Farming Advice Service

Understanding soil biology for soil health and productive agriculture, with Dr Felicity Crotty

Tuesday 26th March 6-7pm

Soil testing requirements

- The Farming Rules for Water requires farmers and land managers to conduct soil tests every 5 years to inform planning for applying manures and fertilisers.

If you're applying manure or fertiliser to cultivated agricultural land, you must also plan by using the results of soil tests.

Cultivated agricultural land is both or one of the following:

- land you've ploughed, sowed or harvested at least once in the last year
- land where you've applied organic manure or fertiliser at least once in the last 3 years

The results of soil tests must show the pH and levels of:

- nitrogen – you can use a soil nitrogen supply calculator instead of a soil test
- phosphorus
- potassium
- magnesium

Soil test results must be no more than 5 years old at the time of application.

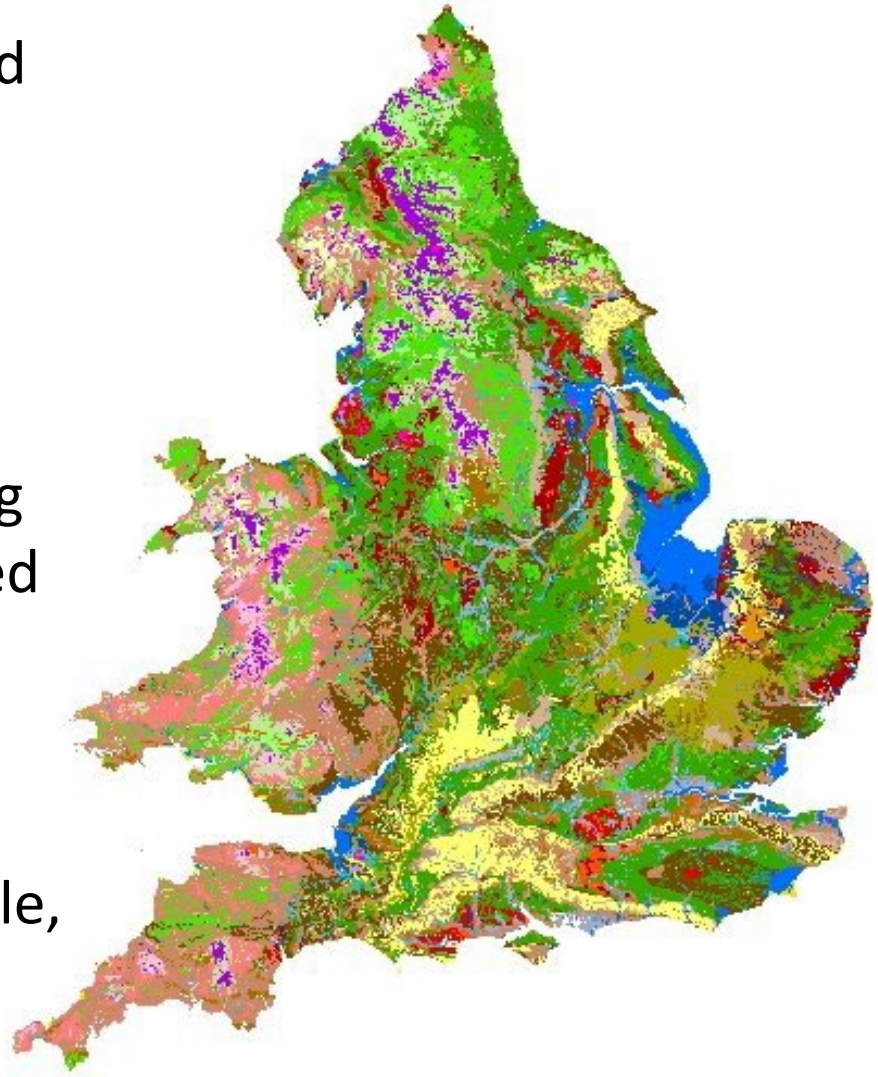
- Existing management plans and results (within last 5 years) satisfy SFI *SAM1: Assess soil, produce a soil management plan and test soil organic matter.*

Funding for soil management

- The Sustainable Farming Incentive (SFI) has three actions for soils, these focus on improving soil health, structure, organic matter and biology.
  - SAM1: Assess soil, produce a soil management plan and test soil organic matter
    - £6 per hectare (ha) and £97 per SFI agreement per year.
  - SAM2: Multi-species winter cover crops
    - £129 per hectare per year.
  - SAM3: Herbal leys
    - £382 per hectare per year.
- These actions can help with the **long-term productivity and resilience** of the soil to benefit food production, as well as **environmental benefits** such as better water quality, improved climate resilience and increased biodiversity.

Soil types in England

- There are 683 soil series in England and Wales.
- You can find your soil type on the LandIS Soilscapes viewer.
- Soils are products of their parent material, with this factor governing inherent soil fertility and associated productivity.
- An unmanaged soil with a low pH can be classified as ‘healthy’, this relates to its formation, for example, upland habitats.



The importance of soil: What makes a "healthy" soil?

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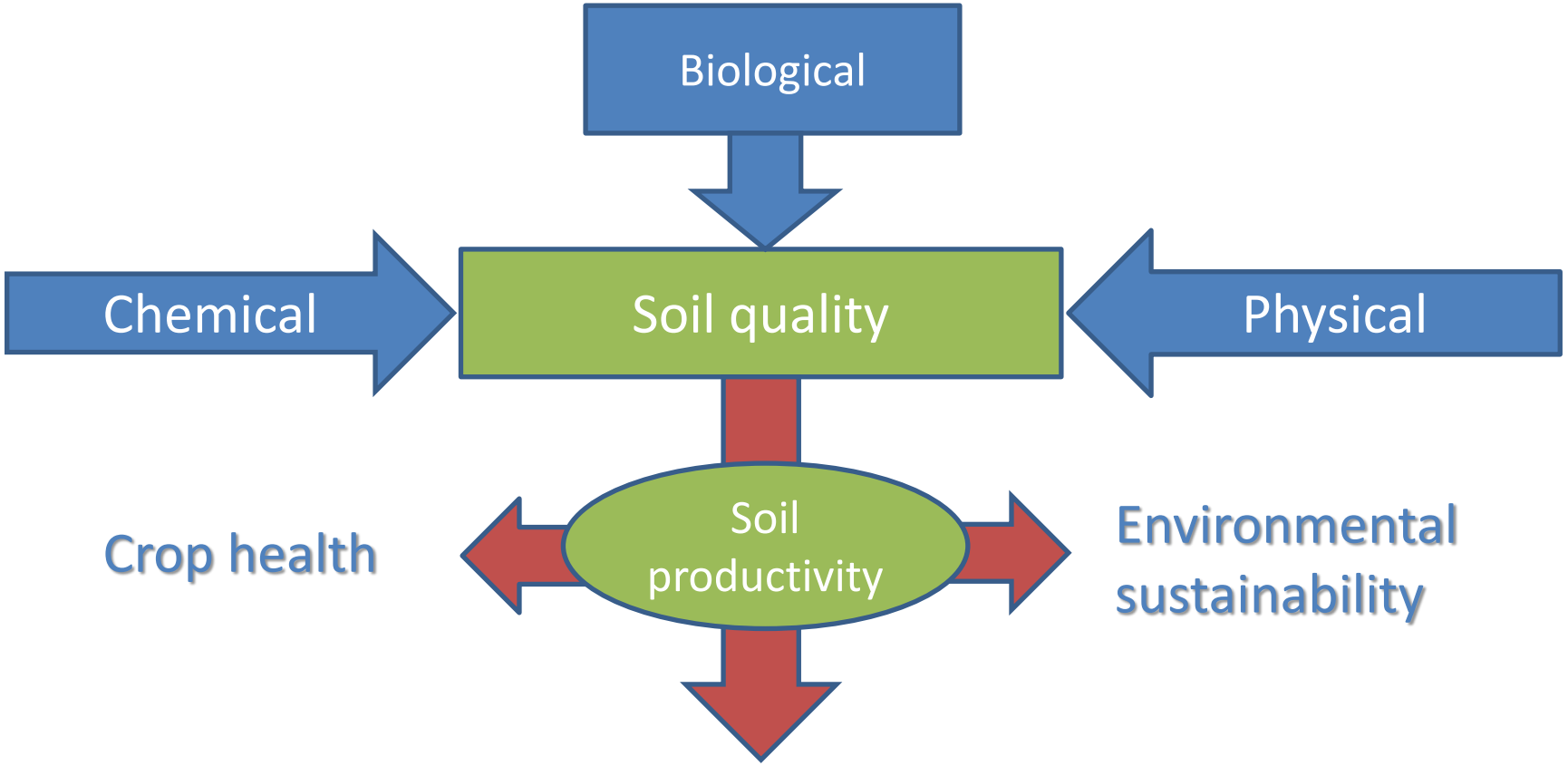

SOIL HEALTH

AND HOW DO YOU MEASURE IT?

What does soil health represent?

