VÄDERSTAD

Make a diagnosis of your soil structure

Soil structure – the 3D design of the soil

Soil structure is by definition the 3-dimensional structure of the soil particles, i.e. how the sand, silt and clay particles are arranged in aggregates. The main binding agents are clay particles and humus. These form stable clay-humus complexes but also glue together the sand and silt fractions into aggregates.

Processes that create structure

The inherent parent material in the soil decides what type of structure the soil will have. On sandy soils the structure formed does not differ very much from the original material. On the other hand, the structure of a clay soil is the result of different processes that act and interact in the soil.

1. **Plants** dry out the soil through the uptake of water. This water uptake forces the clay particles closer to each other, thereby forming aggregates. This is one reason why a ley with grass and clover is a brilliant way of using set-aside land in a long-term strategy, whereas leaving the soil bare in a fallow is a poor alternative as the soil does not dry out. Another reason is that the mucilage from roots and the organic material from plant residues support the formation of a good structure by adding raw material for humus formation.

2. **Drainage** also dries out the soil and leaves it friable in the spring. Drainage is a precondition for even and sufficient soil drying and a basic foundation for structure formation.

3. **Earthworms** eat the organic material from plant residues, thereby mixing it with the mineral soil. That is the start of the decomposition process. When the earthworms eat their way through the soil they create a fine network of tunnels and channels that can involve 4000 - 5000 km on one single hectare. This network is a basic requirement for the drainage and aeration of the soil.

4. **Organic material** is the feed for the soil fauna, e.g. earthworms. Regular applications of slurry, manure and all sorts of plant residues are beneficial for soil structure formation as they support the microorganisms and the soil fauna by feeding them. In return, they stabilize aggregates since the humus that is formed when they break down the organic material binds together the mineral soil. This is especially true on lighter sandy soils where there are no clay particles that can act as binding agents.

5. **Liming** is important for structure formation on clayey soils. The calcium ions force the flat clay particles together, thereby forming small microaggregates.

6. **Drought and ground frost** both act in the same way, by drying the soil out, either by evaporation or by forming pockets of ice lenses. When the soil dries out, the particles are pressed together mechanically and form aggregates. Freezing and ground frost can be important in the topmost soil layer, where the cycle of freezing and thawing is repeated. However in deeper layers, freezing is often overrated as a structure-forming process. A proper drought in the summer has a much bigger influence on subsoil structure.

Earthworms – indicators of soil fertility

In a normal soil on an arable farm, one can find 100,000 - 1,000,000 earthworms per hectare with a biomass of 100 - 700 kg/ha. Earthworms play a very valuable role in soils when they carry out their work. Through their action they increase the drainage and aeration of the soil when they open up tunnels for water and air down to the subsoil.

Porosity increases

Besides the effects of worm-induced drainage and aeration, soil physical properties are also influenced in other ways. The porosity increases and the bulk density decreases when the earthworms dig their way through the darkness of the soil layers. The soil cultivation work that the earthworms do therefore substantially increases the number of macropores (diameter > 0.5 mm) and creates a network of channels and galleries in the soil. This network - 4000 - 5000 km per hectare stretching down to 3 metres - acts as a "motorway system" for roots in the soil. In one year, earthworms bring around 2 - 90 t/ha of soil to the soil surface as casts.

Better availability of nutrients

Soil biology is also enhanced as the earthworm activities stimulate microorganisms and actively spread fungi and bacteria in the soil profile. Finally, the soil chemistry is influenced as the availability of practically all nutrients increases when the organic material passes through the worms. The nitrate concentration is approximately 8 times as high in excrement from earthworms as in the surrounding soil. These casts from earthworms act as "glue" between soil particles and augment aggregate stability.

Earthworms are sensitive to many ingredients in modern agriculture, such as pesticides and soil compaction. Soil cultivation is also a delicate matter as it disturbs the worms and their network of channels. This is especially true during worm reproduction in October. Soil cultivation methods can be classified according to the harm they cause the earthworms. Direct drilling < spring tine harrowing < stubble cultivation < ploughing < rotavating. The effect of the plough is much debated among farmers. One study found that the plough brought up approximately 10 percent of the earthworm biomass to the soil surface. Of these 10 percent, approximately one third were eaten by birds and two thirds found their way back down again.

