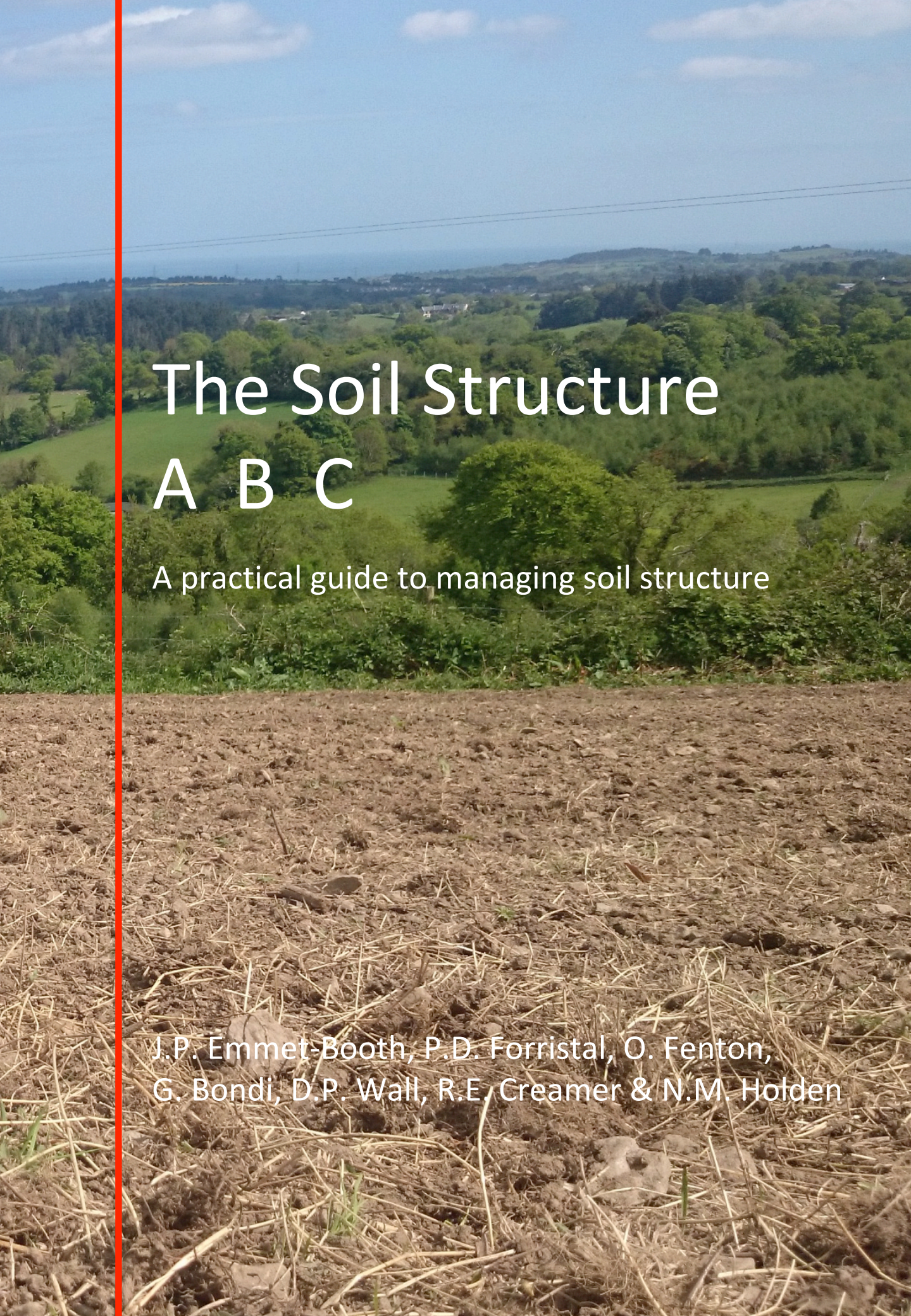




The Soil Structure A B C

A practical guide to managing soil structure

J.P. Emmet-Booth, P.D. Forristal, O. Fenton,
G. Bondi, D.P. Wall, R.E. Creamer & N.M. Holden

What greater a resource than the one on which our everyday existence is grounded. The physical fabric and matrix of Ireland itself, entrusted to a few, whose daily job is to manage and preserve the fate of future generations.
What an honour!