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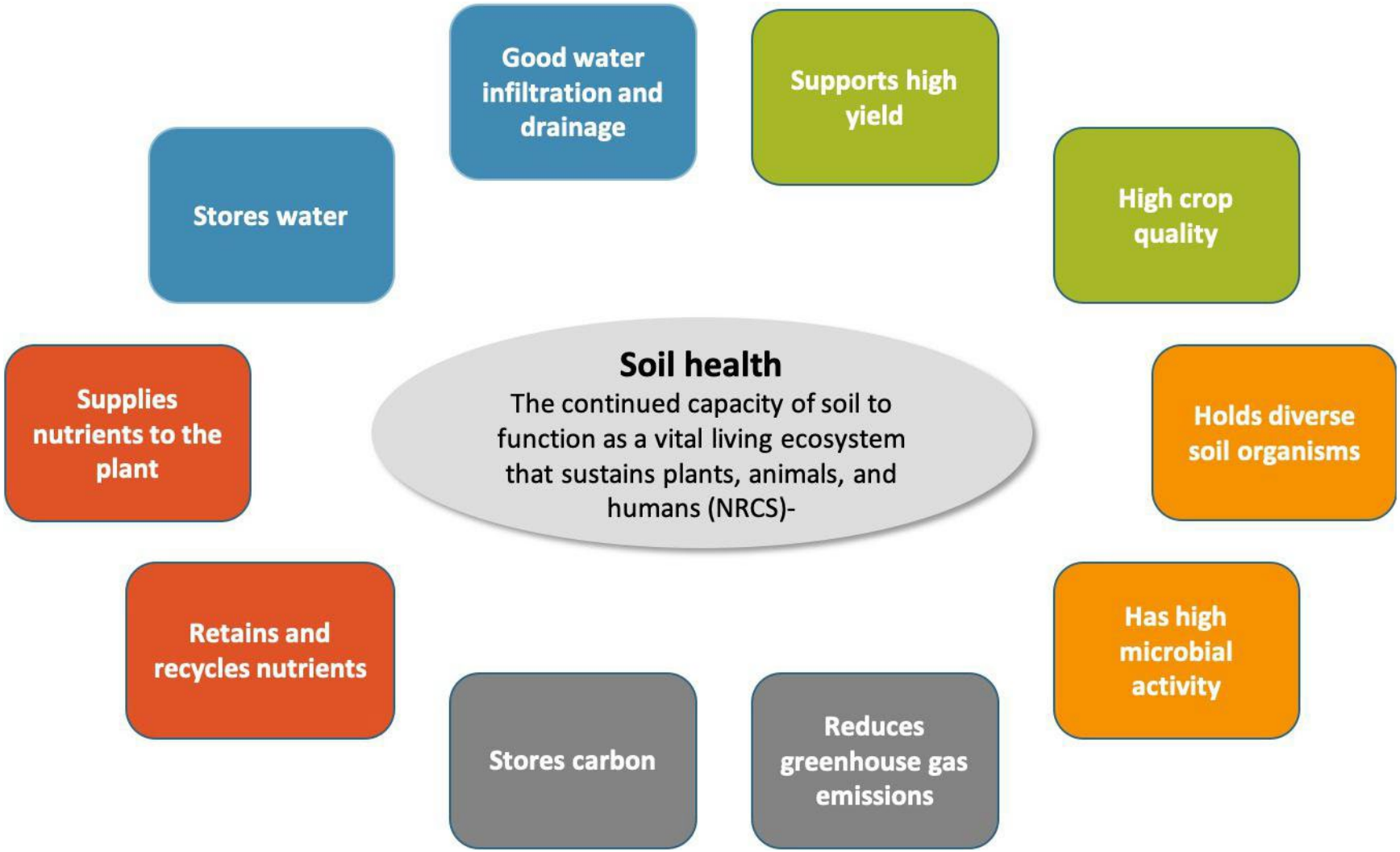

Soil is a non-renewable resource

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UK soil contains about 10 billion tonnes of carbon, equal to 80 years of annual greenhouse gas emissions at current rates.

Intensive agriculture has caused arable soils to lose 40 - 60% of its organic carbon, and the impacts of climate change pose further risks.

The state of the environment: Soil

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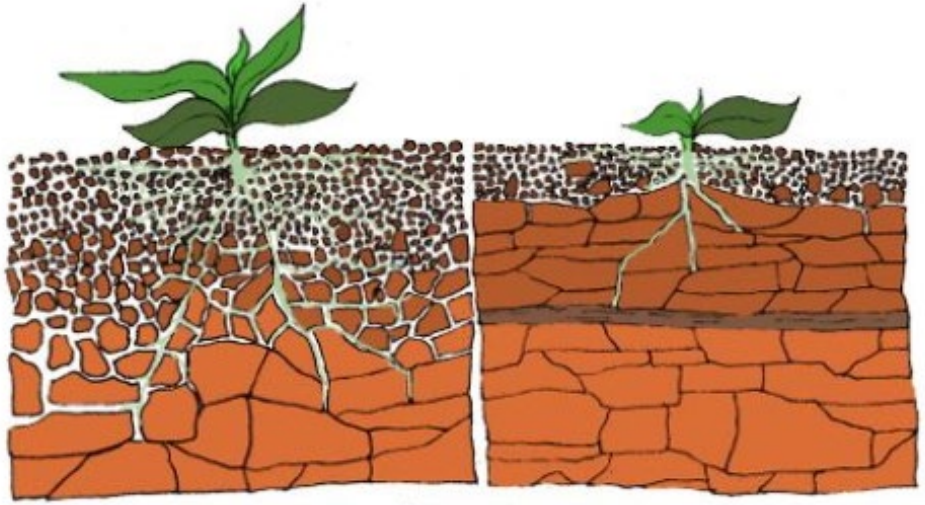
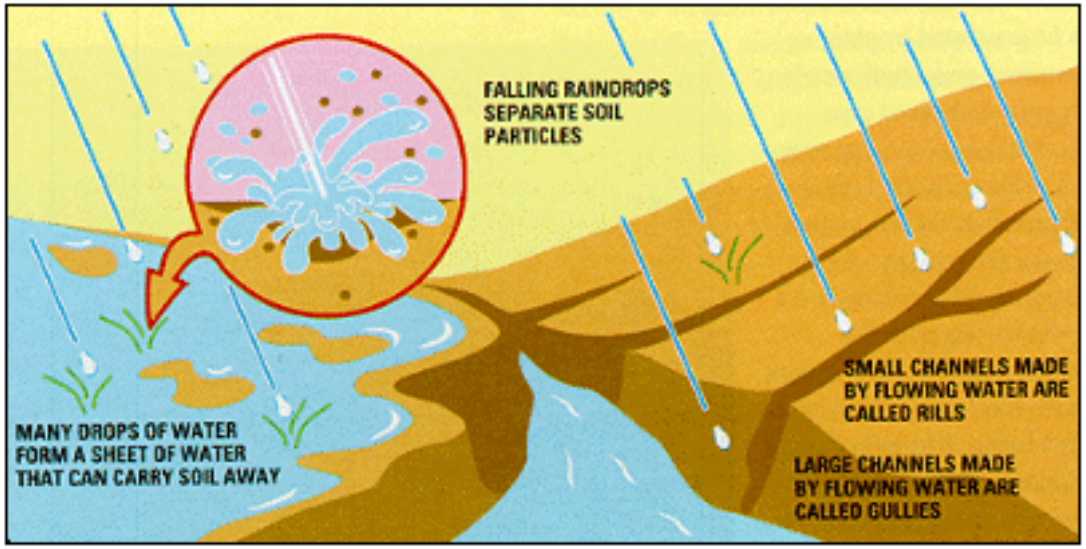
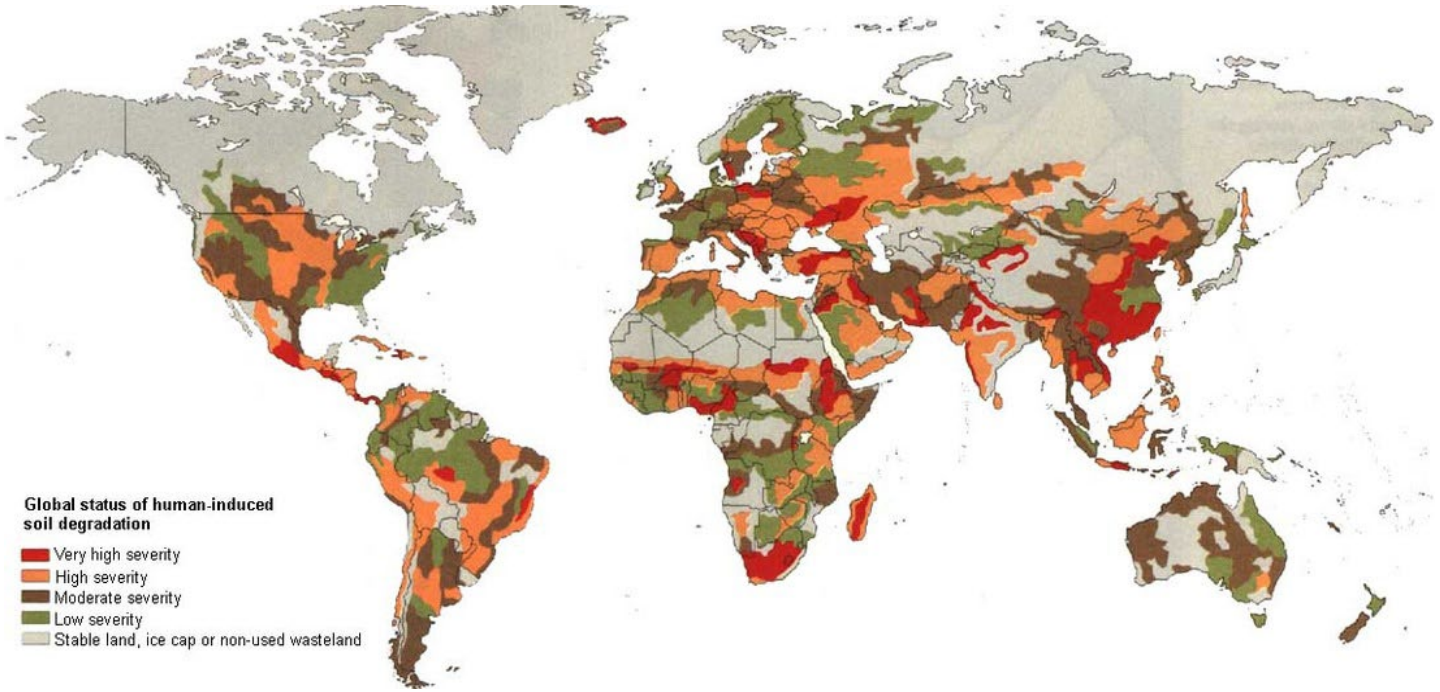
Almost 4 million hectares of soil is at risk of COMPACTION in England and Wales





Over 2 million hectares of soil at risk of EROSION in England and Wales – 17% of arable land.