Feed your earthworms

To support the earthworms, one must feed them regularly. The best way of doing this is by having leys with grass and clover in the crop rotation. However, anything that increases the organic material in the soil also favours the earthworm population. Green manure and catch crops are therefore excellent earthworm feed. In only one year of active set-aside with a ley of grass and red clover, one can increase the number of earthworms by 100 percent in the following crop compared to if winter wheat was grown.

Earthworms are thus good indicators of the fertility of the soil. If the earthworms thrive, the crops will get on well.

"It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures" Charles Darwin

Examine your soil!

To make a diagnosis of your soil structure, e.g. if there are any compacted layers, if the worms thrive, if the roots make their way easily trough the soil, make the following tests:

1) Identify layers in the soil by
2) noting the resistance when digging, and then by studying the wall of the hollow.

For each layer then check:

3) occurrance of worms,
4) layers - e.g. colour, straw,
5) soil class,
6) structure - aggregates,
7) development of roots,
8) water permeability of the soil.

Preferably compare three hollows
To be able to make as good conclusions as possible, preferably perform the measurements in three hollows at three spots:

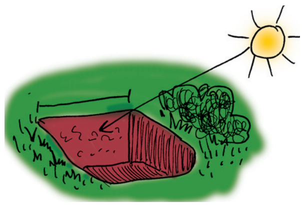
- One spot that represents the general conditions of the field.
- One extremely bad spot, e.g. the field entrance or another spot with a lot of traffic.
- One extremely good spot, e.g. a corner, a long side or undisturbed soil on the other side of the ditch. The soil structure here shows the ideal situation to aim for.

The purpose of this is to get a picture of what the differences are between the field and the extreme spots; what is possible to achieve and what is the worst case. The hollows should be placed not too far from each other, to make sure they have about the same prerequisites such as soil class etc.

Equipment
To conduct most of the tests you need only a spade, pencil, folding ruler and a knife.

If you also want to test the water permeability, you will also need a can, jug, watch, calculator and a piece of pipe (diameter approx. 17 cm, length approx. 12 cm).

Shape of the hollow
The wall of the hollow that you will examine should be directed towards the sun to give the best light conditions for your examinations. In order not to destroy the aggregates in this wall; do not walk on top of it and do not put the remaining soil there.



The hollow should be at least 50 cm deep (it may well be deeper if the roots stretch further down). The width should also be at least 50 cm.

1-2) During the digging
Note how much effort you need to dig the hollow. If it suddenly gets harder or easier, that indicates a new layer in the ground.

When the hollow is finished
Use the knife to brake loose the outermost layer. Feel and look to find the different layers in the soil with of straw etc. Usually you will find the layers:
A) topsoil (darker, rich in organic matter),
B) a more compact layer,
C) subsoil (undisturbed soil).

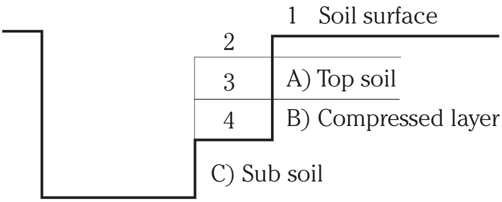
Mark the layers and their thickness in the record.

Examine each layer
After identifying the different layers; conduct all the different tests for each of the layers. For each test, mark the type that best describes each layer.

When you have finished all the tests, evaluate the results with help of the notes on page 11.

8) Test of water permeability
When it is time to test the water permeability of the soil: scrape off one layer at a time according to the drawing below. Then do the measurement on each layer, and on the soil surface as well. Preferably take measurements twice on each layer to increase the accuracy of the result.

NB! Before starting the measurment, saturate the soil with water by pouring approx. 0,5 - 1 litre of water in the pipe and let it soak into the soil.