Quick introduction

When you think about it, the soil is both the physical and productive basis of your farm and therefore the basis of its economic success and future. Soil is your single most important asset, without which, the farm simply would not exist! It makes sense to ensure that this capital resource is maintained at the highest quality possible. Soil quality or soil health is directly linked to soil structure. It is vital to conserve and enhance soil structure, a feature that farmers largely have direct control over. Unfortunately, soil structure can be easily damaged and if severely, it can be difficult to put right. Luckily, soil structure is relatively easy and quick to visually assess directly in the field, so it should be obvious if farm management is having a negative impact and steps can be quickly taken to prevent further damage. This handbook aims to:

- A Describe what soil structure is and why it is so important
- B Show how to evaluate soil structure in the field
- C Give recommendations on how to manage soil structure

As routine assessments of crop yields, crop growth or soil nutrient and pH levels are necessary, it is also important to assess soil structure. In fact, soil structure underpins a lot of the other things that are assessed. It is hoped this handbook provides a practical and useful guide for the management of this key soil property.

A

for architecture

What is soil structure?

There are three parts to soil structure: (1) form, (2) stability and (3) resilience¹. Structural form is perhaps the most important part when considering what soil structure actually is. Stability and resilience are useful when considering management and are discussed on page 13.

Soil structural form can be described as the architecture of the soil². This is because structural form refers to the physical construction of the soil or the arrangement of the soil aggregates, like building blocks in a wall. The building blocks or aggregates are simply naturally formed clumps of soil. These clumps are formed when sand, silt and clay particles stick together forming tiny aggregates. The tiny aggregates then stick together, forming larger aggregates which in turn stick together, forming even larger aggregates - with lots of tiny pores and cracks within them. The larger aggregates then lie together within the soil with gaps and spaces between them. The pores, cracks, gaps and spaces, both within and between the aggregates, are referred to as the soil porosity.

So, soil structural form is about the solid aggregates, but also the empty spaces and pores within and between the aggregates. You can imagine that how the aggregates are arranged or clump together, affects the porosity within and between the aggregates.

Never confuse soil structure with soil texture!

Soil structure describes the physical arrangement of soil constituents or the architecture of the soil. Soil texture describes the proportions of sand, silt and clay particles that make up the soil. Soil texture will affect soil structure, but they are not the same thing. Soil structure can be changed by management, soil texture can rarely be changed.

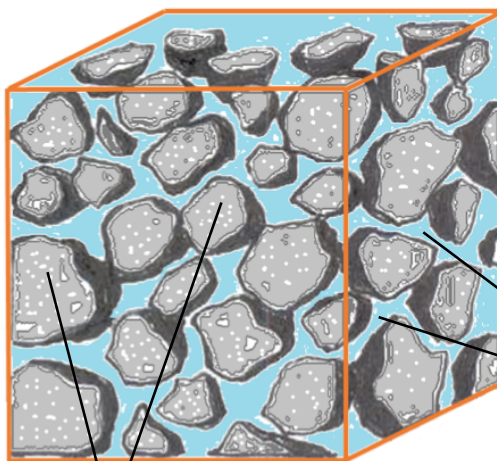
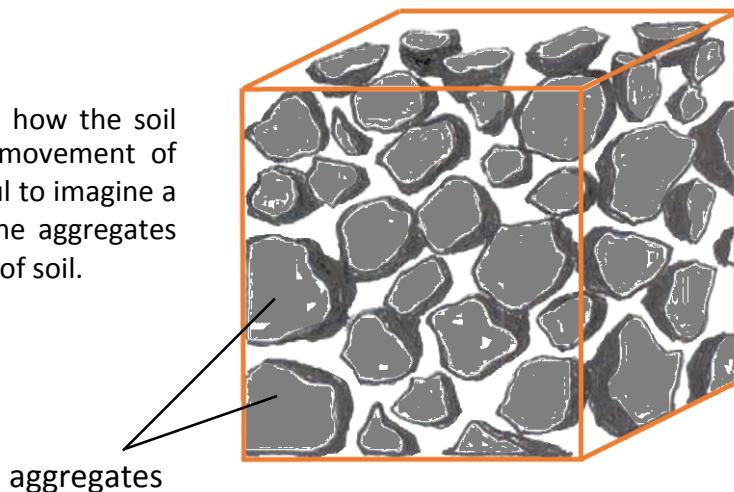
aggregates

Why is soil structure so important?

Who cares!

As we have learnt, soil structure can be described as the “architecture of the soil”. Just as the architecture of a building determines how that building will function, the architecture of the soil will determine how the soil functions. The arrangement of the aggregates and pores directly controls the movement of water and air within the soil, which indirectly impacts soil temperature. Soil moisture, air and temperature affect all life within the soil, including plant roots, earthworms along with millions of micro-organisms. Soil structure ultimately impacts crop yields, fertilizer use efficiency and pollution. **Damaged soil structure has a cost, in terms of production, economics and the environment.**

First, let us understand how the soil structure impacts the movement of water and air. It is useful to imagine a cube of soil for this. The aggregates sit together in the body of soil.