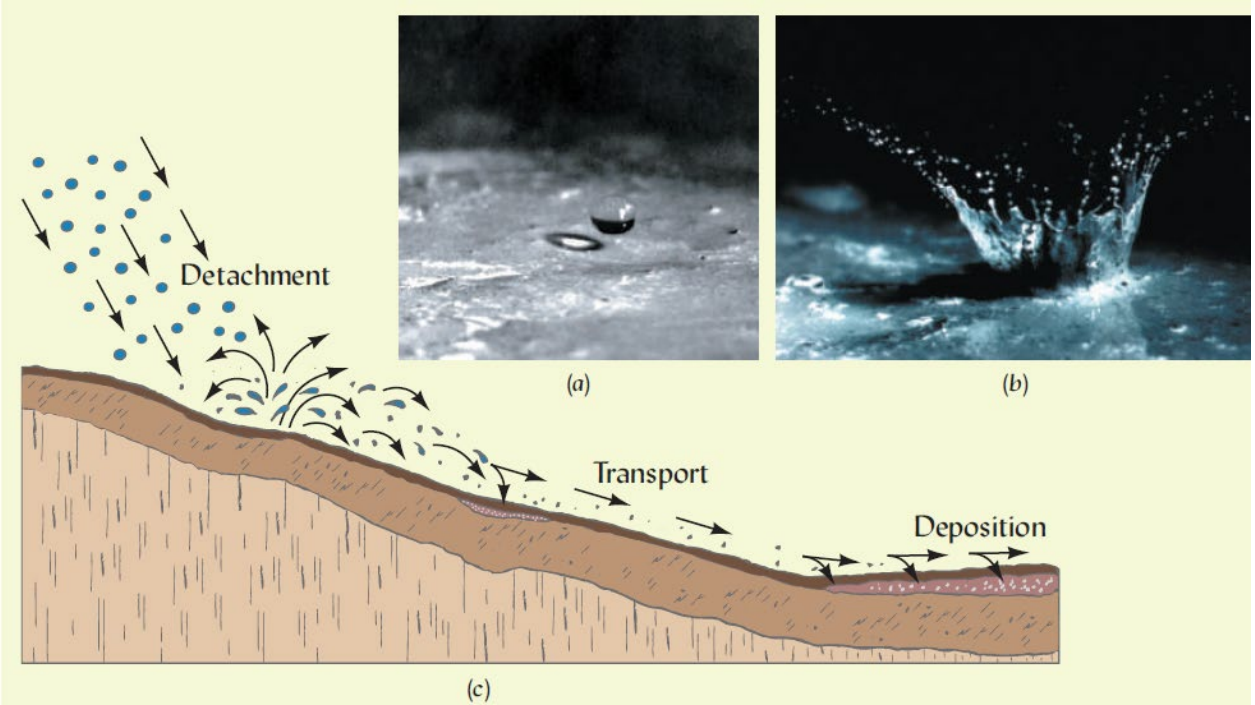
Soil degradation globally



Main issues in UK

- **Wind erosion** – fen blow
- **Water erosion** – splash from raindrops, rill and gully erosion small (to large) channels form, caused by surface runoff.
- **Soil loss by crop harvesting**
- **Compaction**

Water erosion – Splash



- Can occur as soon as raindrops start falling (splash erosion).
- As runs over land or rock surface, collects weathered material (transport).
- Power of moving water increases with more water and ability to carry heavier debris
- Vegetation cover can reduce impact of erosion.

Agriculture water erosion

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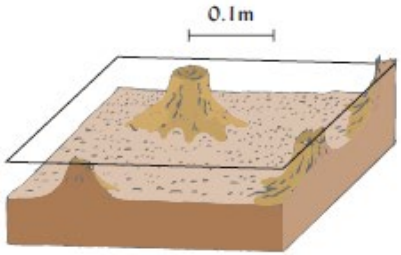
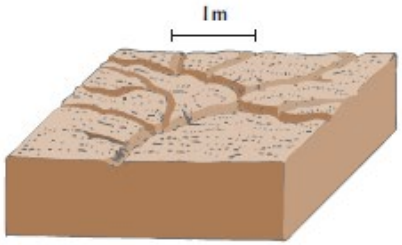
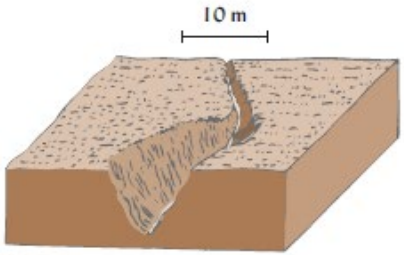
- **Sheet Erosion** – removal of relatively uniform, although thin layer of soil from land surfaced
- **Rill Erosion** – numerous small channels formed. Results from concentrated overland flow.
- **Gully Erosion** – larger channels formed from concentrated rill or sheet flow



(a) Sheet erosion



(b) Rill erosion



(c) Gully erosion

Large scale erosion event

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Before

After

https://www.bbc.co.uk/news/world-europe-57862894

Restoration one year later

- BUT is this soil healthy?
- Will it still produce productive crops?
- If not why not?

Other forms of soil loss

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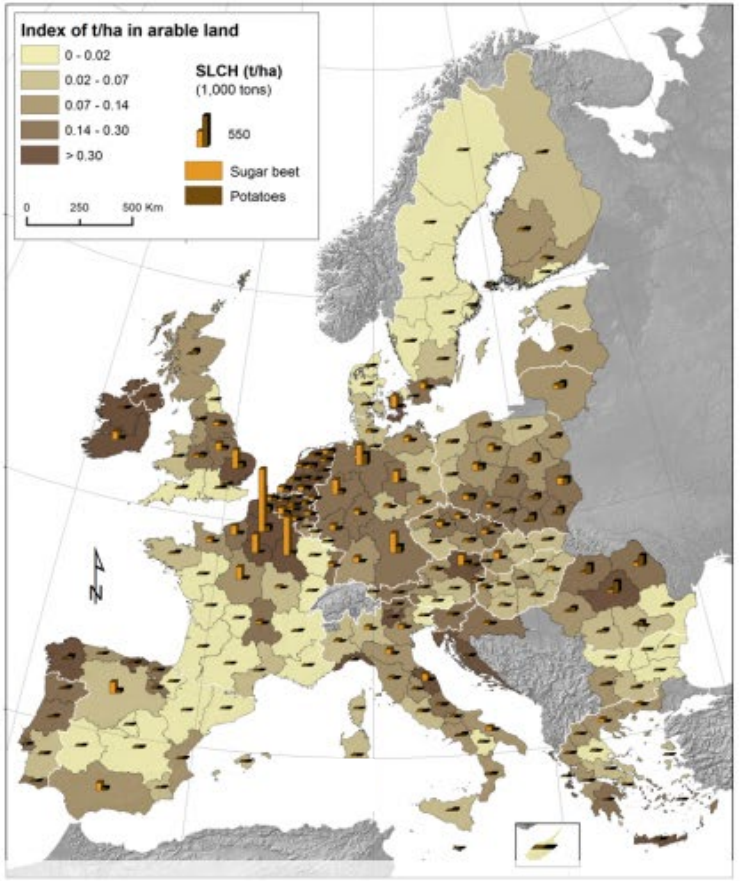
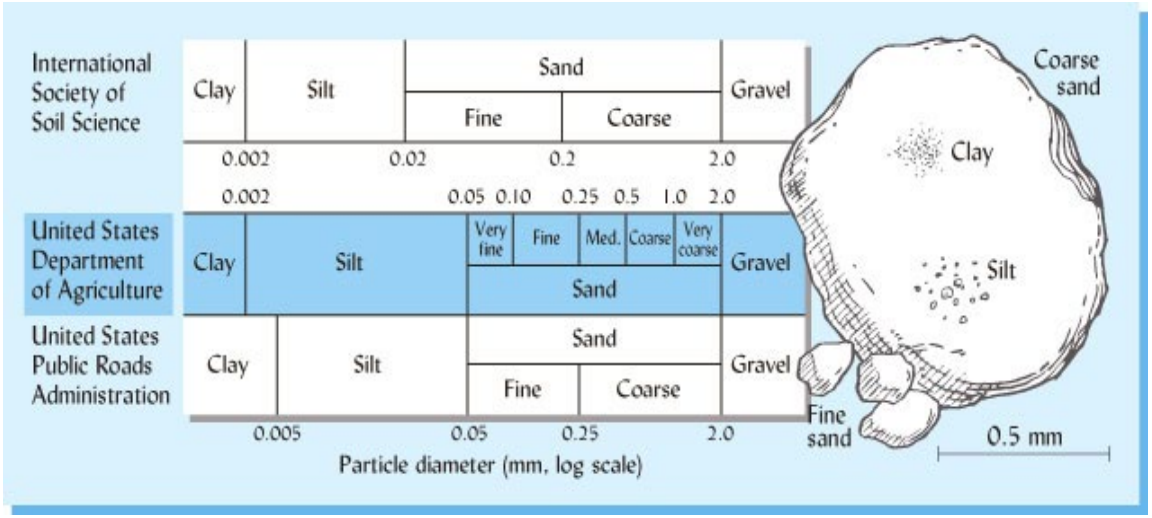
Soil Loss Due to Crop Harvesting in the EU

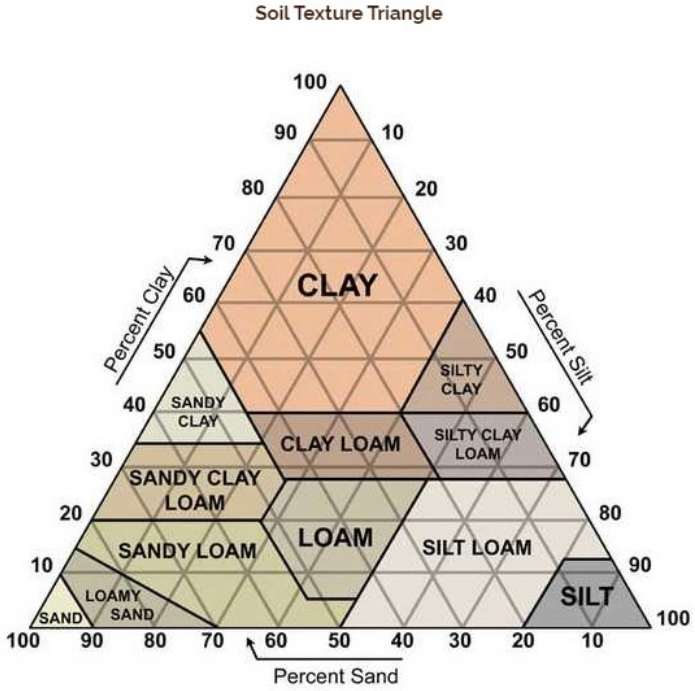


The 4.2 million ha of EU root crops contribute to 14.7 million tonnes of SLCH

Soil texture

- Critical for understanding soil behaviour and management
- Most permanent feature of any soil
- Particle size distribution - Sand, silt and clay only
- Stones are ignored
- OM treated separately





