

Fall seeding must cover ground at least 6 weeks before frost. Winter cereals, wheat and especially rye, are an exception and can be seeded a little bit later. If plant coverage and N recycling needs are minimal, rye can be seeded as late as the first week of frost.

Ideally seed the cover crop just after the harvest. In the cool climate, you can have a larger window for interseeding a cover crop that has a certain resistance to shading before harvesting main crop. White clover, annual ryegrass, rye, hairy vetch, red clover are shade tolerant.

If you interseed, it's better to do so before a rain. Species with smalls seeds, like clover, don't need much moisture to germinate and also can find their way through a small residue layer. However, large seeds need many days of moisture before germinating. Ensure adequate light from cover crop, seeding must take place before the main crop closes the row completely or just before plant canopy opens (for example when soybeans leaves turn yellow).

3 Do some trials

In a small field (it is best to make some trials on 1 hectare, always on the same field), clearly define your goals for the trials for 2 to 5 species or mixtures. Keep in mind; you will have to regulate a few things (like the seeding rate, and seeding date) to have the best results.

4 Data collection and observations

Location, field history and size, seeding method and rate, seeding date, weather conditions, rain after seeding, germination rate, growth vigor, height periodically measured during growth, and plant coverage estimation, weed pressure, biomass evaluation, first frost date, climate conditions, cover crop destruction method, residues before the next crop, survival rate for winter crop in spring, and overall trial appreciation.

5 Answer the following question

Did the chosen cover crop:

- Establish easily and was easy to manage?
- Do its job successfully?
- Compete with the main crop?
- Have versatility?
- Perform well under different conditions?
- Adapt to my equipment?
- Provide an affordable option?

Second Year
Increase the test plot. Don't expect immediate economic benefits, some advantages are hard to evaluate.

Legend poor★ medium★★ good★★★ very good★★★★ excellent★★★★★		Legumes						Brassica			
	Crimson clover	Trèfle blanc ladino, Trèfle Huia (blanc nain)	Sweet clover	Faba bean	Forage peas (i), winter peas (ii)	Common vetch	Trefoil	White mustard (i), Brown mustard (ii)	Forage radish, Oilseed radish, Tillage radish	Forage turnip	Kale
Pure seeding rate (kg/ha)	15-20	6-10	10-15	150-200	60-100	40-50	10-15	8-10 (i); 3-4 (ii)	8-12	6-10	10
Seeding depth (inches)	1/4-1/2	1/4-1/2	1/4-1/2	1-1 1/2	1-1 1/2	1/2-1 1/4	1/4-1/2	1/4-3/4	1/4-3/4	1/4-1/2	1/4-1/2
Water needs	★★★★	★★★★	★★★★	★★	★★	★★★	★★★	★★	★★★★★	★★★★★	★★
N source	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★ (i), ★★★★(ii)	★★★★★	★★★★★	★	★	★	★
Mulch persistence	★★★	★★	★★★★	★★	★★	★★		★★★	★★	★★	
Soil builder	★★★★★	★★★★	★★★★★	★★★★★	★★★	★★★★	★★★★	★★★	★★★★	★★★	★★★★
Quick growth	★★★	★	★★	★★★	★★★★	★★	★★	★★★★	★★★★★	★★★★★	★★★★★
Decompacting potential	★★★	★★	★★★★★	★★★★	★★	★★★	★★★	★★★	★★★★★	★★★	
Weed control	★★★★	★★★	★★★★	★★★	★★★	★★★★	★★	★★★★	★★★★	★★★★	★★★
Allelopathic effect			★★★★★		★★	★★★		★★★★	★★★★	★★★★	
Easy to destroy	★★★	★★	★★	★★★	★★★ (i), ★★(ii)	★★★	★★	★★★ (i), ★★★★ (ii)	★★★	★★	★★★★
Mycorrhiza use	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★	★	★	★

Legend poor★ medium★★ good★★★ very good★★★★ excellent★★★★★	Grasses									Others			
	Annual ryegrass	Rye	Pearl millet (i), Japanese millet (ii)	Spring oats (i), Black winter oats (ii)	Triticale (rye x wheat)	Sorgho-Sudan grass	Tall Fescue	Festulolium	Bunch grass	Phacelia	Buck-wheat	Rattle-pods	Flax
Pure seeding rate (kg/ha)	15-25	70-100	12-15 (i), 15-20 (ii)	35-60 (i), 70-100 (ii)	80-120	15-30	15-20	30-35	10	8-12	50-70	20-25	20-30
Seeding depth (inches)	1/4-1/2	3/4-1 1/2	1/2-1	1/2-1 1/2	3/4-1 1/2	1/2-1 1/2	1/4-1	1/4-1	1/4-1/2	1/4-1	1/2-1	1/2-3/4	1/4-1
Water needs	★★★★	★★★★	★★	★★★★	★★★★★	★★★★	★★★	★★★★	★★	★★	★★★★		★★★★
N source	★	★	★	★	★	★	★	★	★			★★★★★	
Mulch persistence	★★★★	★★★★★	★★★★	★★★★★	★★★★★	★★★★					★		★★★★
Soil builder	★★★★★	★★★★★	★★★★	★★★★	★★★★	★★★★★	★★★★	★★★★	★★★★	★★★	★★★	★★★★	★★★★
Quick growth	★★★★	★★★★★	★★★★★	★★★★★	★★★★	★★★★★	★★★★	★★★★	★★★★	★★★★	★★★★★	★★★★	★★★★
Decompacting potential	★★★★★	★★★★	★★★ (i), ★★(ii)	★★	★★★	★★★	★★★			★	★	★★★	★★★★
Weed control	★★★	★★★★★	★★★★	★★★★★	★★★★	★★★★★	★★★	★★★	★★★	★★★★★	★★★★★	★★★★	★★★
Allelopathic effect	★★★	★★★★★				★★★★★				★★	★★★★		
Easy to destroy	★★★★	★★★	★★★★	★★★★	★★	★★★★	★★	★★	★★★	★★★★	★★★★★	★★★★	★★★★
Mycorrhiza use	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★★★★	★	★★★★	★★★★

Practical advice for successful no-till

Thirty producers who had experience with no-till were consulted to make a technical list of success factors.

1) The very first thing to do

- Follow a training to acquire the bases on no-till;
- Visit and meet producers who have experience;
- Plan steps to follow through with transition: fields to prioritize and crop rotation to establish.

2) Soil

- Choose the best field to start;
- Drain, level and lime the field;
- Take soil analysis and make necessary correction
- Evaluate the structural stability.

3) Residue management

- Ne pas trop hacher les résidus à la récolte, laisser les tiges longues;
- Bien répartir les résidus sur toute la surface du sol;
- S'équiper de tasse-résidus (optionnel).

4) Fertilizer

- Considered the contribution of solid and liquid manure;
- Don't neglect nitrogen starter;
- Make some trials before greatly reducing fertilizers.

5) Crop rotation

- Have a minimum of three crops (ex.: corn –soybean-cereals);
- Avoid seeding the same crop two years in a row;
- Brake disease and insect cycle by rotating plants families.

6) Cover crops

- Capture nutrients for the following crop;
- Choose the plant that fits with the needs;
- Make some trials with different crops under different management.

7) Weed control

- Burndown before seeding;
- Destroy perennials in fall (ex.: burndown dandelions before cereals);
- Rotate herbicides families to avoid resistance.

8) Machinery modifications

- Use custom work at first before investing a lot of money in a seeder or modifying machinery;
- Adjust tractor tire pressure. Always check the results behind the machine;
- Have good row-cleaner and no-till fertilizer disk for the corn planter.

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