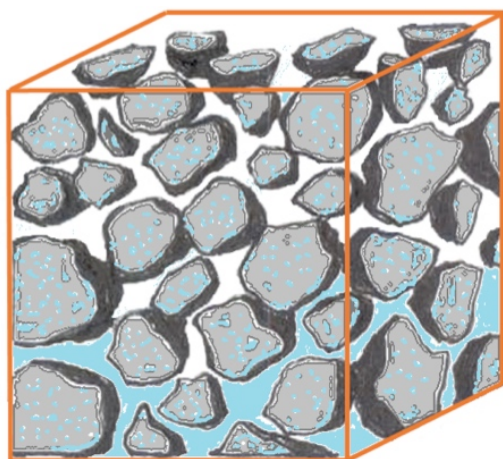
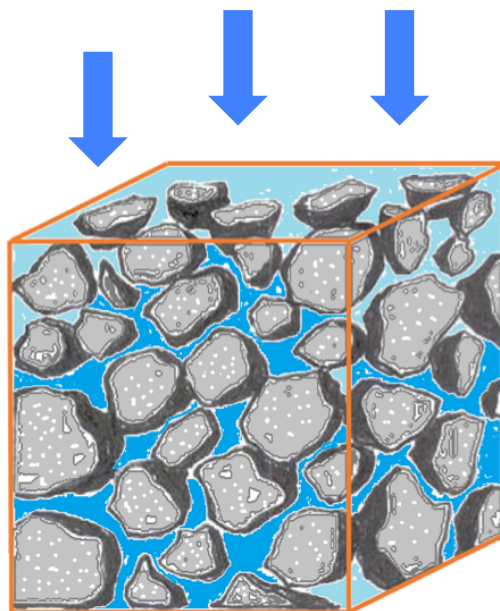


The spaces between the aggregates, highlighted in blue, are the macro-pores or “inter-aggregate porosity”. However, the aggregates themselves also have spaces and cracks inside, forming micro-pores or “within-aggregate porosity”.

macro-pores

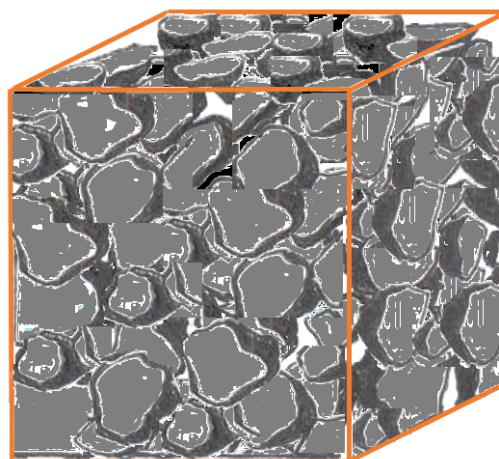
micro-pores

When it rains, water will gather on the soil surface and should start to drain down through the soil, filling the macro-pores with water. Depending on soil drainage, water will also soak into aggregates, filling the micro-pores.



Once the rain stops and if the soil structure is not damaged, a proportion of this water will gradually drain down through the macro-pores. However, the micro-pores may retain some of the water. It is important that excess water drains away, so that the soil is not water-logged and air is allowed back in, but also that some water remains to sustain the soil life including plants. Macro-pores allow the rapid drainage of excess water, while micro-pores help to retain or store some water for future use.