Soil types – Colour is important

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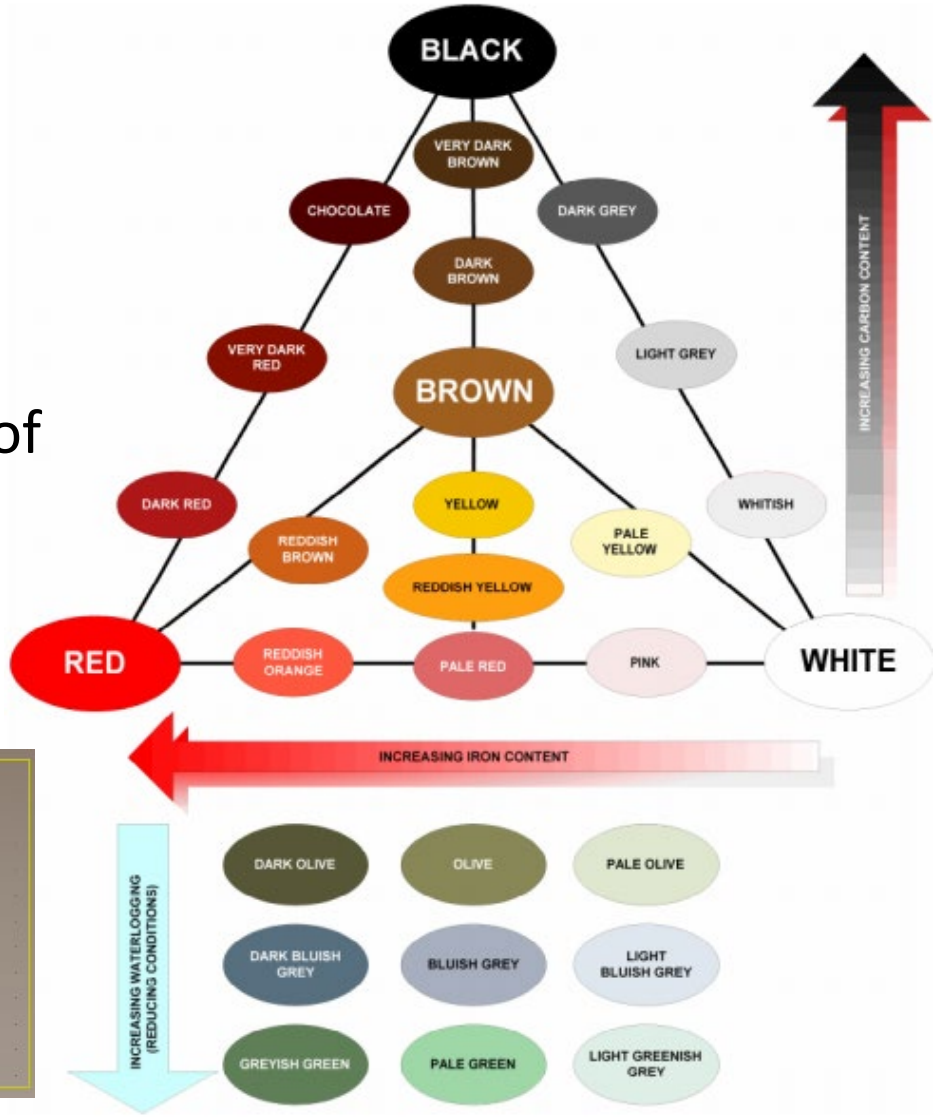
Three major factors influence soil colours:

1. Organic matter content,
2. Water content
3. Presence and oxidation states of iron and manganese oxides in various minerals.



Form	Chemical Formula	Color
Ferrous oxide	FeO	Gray
Ferric oxide (Hematite)	Fe_2O_3	Red
Hydrated ferric oxide (Limonite)	$2Fe_2O_3 \cdot 3H_2O$	Yellow

Colour – an indicator of organic matter

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Figure 7. Examples of soil with less than 1%, 2% and 3% organic matter from left to right, respectively. Photo: Jodi DiJong-Hughes

Soil carbon

- The soil organic carbon pool is the second largest on the planet; sequestrating atmospheric carbon in the soil is a cost-effective climate change mitigation strategy.
- Farmers and land managers can estimate their farm/estate soil carbon sequestration using carbon calculators.
  - ahdb.org.uk/knowledge-library/carbon-footprint-calculators-what-to-ask-to-help-you-choose
- Soil carbon measures can be entered as carbon credits and used as an alternative income stream
  - farmcarbontoolkit.org.uk/toolkit-page/getting-paid-for-carbon/
  - ahdb.org.uk/news/schemes-in-the-carbon-market-what-to-look-out-for

Image from rural.struttandparker.com/article/5-ways-to-generate-income-from-carbon-farming/

The influence of organic matter

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The influence of organic matter (OM) on the stability of soil aggregates against slaking (falling apart) when wetted. Although both soils appeared well aggregated when dry (left), when the same amount of water was added to each the aggregates in the low OM soil rapidly fell apart while those in the higher OM soil remained intact.

Active organic matter?

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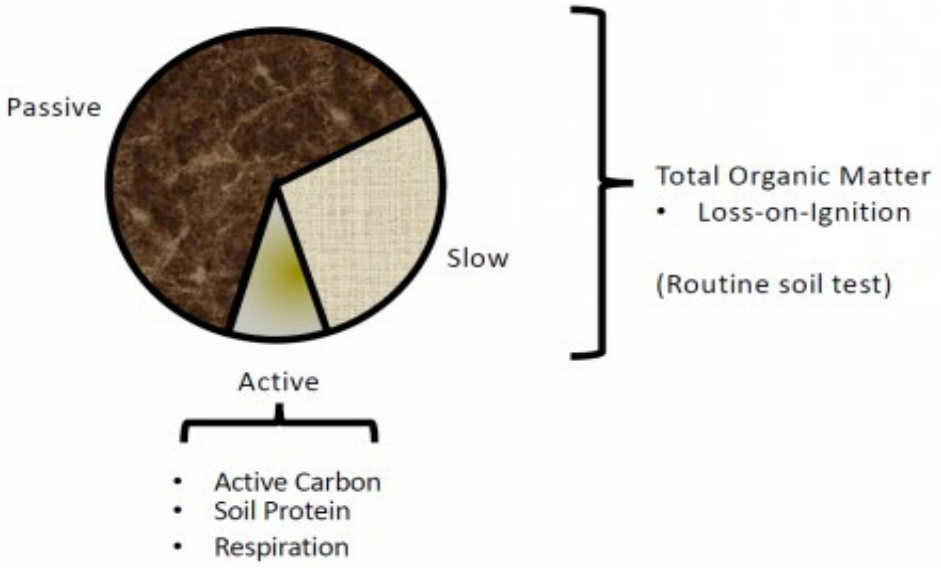
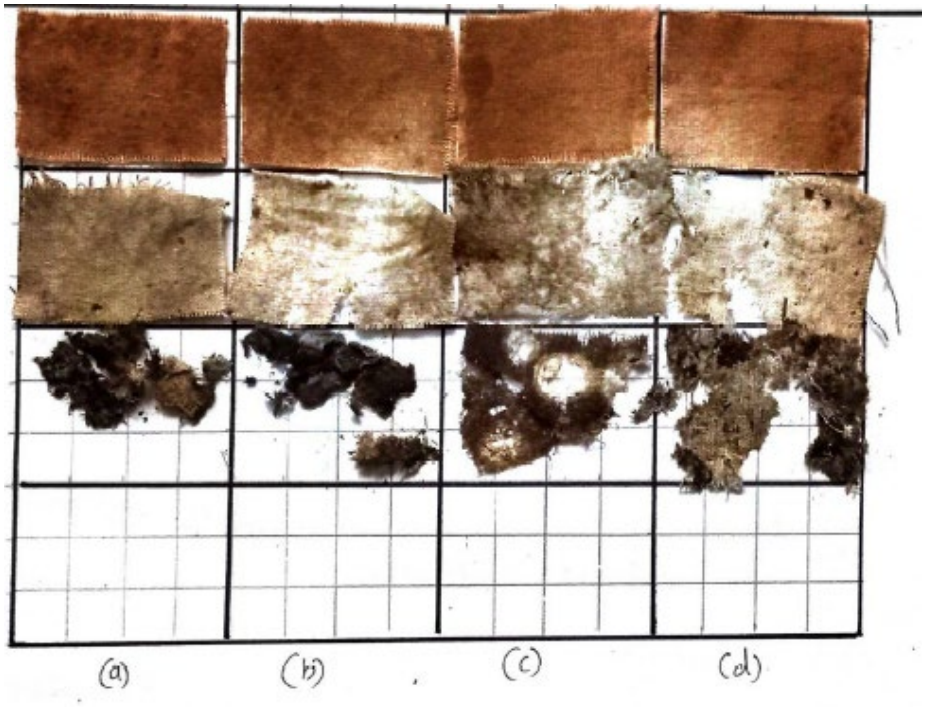
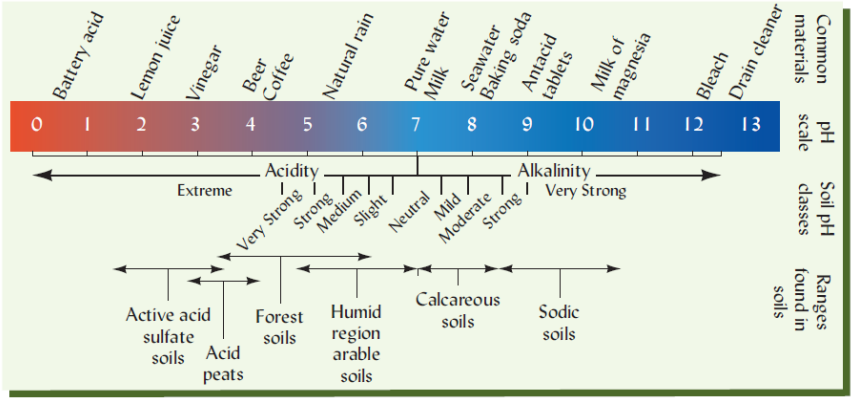
- Soil organic matter is estimated to contain 58% organic carbon
- SOM mixture of active and more recalcitrant (passive) fraction (total measured)





pH

measured by **pH scale**



2 ---------- 6.5 ------- 8.2 ---------- 14

acid "neutral" calcareous saline

i.e. suitable for most crops

- Balance between hydrogen ions (H^+) and hydroxyl ions (OH^-).
- 2 processes promote soil acidification.
  1. The production of H^+ ions.
  2. The washing away of nonacid cations.
- Soil acidity is closely related to the amount of annual precipitation.