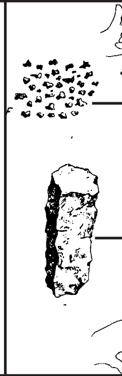
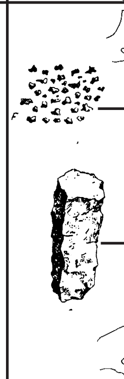
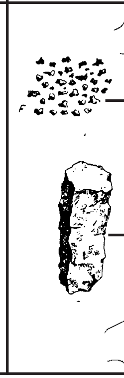
5) Scheme for soil classification of mineral soils
(Kungliga lantbruksstyrelsen, 1965)

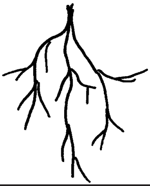
Size of particles (mm)	Clay (%)	"Rollingtest" thickness of the roll (mm)	Colour of dry subsoil
Gravel (20-2)	<2	impossible to roll	like redish sand
Coarse/medium sand (2-0,2)	<2	impossible to roll	like redish sand
Fine sand (0,2-0,06)	<2	impossible to roll	light grey or weak sandy colour
Coarse/medium silt (0,06-0,02)	<2	4 - 6 mm	light grey
Fine silt (0,02-0,002)	2 - 5	4 - 6 mm	greyish white
Loam	5 - 15	ca 3 mm	light grey
Loam	15 - 25	ca 2 mm	light grey
Clay loam	25 - 40	1 - 1,5 mm	light grey or light redish brown
Clay brown	40 - 60	1 mm	grey, greyish brown or redish
Clay	>60	<1mm	dark grey/ greyish brown

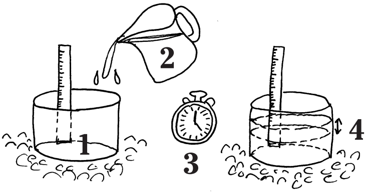
RECORD

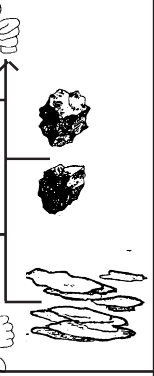
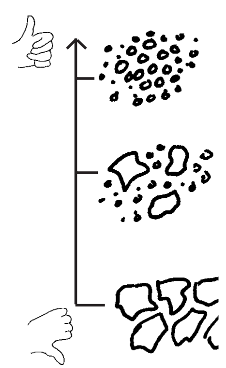
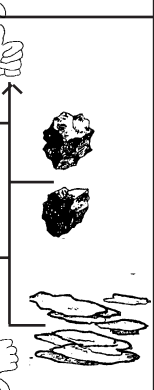
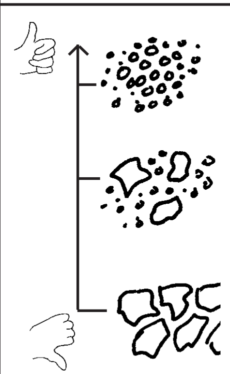
Date:
Field:
Crop:
Moisture:

☐ Repr. spot
☐ Excellent spot
☐ Bad spot

	2)Digging resistance (number of treads to fill the spade)	**3) Worms** number of worms per full spade (20x20x10 cm)	**4) Layer charac-teristics;** colour, straw etc.	**5) Soil classific.** (see table page 7)	**6) Characte… in s…** size (cm)	shape aggreg…
1) Layers **A** Depth/ thickness – cm ……………………	very loose 0 1 2 3 4–5 6–7 > 7 extremely compact	10 5 2 0				
B Depth/ thickness – cm ……………………	very loose 0 1 2 3 4–5 6–7 > 7 extremely compact	10 5 2 0				
C Depth/ thickness – cm ……………………	very loose 0 1 2 3 4–5 6–7 > 7 extremely compact	10 5 2 0				