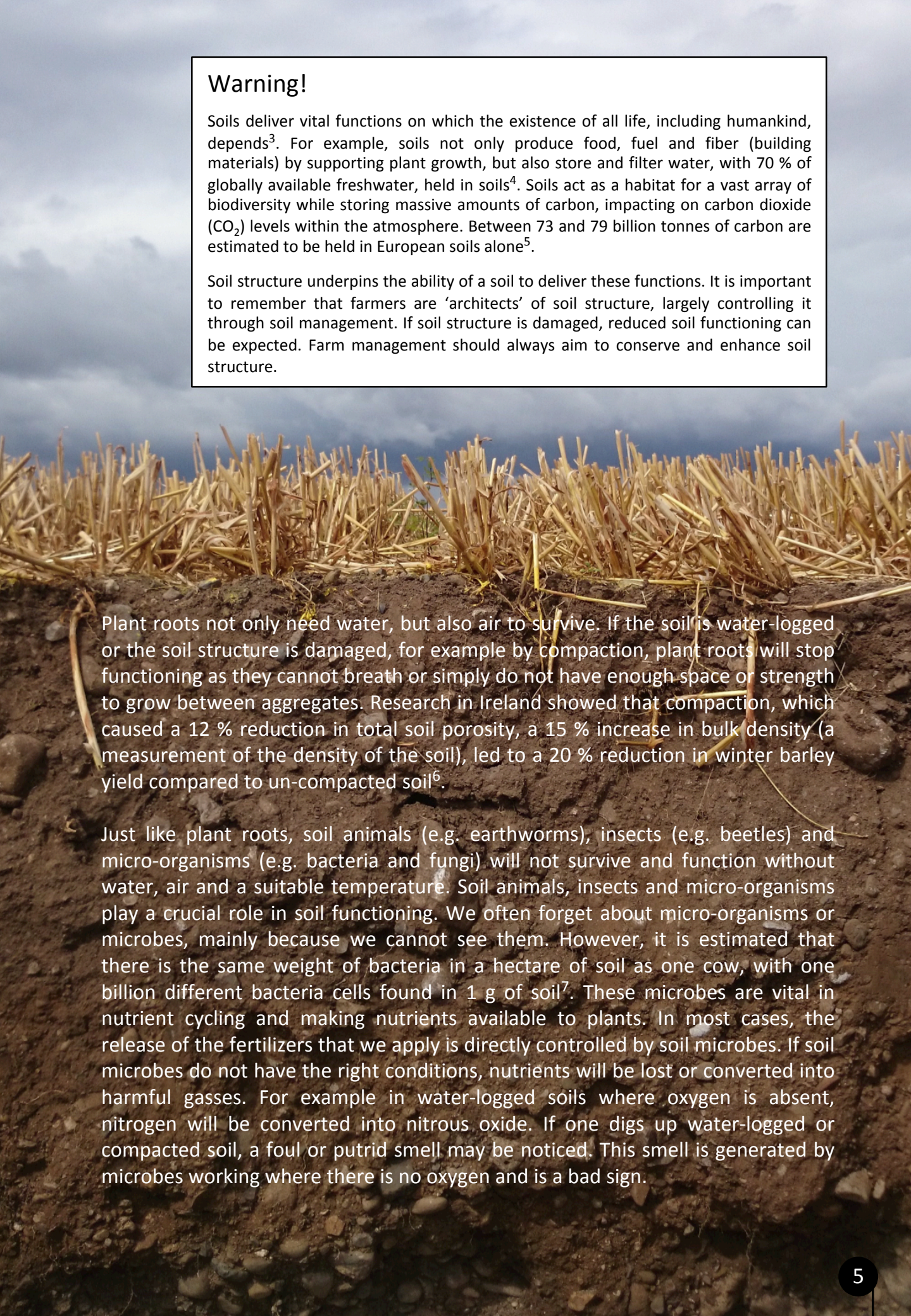
Soil structure is commonly damaged by soil compaction. Soil compaction is simply the squashing of the soil aggregates together, reducing the amount of macro-pores and in severe cases, reducing the amount of micro-pores. Imagine that the cube of soil was compacted, not only does the cube now contain less air, but rain water will be restricted from draining through, leading to water-logging or water to run-off over the soil surface.



Warning!

Soils deliver vital functions on which the existence of all life, including humankind, depends³. For example, soils not only produce food, fuel and fiber (building materials) by supporting plant growth, but also store and filter water, with 70 % of globally available freshwater, held in soils⁴. Soils act as a habitat for a vast array of biodiversity while storing massive amounts of carbon, impacting on carbon dioxide (CO₂) levels within the atmosphere. Between 73 and 79 billion tonnes of carbon are estimated to be held in European soils alone⁵.

Soil structure underpins the ability of a soil to deliver these functions. It is important to remember that farmers are 'architects' of soil structure, largely controlling it through soil management. If soil structure is damaged, reduced soil functioning can be expected. Farm management should always aim to conserve and enhance soil structure.



Plant roots not only need water, but also air to survive. If the soil is water-logged or the soil structure is damaged, for example by compaction, plant roots will stop functioning as they cannot breathe or simply do not have enough space or strength to grow between aggregates. Research in Ireland showed that compaction, which caused a 12 % reduction in total soil porosity, a 15 % increase in bulk density (a measurement of the density of the soil), led to a 20 % reduction in winter barley yield compared to un-compacted soil⁶.