Causes:

Parent Material

Leaching

Fertiliser use

Precipitation

pH

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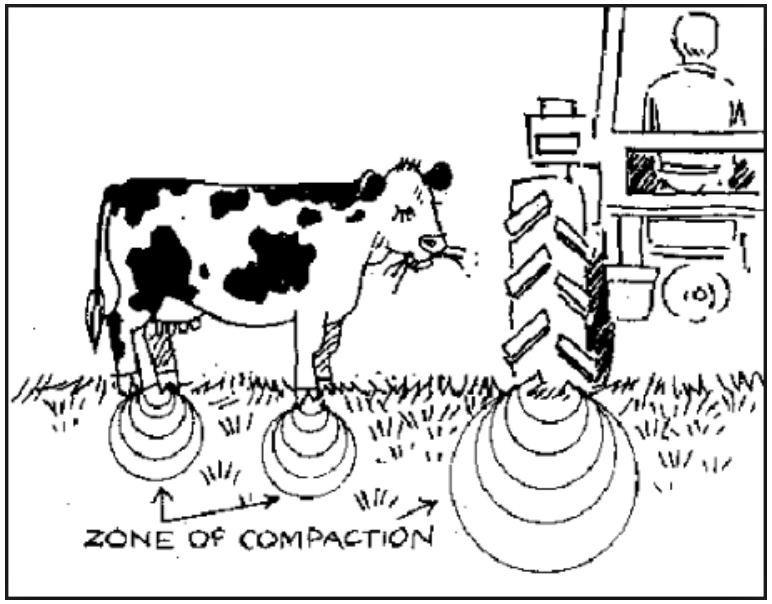
pH	Flower Color
4.5	deep, vivid blue
5.0	medium blue
5.5	lavender-purple
6.0	purplish-pink
6.5	mauve-pink
6.8	medium pink
7.0	deep, vivid pink

Soil structure formation

- Plant root secrete compounds gluing soil particles together
- Fungal mycelia act like threads to tie up soil particles
- Earthworms ingest and excrete soil - "crumb" structure in grasslands
- Decomposed organic matter acts to bind soil particles together
- External factors influence compaction – traffic, livestock
- Soil compaction reduces plant biomass



How to manage soil to reduce compaction?

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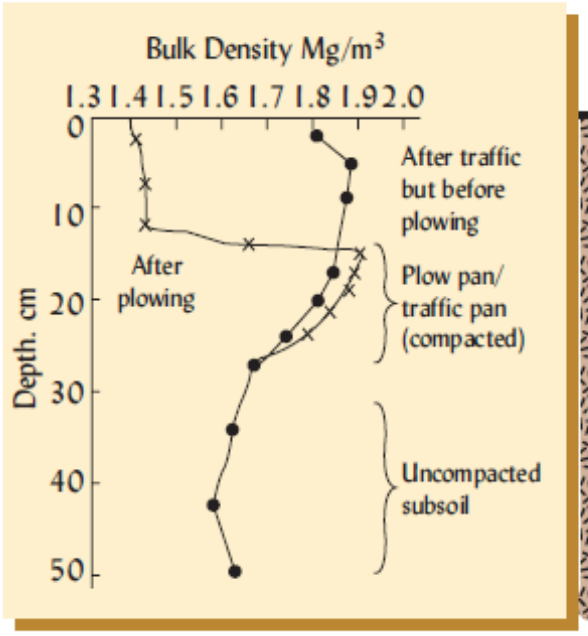
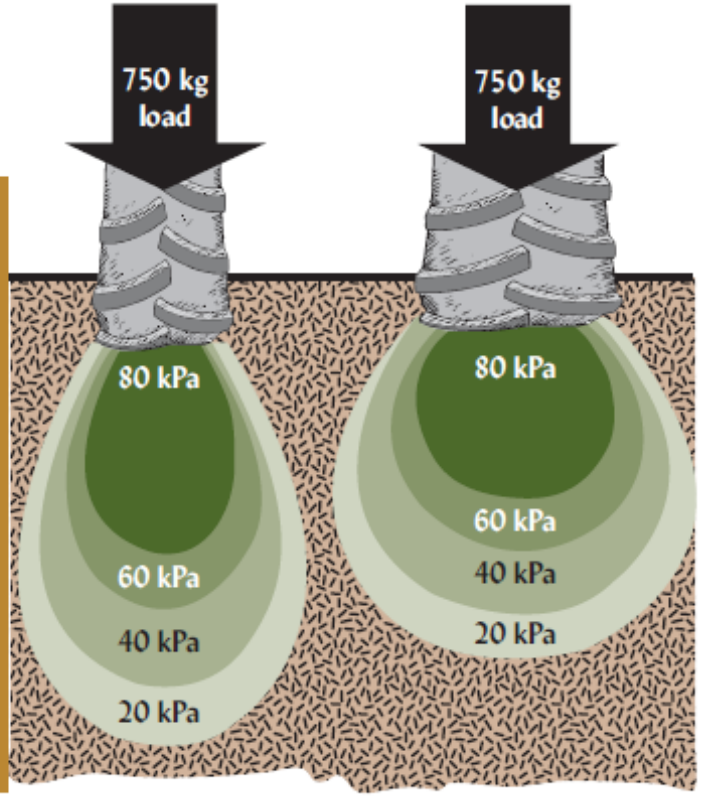
Figure 4.50 *Vehicle tires compact soil to considerable depths. (Left) Representative bulk densities associated with traffic compaction on a sandy loam soil. Plowing can temporarily loosen the compacted surface soil (plow layer), but usually increases compaction just below the plow layer. (Right) Vehicle tires (750 kg load per tire) compact soil to about 50 cm. The more narrow the tire, the deeper it sinks and the deeper its compactive effect. The tire diagram shows the compactive pressure in kPa. For tire designs that reduce compaction, see Tijink and Van der Linden (2000).* (Diagrams courtesy of Ray R. Weil)





Prevention better than cure

- Compaction is easy to do but difficult and expensive to fix
- On grassland – aeration and organic amendments
- On arable – minimise traffic from heavy machinery and utilise weigh distribution techniques (low pressure tyres), no till farming and varying conventional practice

- **Subsoiling** – results maybe temporary
- **Add organic matter** – increases fertility and biological activity
- **Increase earthworm numbers**!

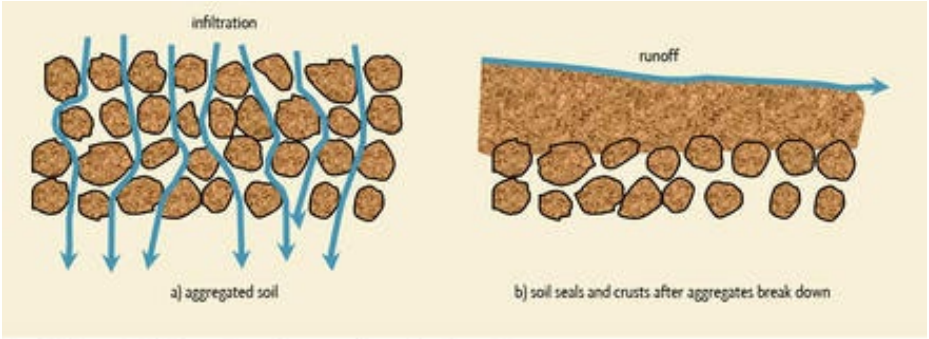


Figure 2.6. Changes in soil surface and water-flow pattern when seals and crusts develop.

VESS

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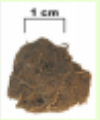
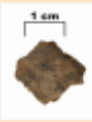
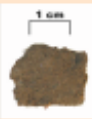
Factors increasing score

- Block extraction
- Aggregate shape and size
- Roots
- Anaerobic
- Aggregate fragmentation

Structure quality	Size and appearance of aggregates	Visible porosity and Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature	Appearance and description of natural or reduced fragment of ~ 1.5 cm diameter
Sq1 Friable Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous Roots throughout the soil			 Fine aggregates	 The action of breaking the block is enough to reveal them. Large aggregates are composed of smaller ones, held by roots.
Sq2 Intact Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous Roots throughout the soil			 High aggregate porosity	 Aggregates when obtained are rounded, very fragile, crumble very easily and are highly porous.
Sq3 Firm Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Porosity and roots both within aggregates.			 Low aggregate porosity	 Aggregate fragments are fairly easy to obtain. They have few visible pores and are rounded. Roots usually grow through the aggregates.
Sq4 Compact Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks All roots are clustered in macropores and around aggregates			 Distinct macropores	 Aggregate fragments are easy to obtain when soil is wet, in cube shapes which are very sharp-edged and show cracks internally.
Sq5 Very compact Difficult to break up	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low porosity. Macropores may be present. May contain anaerobic zones. Few roots, if any, and restricted to cracks			 Grey-blue colour	 Aggregate fragments are easy to obtain when soil is wet, although considerable force may be needed. No pores or cracks are visible usually.

Need to think about the different textures of soil, when doing a VESS

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Some General Properties of the Three Major Size Classes of Inorganic Soil Particles

	Property	Sand	Silt	Clay
1.	Range of particle diameters in millimeters	2.0–0.05	0.05–0.002	Smaller than 0.002
2.	Means of observation	Naked eye	Microscope	Electron microscope
3.	Dominant minerals	Primary	Primary and secondary	Secondary
4.	Attraction of particles for each other	Low	Medium	High
5.	Attraction of particles for water	Low	Medium	High
6.	Ability to hold chemicals and nutrients in plant-available form	Very low	Low	High
7.	Consistency when wet	Loose, gritty	Smooth	Sticky, malleable
8.	Consistency when dry	Very loose, gritty	Powdery, some clods	Hard clods

How to VESS

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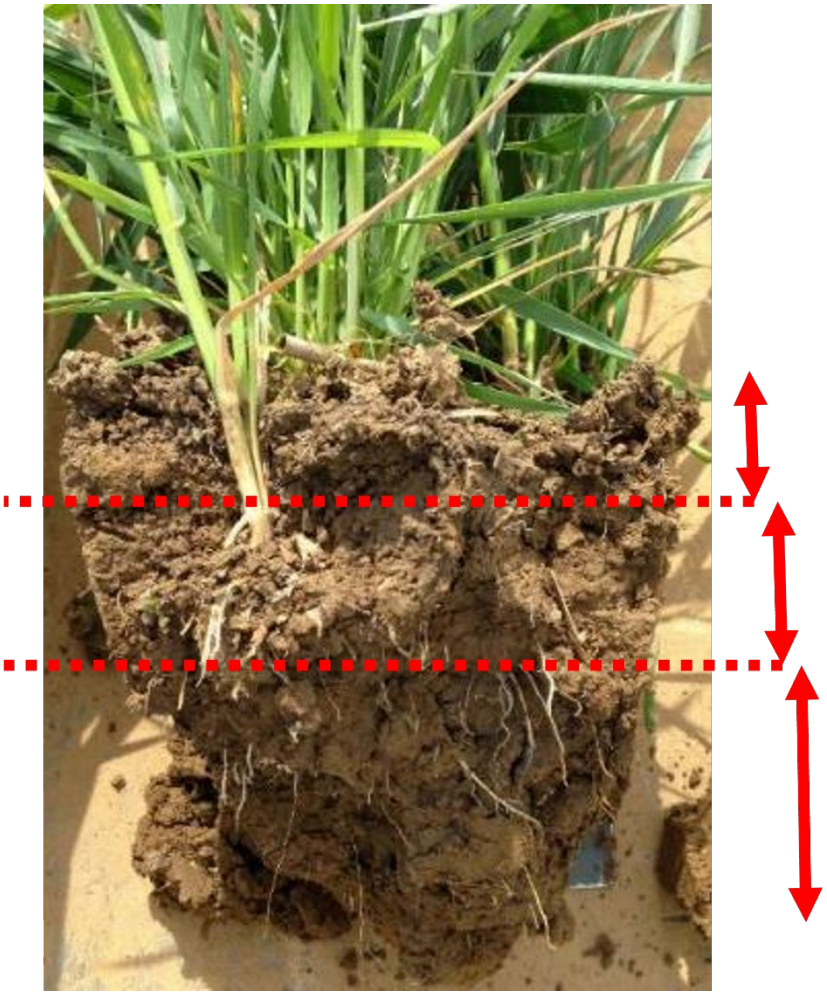
score of each layer x thickness of layer/overall depth of soil block

Identifying layers within soil block for VESS



- 3 layers visible
- Friability will likely feel different
- May give each layer a different VESS score
- Add each VESS score together and divide by depth to get overall VESS score.