...eristics of aggregates ...oils with clay		7) Root development		8)Permeability of water			
...e of the ...gates	stability of aggre-gates, pressure	(size, mm)	(number/ dm^2)	↕ (cm)	(min)	permeability (cm/min)	
		< 2 mm	200 50 20 1 0	SOIL SURFACE			0,7 0,07
		> 2 mm	20 5 2 1 0	LAYER A			0,007
		< 2 mm	200 50 20 1 0				0,7 0,07
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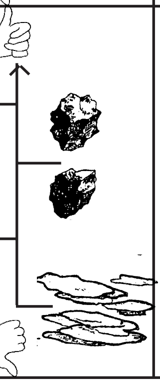	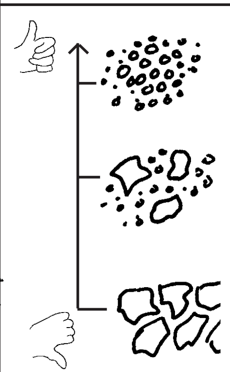	< 2 mm	200 50 20 1 0				0,7 0,07
		> 2 mm	20 5 2 1 0				0,007

Evaluation of the results

When you have conducted the tests on your three hollows, look through the records:

- Sum up the results for each hollow. What does each test say about the topsoil, compressed layer and subsoil respectively? Do all the tests point in the same direction or are there any differences?
- What are the differences between the field and the extreme spots?
- Does the soil in the field have a good structure?
- How could the soil structure be improved?
- Write down your thoughts and ideas.

Steps to improve soil structure
There are many possible ways to improve your soil structure.

Basic improvements
Techniques that improve the soil structure on a long term basis are:
- Drainage
- Liming
- Addition of external organic material.

Cultivational system
The cultivational system has both positive and negative impacts on soil structure. It is important to find a balance so that the factors that promote the soil structure dominate.

To decrease soil compaction important measures are for example good tyre equipment, low inflation pressure and to minimize the number of passes over the field.

Factors with positive impact on soil structure
- Roots; choose crops with good root systems, e.g. pasture, winter crops, legumes etc.
- Drying of the soil; a good root system dries up the soil.
- Organic material; e.g. leaving of straw in the field, use of manure.

Factors with negative impact on soil structure
- Field traffic; try to use machinery that decreases the number of passes.
- Bare soil; decreases with winter crops, pasture, cover crops etc.
- Soil compaction; decreases when using light machinery, good distribution of axle loads, low inflation pressure, few heavy passes.
- Driving on wet soil.

Steps to take

Conclusions	Planned actions to improve soil structure

Roots – a long network under your feet

Roots are the anchors of the plants and supply them with water and nutrients. The root system of a plant is usually as genetically determined in shape and form as are the leaves and stem above the soil surface. However, the environment in the soil (sandy soil, peat soil, clay soil) restricts the development of the roots. In a well-drained clay soil with a good soil structure, the roots of some plants can reach as far down as 2 - 3 metres.

Two different systems
Dicotyledons (herbs such as oilseed rape) have a root system consisting of a tap root with side roots.
Monocotyledons (grasses as cereals) have 3 - 5 primary roots coming from the seed and crown roots that origin from the basal part of the stem.
Approximately 20 - 30 cm behind the front of unbranched roots comes a highly branched zone.

High speed but limited draught
Roots move forward in the soil profile at a speed of 0.5 - 3.0 cm/day when they are growing at maximum speed.
However, the roots are dependent on cracks and channels in the soil for their growth, since their ability to create channels is quite limited. In a wet soil, the root tip can move soil particles, but in a dry soil the roots are obliged to use pores with a diameter larger than the root diameter. Mechanical resistance in a soil can be seen as thickened and branched root tips. Roots and earthworms interact so that roots grow in earthworm tunnels and earthworms use old root channels when they move around in the soil profile.

Thin threads
The roots are very effective in taking up nutrients and water in the soil. At the front of the root tip is the root cap, behind which is the growth zone where cells divide and elongate. Behind this comes a zone with fine root hairs with a diameter of approximately 0.01 mm and a length of 1 - 10 mm. Due to these root hairs the ability to absorb water and nutrients increases substantially. A wheat root with a diameter of 0.5 mm can reach an absorbing surface of 5 cm^2 per cm of root thanks to the root hairs. The root hairs secrete mucilage to increase the contact with the soil.