Just like plant roots, soil animals (e.g. earthworms), insects (e.g. beetles) and micro-organisms (e.g. bacteria and fungi) will not survive and function without water, air and a suitable temperature. Soil animals, insects and micro-organisms play a crucial role in soil functioning. We often forget about micro-organisms or microbes, mainly because we cannot see them. However, it is estimated that there is the same weight of bacteria in a hectare of soil as one cow, with one billion different bacteria cells found in 1 g of soil⁷. These microbes are vital in nutrient cycling and making nutrients available to plants. In most cases, the release of the fertilizers that we apply is directly controlled by soil microbes. If soil microbes do not have the right conditions, nutrients will be lost or converted into harmful gasses. For example in water-logged soils where oxygen is absent, nitrogen will be converted into nitrous oxide. If one digs up water-logged or compacted soil, a foul or putrid smell may be noticed. This smell is generated by microbes working where there is no oxygen and is a bad sign.

B

for breaking-down

How to assess soil structure in the field

Soil structure can be visually assessed by carefully **breaking-down** a sample of soil by hand and looking at different features. The state of the different features indicates, not only the ability of the soil to function (the soil quality), but also the impact of management. Visual Soil Evaluation (VSE) techniques are procedures for doing this. Lots of VSE techniques are used around the world and this handbook is based on the VESS method. VESS was developed in Scotland and is widely used by farmers, advisors and researchers. It involves carefully digging out a block of topsoil and assessing different soil structure features using the VESS score sheet as a reference. In the end, this gives an overall score between 1 and 5, which indicates soil structural quality and how best to manage it. VESS doesn't cost anything but an hour or two of your time. It requires very basic equipment and gives you immediate results. There is no need to send soil samples off to a lab for analysis. It is quick, simple and scientifically proven to work! We have developed difference versions of VESS for different farm management.



Grassland soils

For assessing grassland soil structure use the **GrassVESS**⁸ method. This assesses to 20 cm depth. All you need is a spade, a measuring tape, a plastic sheet or tray, a knife or trowel and the GrassVESS score sheet. Each assessment takes roughly 15 minutes and we recommend conducting at least 5 assessments to represent the field/paddock. The scores can be recorded on the GrassVESS Records Sheet.



Arable soils

For assessing arable topsoil structure we recommend using the **VESS** method. This assesses to 25 cm depth. If you are worried about what is happening below the cultivation zone (e.g. plough pans) use the **Double Spade**⁹ method which assesses to 40 cm depth. Both methods require a spade, a measuring tape, a plastic sheet or tray, a knife or trowel and the score sheets. VESS takes roughly 15 minutes and the Double Spade, 20 minutes per assessment.

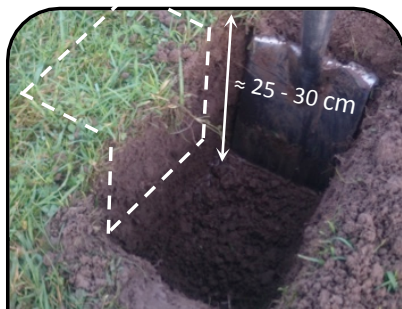
Assessments should be conducted when the soil is moist, but not waterlogged, typically in early Spring or Autumn. **Details on where to download the VESS, GrassVESS and Double Spade score sheets are given on page 15.** GrassVESS and Double Spade score sheets are also provided on pages 16 to 19.

Before using any of the VSE methods, it is important to know the general principles of how to assess soil structure. More detailed information is provided in the method score sheets.

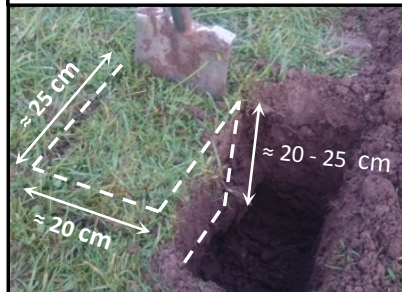
Preparing the soil for assessment

The first step is to prepare the soil for assessment. VESS and GrassVESS involve extracting a sample block of topsoil out of the ground, while Double Spade involves assessing the wall of a soil pit.

VESS and GrassVESS



Dig a hole, wider and deeper than an intended sample block. Do not stand on or lean the spade against the sample block.



Mark out and carefully loosen the sample block with straight spade insertions.



Carefully lever out the sample block on the spade and place on a plastic sheet or tray.

Double Spade



Carefully dig a soil pit (trench), roughly 45 cm deep, 50 cm long and 30 cm wide. While digging, do not stand on, lean the spade against or damage the wall of the soil pit that is to be assessed.



Soil features to examine

The soil features examined are the same for the three methods, though the specifics differ between the methods. This section gives a general overview, and how the features relate to soil quality. Refer to the method score sheets for more information and on how to score the features.