- = 1 x 6cm + 2 x 7cm + 2.5 x 7cm /20
- = 6 + 14 + 15 = 35 / 20 = 1.75 VESS

Soil physicochemistry

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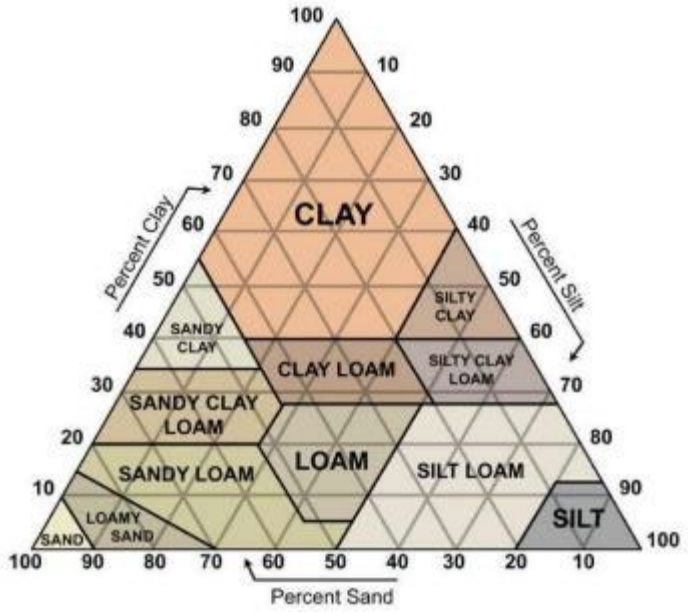
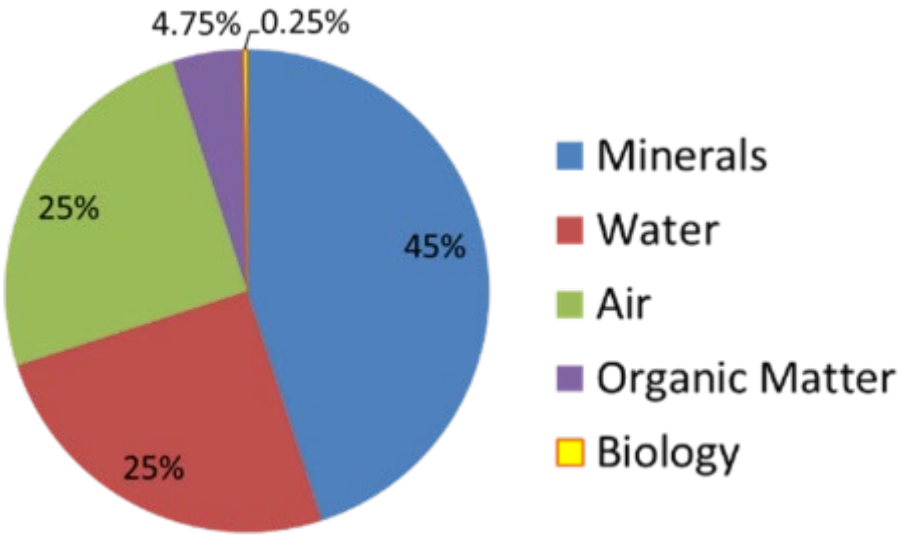


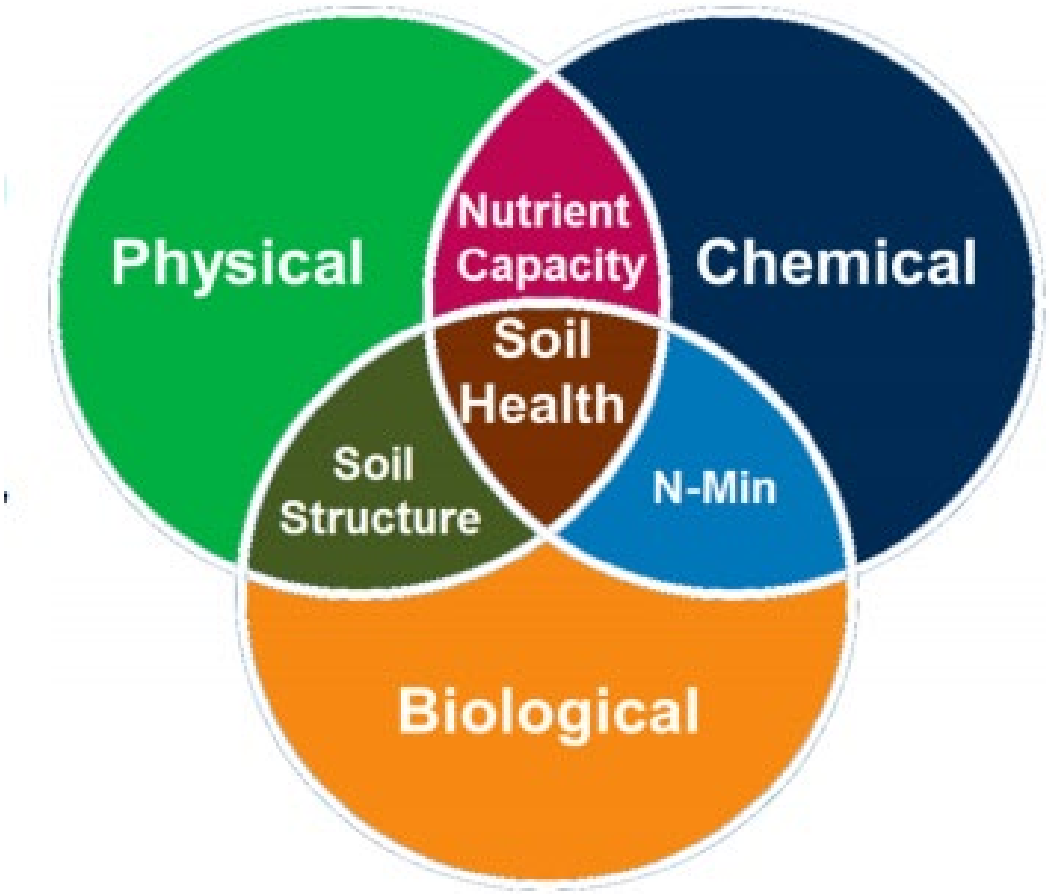


- Soil science is often taught emphasising the physicochemical properties….
- BUT without biology, soil is just an inert substrate!
- **HEALTH = LIFE**

What is soil health?

- Soil quality refers to "*the continued capacity of a soil to function*" (Doran and Zeiss, 2000).

- BUT// Only something living can have health, thereby we are (unconsciously) acknowledging that we regard soil as a living ecosystem and not just an inert base for agriculture.



Greater weight of fauna below ground than livestock

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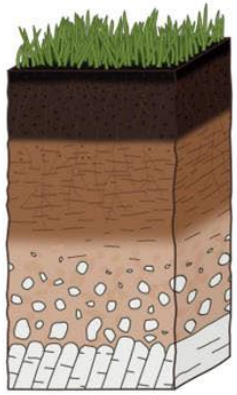
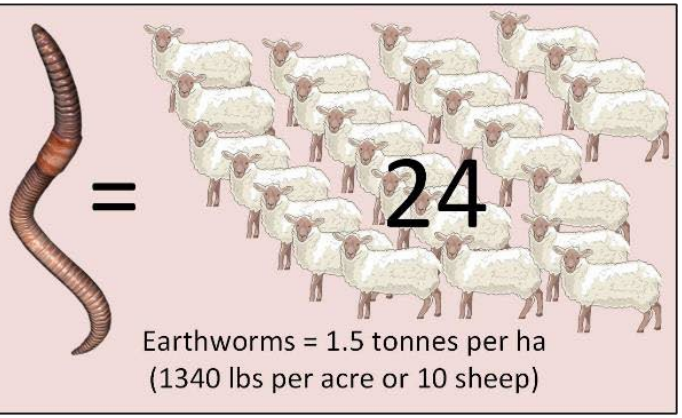
Fungi & Bacteria

17 =

1 tonne per ha
(900 lbs per acre
or 7 sheep)

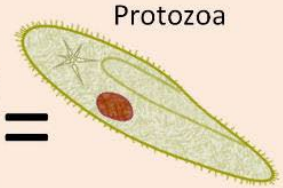




Earthworms = 1.5 tonnes per ha
(1340 lbs per acre or 10 sheep)

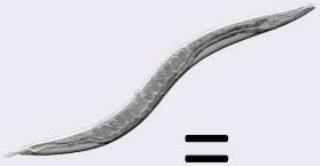
Protozoa

6 =



400 kg per ha
(360 lbs per acre or 2.5 sheep)

Nematodes



=

5

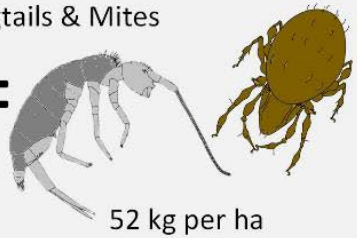
317 kg per ha
(285 lbs per acre or 2
sheep)

Normal number of sheep per hectare = 16
Or 6.5 per acre

Belowground animal biomass =
53 sheep per hectare or 22 per acre

Springtails & Mites

1 =



52 kg per ha
(45 lbs per acre or 0.5 sheep)