100 metres in 1 litre of soil
The efficiency of the root system to take up water and nutrients is a function of how well the roots can exploit the soil, often measured as the root length per cm^3 soil. In cereals, it is common to find 10 cm of roots/cm^3 soil in the topsoil, decreasing down to 0.1 cm of roots/cm^3 soil at a depth of 1 metre. This means that one litre of soil contains 100 metres of roots in the topsoil, but only 1 metre of roots at a depth of 1 metre in the profile. The root length per unit of land surface is also fascinatingly high. When standing on 1 m^2 of a sugarbeet field, one has approximately 10 km of roots under one's feet. Winter wheat has an even higher density of roots, with 30 km of roots/m^2. This means that one hectare of winter wheat is supported by 300,000 km of roots under the soil surface!

Straw decomposition – goes on down under

When straw is incorporated into soil, it is immediately attacked by fungi and bacteria. These microorganisms need carbohydrates for their growth and utilize the straw as a source of carbon and energy. This means that the weight of the straw decreases successively as the microorganisms feed and break it down.

Weight loss starts directly

If a stubble is turned into the soil in mid-September, it will have lost one third of its weight by mid-October. By the following spring, half of the straw weight is lost and in September of the following year only 10-20 percent of the straw weight remains. The rest of the carbon has become new bacteria and fungi, has been lost as carbon dioxide or has formed humus in the soil.

No need for extra nitrogen

During the decomposition process, the microorganisms also need nitrogen. In the very start of the decomposition, the process "steals" some nitrogen from the soil, thereby immobilizing this nitrogen out of the reach of plants. Approximately 3 kg N/tonne of straw is immobilized during this period. When half of the straw weight is lost due to decomposition, the process is reversed and the nitrogen is returned to the soil. Nowadays the levels of mineral nitrogen in soil are sufficiently high and nitrogen deficiency due to straw incorporation and N immobilization rarely occurs. However, it may still be seen on headlands or areas missed by the combine, where a lot of straw can be accumulated. The immobilization of nitrogen when straw is being broken down has the positive effect that nitrogen leaching is reduced over the winter, compared to if the straw had been baled or burnt.

Get the straw dirty

The process of decomposition starts as soon as the straw comes into contact with soil and the microorganisms can attack. This means that the depth of incorporation is insignificant as long as the straw has contact with the soil and the moisture is sufficient. The chop length of the straw is not significant for its breakdown, so there is no benefit in chopping it too finely as long as the cultivator can handle the amount of straw. However, things also happen when the straw is left on the soil surface. With three heavy showers of rain the straw can lose up to 90 percent of its potassium and 60 percent of its phosphorus, which leach back to the soil.

Scratching of straw important

Although the burial depth is unimportant, it is essential that the straw surfaces are scratched on passing through the combine. If not, the microorganisms have problems in attacking the organic structure of the straw. This is why for example a thatched roof can withstand rain, snow and microbial breakdown for decades. If thatching straw had passed through a combine, that would not be possible.

Straw incorporation increases fertility

The effects of regular straw incorporation - as opposed to straw burn – are better aggregate stability, more earthworms and a soil with a higher porosity and infiltration rate for water. Many a farmer around Europe has come to notice these effects since straw burning was banned.

The test is based on a research project
This soil structure test is an interpretation of a research project conducted by Kerstin Berglund, Örjan Berglund and Anna Gustafson Bjuréus at the Departement of Soil Sciences, hydrotechnics, at the Swedish university of agricultural science, SLU, tel +46 (0)18 67 10 00. A detailed description of the test is available in the report ”Avdelningsmeddelande 02:4”.

The soil structure test is intended to be used as a tool to learn more about ones fields. The test is a part of the development of a model for evaluating different cultivational system and their short and long term impact on soil structure.

VÄDERSTAD

VÄDERSTAD-VERKEN AB

SE-590 21 VÄDERSTAD • Sweden
Tel. +46 142 820 00 • Fax +46 142 820 10

www.vaderstad.com