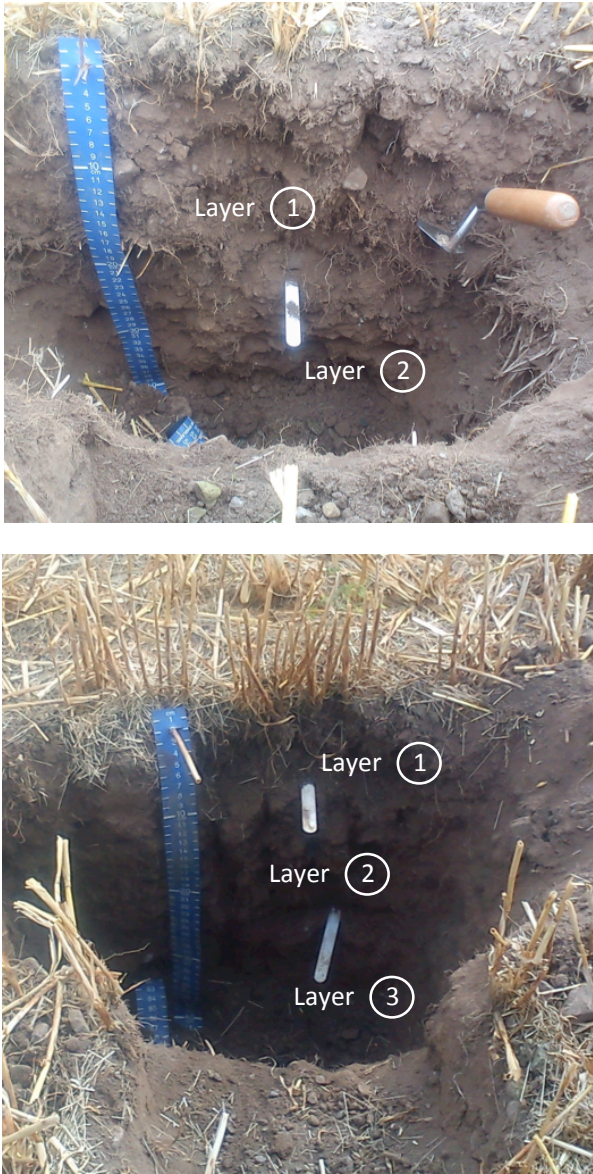
Soil layers with different structure

Identify the soil layers with different structure by simply looking at the soil, or by comparing how easy it is to gently stick a trowel or knife tip into the soil. Different layers may have different resistance. This can be carried out on either a sample block or on a soil pit wall. Record the position and depth of these layers, as this is important information as described in Section C.

VESS and GrassVESS

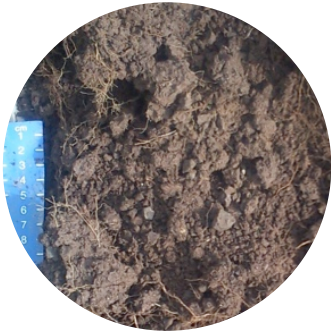


Double Spade



Aggregate size

For each layer, gently break up the soil and assess the size of aggregates. Generally, the larger the aggregates, the poorer the soil structural quality.



Good Quality

Predominantly small



Moderate Quality

A mixture of sizes



Poor Quality

Predominantly large

Aggregate shape

Assess the shape of the aggregates. The sharper (more angular) the aggregates, the poorer the structural quality.



Good Quality

Predominantly round



Moderate Quality

Rounded but with edges



Poor Quality

Predominantly sharp/angular

Aggregate strength / Rupture resistance

Try and break the aggregates, first between your finger and thumb, then with one hand. Assess how easy it is to break.



Good Quality

Easy to crumble between finger and thumb



Moderate Quality

Firm but fairly easy to break with one hand



Poor Quality

Difficult to break with one hand

Aggregate Porosity

Break aggregates open and examine the porosity within. If aggregates are too small to examine inside (i.e. aggregates 1 to 2 cm in width) it is a sign that the entire soil layer has good porosity.



Good Quality

Many pores and cracks



Moderate Quality

Limited pores or cracks



Poor Quality

No pores or cracks

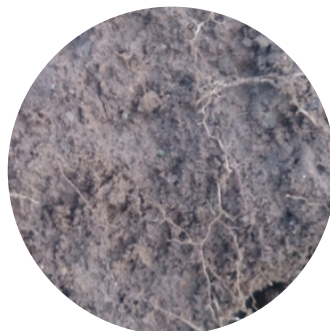
Rooting

Assess root growth within the layer and within aggregates. Fibrous roots should be able to grow unrestricted through the soil layers and aggregates, while tap-roots should not be distorted.