Crotty, 2022 *Frontiers for Young Minds*

Soil: The poor man's tropical rainforest

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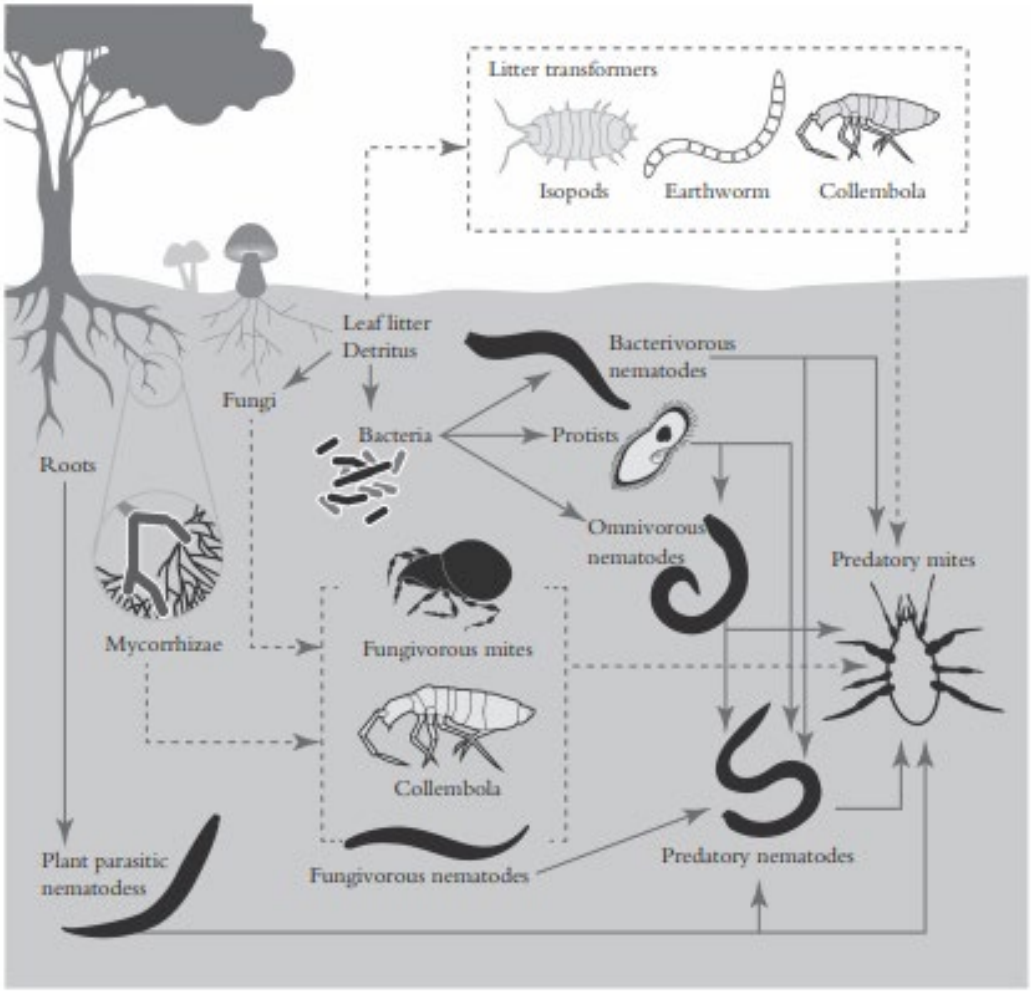
- Soil organisms drive decomposition and nutrient cycling.
- Agricultural practices can change the soil habitat influencing the abundance and diversity of soil fauna.
- Soil is home to ¼ of all living species on earth.



Importance of soil biology

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- Biology is one of the main components of the soil.
- 60-90% of primary production is decomposed.
- Some known specialist feeders BUT many generalist feeders.
- “Enigma of soil animal diversity” due to lack of niche specificity.

What soil animals do you know?

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What soil animals do you know?

- 90% of all insects spend part of their lifecycle in the soil

Soil Biodiversity – time spent in soil

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Time	Characteristics	Organisms
Permanent	Entire life cycle in the soil	Mites, springtails, earthworms
Temporal	Part of life cycle in the soil	insect larvae
Periodical	Frequently enter into the soil	Some insects and larvae
Transitory	An inactive phase in the soil (egg, pupa and hibernation) not an active period	Some insects
Accidental	Animals that fall down on to soil or are transported by runoff	Insect larvae, canopy insects

Microfauna, mesofauna, Macrofauna

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Microfauna

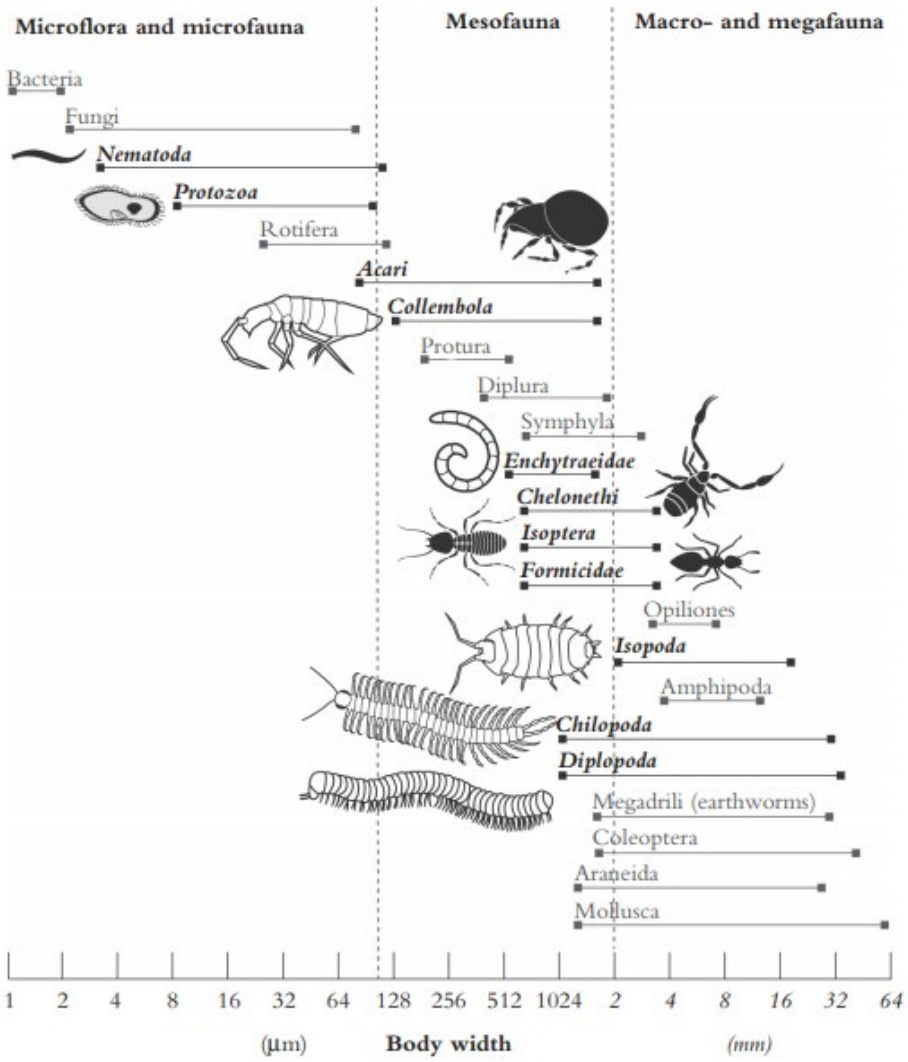
- Bacteria
- Fungi
- Protozoa
- Rotifers
- Flatworms
- Tardigrades
- Nematodes

Mesofauna

- Springtails
- Protura
- Symphyla
- Diplura
- Mites
- Beetle larvae
- Fly larvae
- Centipedes
- Millipedes

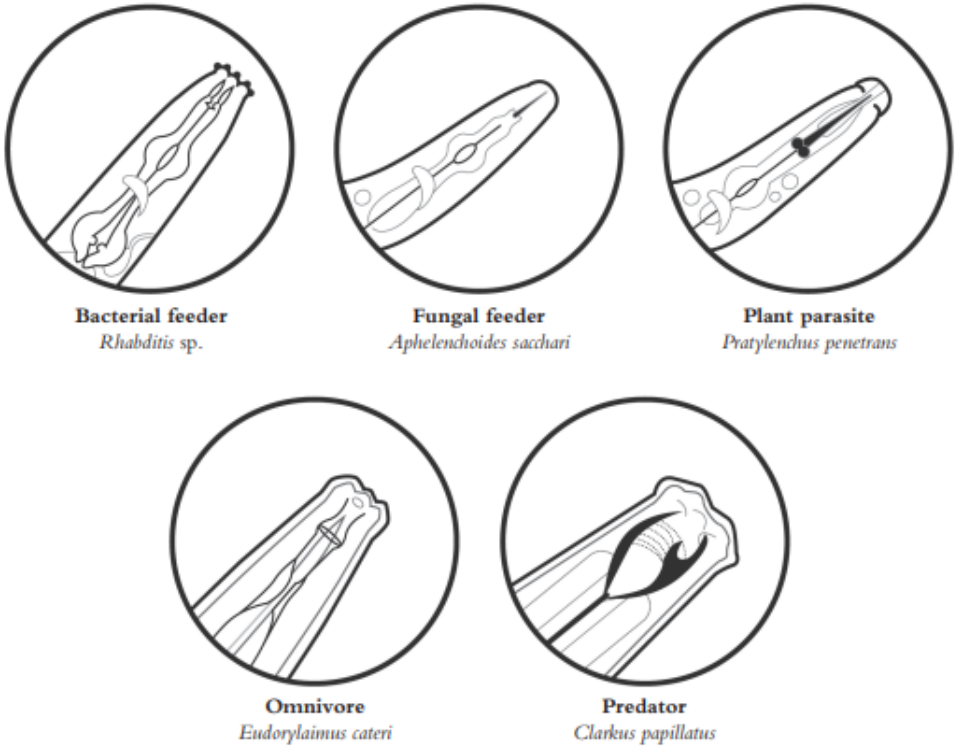
Macrofauna

- Earthworms
- Beetles
- Slugs
- Snails
- Ants
- Termites
- Spiders



Microfauna: Nematodes (roundworm)

- Millions per m^2 – most abundant animals on earth (80%?)
- Many functional groups: Bacteriovores, fungivores, herbivores, omnivores, predators
- Release large amounts of N while feeding -> microbial loop
- Found everywhere – important part of the soil food web and soil health
- Most focus has been on plant parasitic nematodes e.g. PCN



Microfauna Tardigrades

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- Have been around for 530 million years
- Tardigrades are classified as extremophiles
- Can live in boiling water and solid ice
- Brought back to life after being rehydrated from 100+ year old moss samples
- Have survived 30 days in space
- Can repair their DNA after radiation damage
- Most tardigrades are phytophagous or bacteriophagous

But what are mesofauna?

https://www.chaosofdelight.org/collembola-springtails

But what are mesofauna?