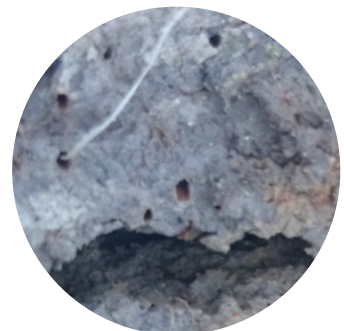
Good Quality

Many growing throughout



Moderate Quality

Fewer but within aggregates



Poor Quality

Distorted, restricted or no roots

Soil colour and smell

Soil colour and smell can indicate the drainage status of the soil. Soil should smell earthy but poor drainage can cause foul or putrid smells and is a sign of poor structural quality.



Good Quality

No orange or blue/grey zones



Poor Quality

Orange or blue/grey zones

C for conservation

How to conserve, enhance and fix soil structure

1 Know your soil structure

Using the methods described in Section B, visually assess your soil structure. Determine whether your management is having a negative impact and if there are problems, know where the problems are located within fields/paddocks. In each case, be aware of the depth and position of the damage. This will help determine what is necessary to fix the problem¹⁰. For example, if the damage is near the surface (0 to 15 cm depth), it is likely that the soil will recover naturally by the action of grass roots, earthworms and other soil organisms in grasslands¹¹, or by annual cultivations in arable soils. If the damage is severe and occurs deeper (> 15 cm depth), then mechanical intervention may be necessary.

Though it seems laborious and time consuming, using a spade and simply looking at the soil can be the most effective practice, often saving time and money in the long term.



2 Prevention is better than cure

In all cases, preventing soil structural damage is far better than having to fix it, especially subsoil compaction. Research suggests that compaction below 40 cm depth may be semi-permanent¹⁰. The following steps should be routinely used to prevent damage but equally, can be used to fix minor problems by allowing the soil structure to recover naturally without further damage.

● Avoid machinery and livestock traffic on wet soils.

Soil structure is weaker when wet and prone to damage. In grasslands, pugging and poaching from livestock treading, as well as machinery rutting, will occur if soils are wet and must be avoided. Livestock treading can cause damage to 15 cm depth¹¹. Lower stocking densities or strip grazing can help minimise impacts. If poaching occurs, the exclusion of livestock will allow the soil to recover naturally¹¹. Long-term subsoil compaction can be caused by slurry or fertilizer spreading early in the year, when soils are typically wet. Careful timing of application is important.

In arable soils, not only will heavy machinery cause compaction (potentially to 50 cm depth¹²) but cultivation equipment can cause smearing if soils are wet. This effectively creates a cemented or sealed layer which restricts water, air and roots. The deeper this happens the more difficult it is to remedy. For example, ploughing in wet conditions may cause smearing at the bottom of the plough furrow creating a “pan” at 20 to 25 cm depth. This is made worse if a tractor wheel drives through the furrow.

● Lighten the load.

Machinery is getting larger and heavier. In theory, soil should never be driven on. Of course, this is not always possible in farming. When driving machinery across soil, stick to tramlines or straight passes and avoid trafficking the entire field, even in dry conditions. Controlled traffic farming (CTF) which uses GPS technology is designed to ensure machinery uses defined and permanent paths. Try also to reduce axle loads by using trailers with multiple axles. Lowering tyre pressures (to safe levels) helps to spread weight over greater surface areas and can greatly reduce the risk of soil compaction¹³. Tracks, wide tyres or dual wheels work on the same principle and can also be beneficial⁵.



● **Alternate the management impact depth.** In arable soils, aim to vary the depth the soil is impacted by management. A compacted layer may form if cultivation is conducted to the same depth each year. Aim to alternate the cultivation depth by using different tillage strategies or equipment. Similarly, a good rotation should include crops with different rooting depths, which help to break up compacted layers while introducing organic matter to lower soil depths. This may be particularly important in zero-till systems where the use of cultivation to improve soil structure is not an option. Deep rooting crops should follow shallow rooting crops¹⁴.



● **Enhance soil structural stability and resilience.** Even with good management, farming will always pose a risk to soil structure. It is important to ensure that the soil is in its optimal condition to resist damage. In Section A we learnt that soil structure is made up of form, stability and resilience. Stability refers to the ability of the soil structure to withstand compacting forces without damage. Resilience refers to the ability of the soil structure to recover when damaged.

Soil organic matter (SOM) is key to stability as it helps form soil aggregates by gluing soil particles together, while also giving the soil a sponge like quality, helping it to resist compaction. In arable soils, SOM is broken down by tillage and it is vital to maintain as high a level as is possible. As grasslands are rarely cultivated, they naturally have higher SOM levels and better structural resilience. Organic matter also acts as a source of food for soil biology. Soil biology, including plant roots, are key to structural resilience. When soil structure is damaged, it is the action of soil organisms and roots which helps repair the damage, for example, by breaking up compacted layers. Interestingly, soil structure may be better under dung pats, which are a source of SOM, leading to increased biological activity. Encouraging soil biology, such as earthworms, by providing organic matter and the right environment for them to thrive, will help increase soil structural resilience.



3 Worst case scenario - mechanical intervention

Where soil structure is badly damaged and natural recovery is not possible, especially if damage is at lower soil depths, mechanical intervention may be necessary.

- **Grassland aerators, slitters and sward lifters.** Various equipment is available to help break up grassland surface compaction. However, apart from improving surface infiltration in the short term, the value of some techniques may be limited. If compaction is not severe and occurs within the upper 15 cm, grassland soils should recover naturally though may take a couple of months¹¹. The key is to allow it to recover by following the advice on pages 12 and 13.
- **Ploughing.** Where structural damage occurs within 25 cm depth, ploughing, may be necessary to alleviate problems. In arable soils, this may be part of the annual tillage strategy, removing the previous years topsoil compaction. Though grasslands show a high level of natural self-recovery¹¹, those with severe compaction may require ploughing and reseeding.
- **Subsoil loosening.** Where severe structural damage has occurred below a ploughing depth (> 25 cm), subsoiling may be appropriate. However, we advice extreme caution. Subsoilers are designed to cause shock-waves as the legs pass through the soil, creating cracks and fissures to the desired depth. For this to happen, the soil must be extremely dry. If the soil is not dry, a subsoiler will simply smear the soil at depth, creating a more serious problem than before. Subsoil loosening should take place just below the compacted layer and can alleviate problems to 45 cm depth, though research has shown mixed results¹⁰. Careful soil management is also required following subsoiling to avoid re-compaction¹³.
- **Field drainage.** As soil structure is weaker when wet, soils that are affected by high water tables or that are naturally poorly drained, will always be prone to structural damage. Field drainage may lessen the risk of compaction and help aerate the soil, creating a better environment for soil biology and plant roots. This in turn will improve soil structural resilience, help to repair existing structural damage while preventing future damage. However, field drainage installation is expensive and if the design is not correct for the specific field, it may be completely ineffective. Expert advice is always recommended.



Information Sources

VESS

The VESS (Visual Evaluation of Soil Structure) method is available from Scotland's Rural College (SRUC) at: www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure

GrassVESS and Double Spade

The GrassVESS and Double Spade methods are provided on pages 16 to 19 but are also available from Teagasc at: www.teagasc.ie/environment/soil/research/square

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- ⁵ Gobin, A., Campling, P., Jansen, L., Desmet, N., van Delden, H., Hurkens, J., Lavelle, P. & Berman, S. 2011. *Soil organic matter management across the EU- best practices, constraints and trade offs*. Final report for the European Commission's DG Environment, September 2011. European Commission.
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- ⁷ Turbé, A., DeToni, A., Benito, P., Lavelle, P., Ruiz, N., Van der Putten, W.H., Labouze, E. & Mudgla, S. 2010. *Soil biodiversity: functions, threats and tools for policy makers*, Technical Report -2010-049. European Commission.
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- ⁹ Emmet-Booth, J.P., Forristal, P.D., Fenton, O., Bondi, G. & Holden, N.M. 2018. The influence of depth of observation on the information conveyed by visual soil evaluation. *Soil & Tillage Research*. Under Review.
- ¹⁰ Batey, T. 2009. Soil compaction and soil management – a review. *Soil Use & Management*, **25**, 335-345.
- ¹¹ Drewry, J.J. 2006. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. *Agriculture, Ecosystems & Environment*. **114**, 159-169.
- ¹² Creamer, R.E., Brennan, F., Fenton, O., Healy M.G., Lalor S.T.J., Lanigan G.J., Regan J.T. & Griffiths B.S. 2010. Implications of the proposed soil framework directive on agricultural systems in Atlantic North-west Europe – a review. *Soil Use & Management*. **26**, 198-211.
- ¹³ Forristal, P.D. & Ball, B.C. 2013. Managing wet and weak soils. In: *Teagasc Manual on Drainage and soil management*. Teagasc, Dublin, pp.21-34.
- ¹⁴ Lampkin, N. 1998. *Organic farming*. Farming Press, United Kingdom.



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