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https://www.chaosofdelight.org/collembola-springtails

But what are mesofauna?

https://www.chaosofdelight.org/mites

But what are mesofauna?

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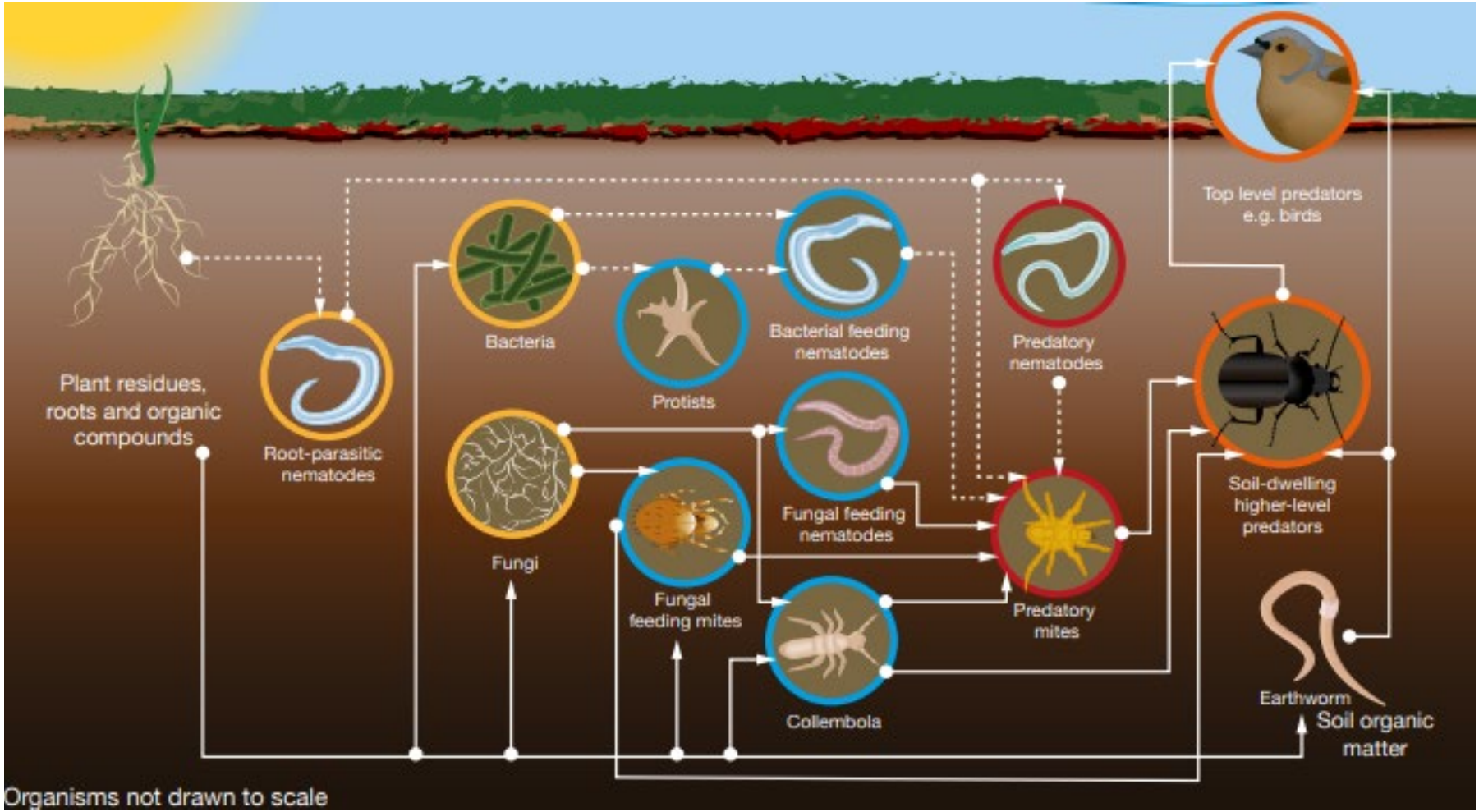
Food web



https://ahdb.org.uk/knowledge-library/soil-food-web

Macrofauna: earthworms

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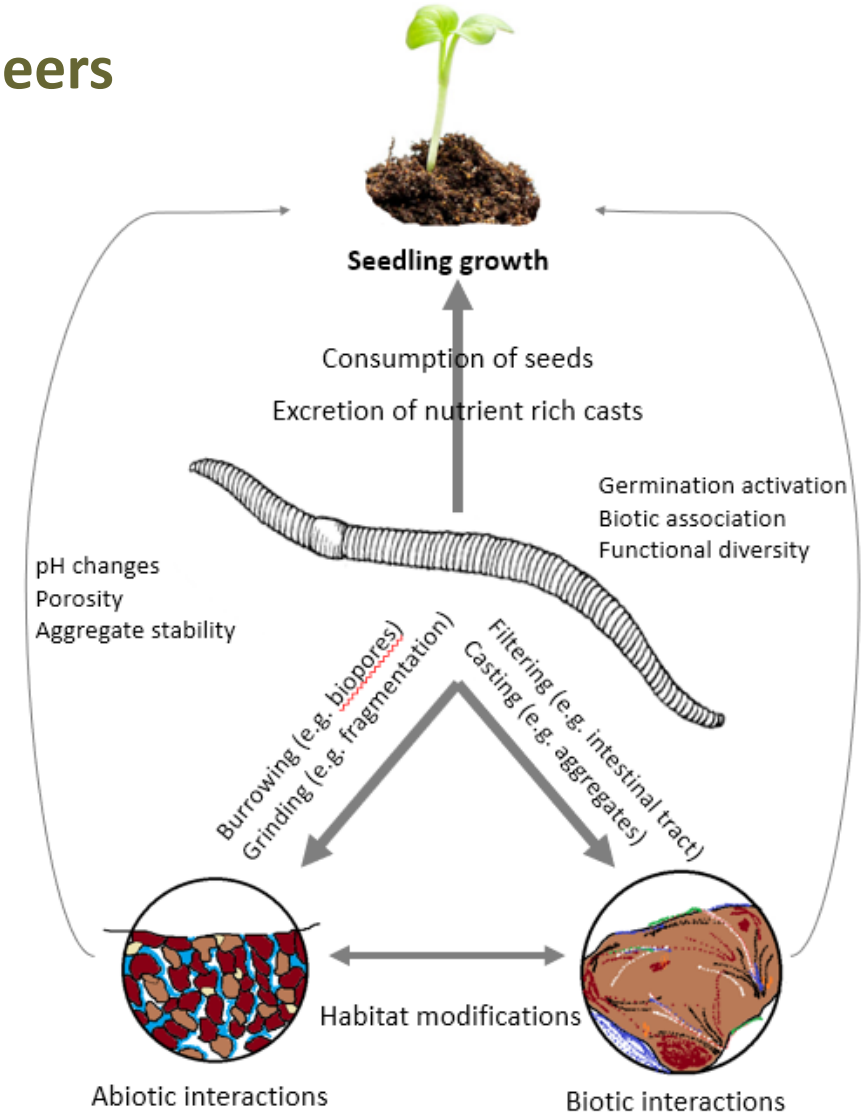
Earthworms are ecosystem engineers

Up to 3 tonnes per ha



Earthworms as ecosystem engineers

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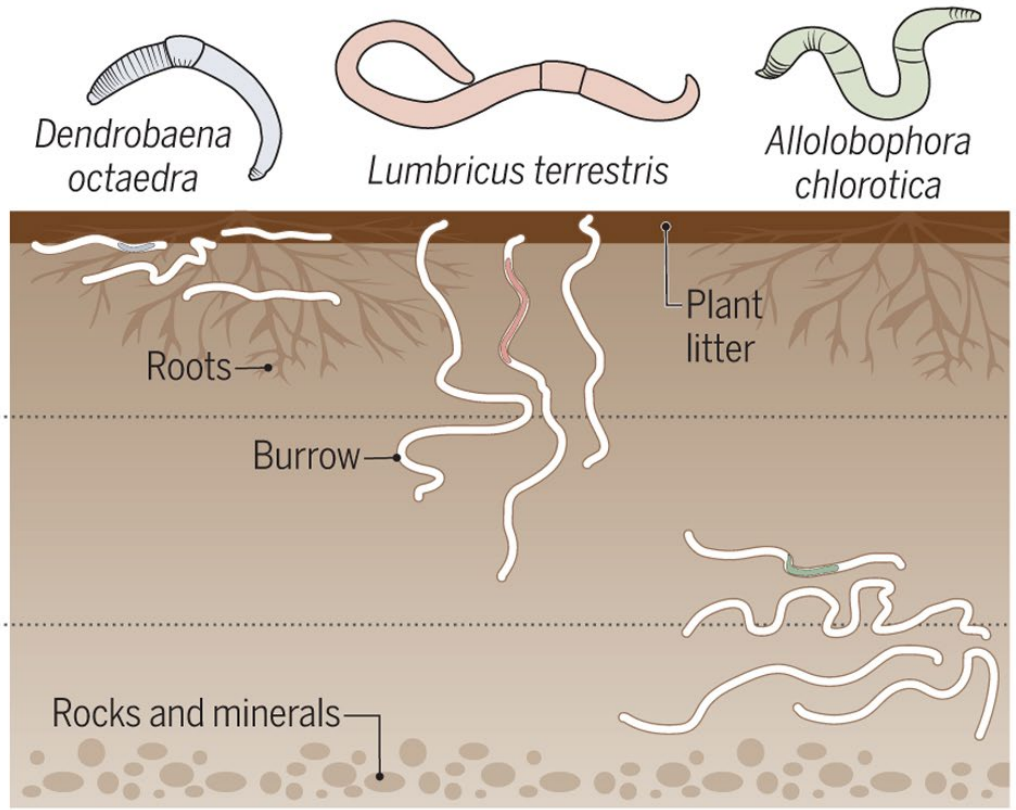
Earthworm ecology

Shown are three main ecological categories of earthworms and examples of resident earthworm species. Not all species fall neatly into these categories, as some earthworms can vary their burrowing and feeding preferences depending on life stage and soil conditions.



Epigeic
Live close to the soil's surface and feed on plant litter

Anecic
Feed on plant litter and soil and form nearly vertical burrows

Endogeic
Live at various depths in mineral soil horizons and feed on soil

Earthworms

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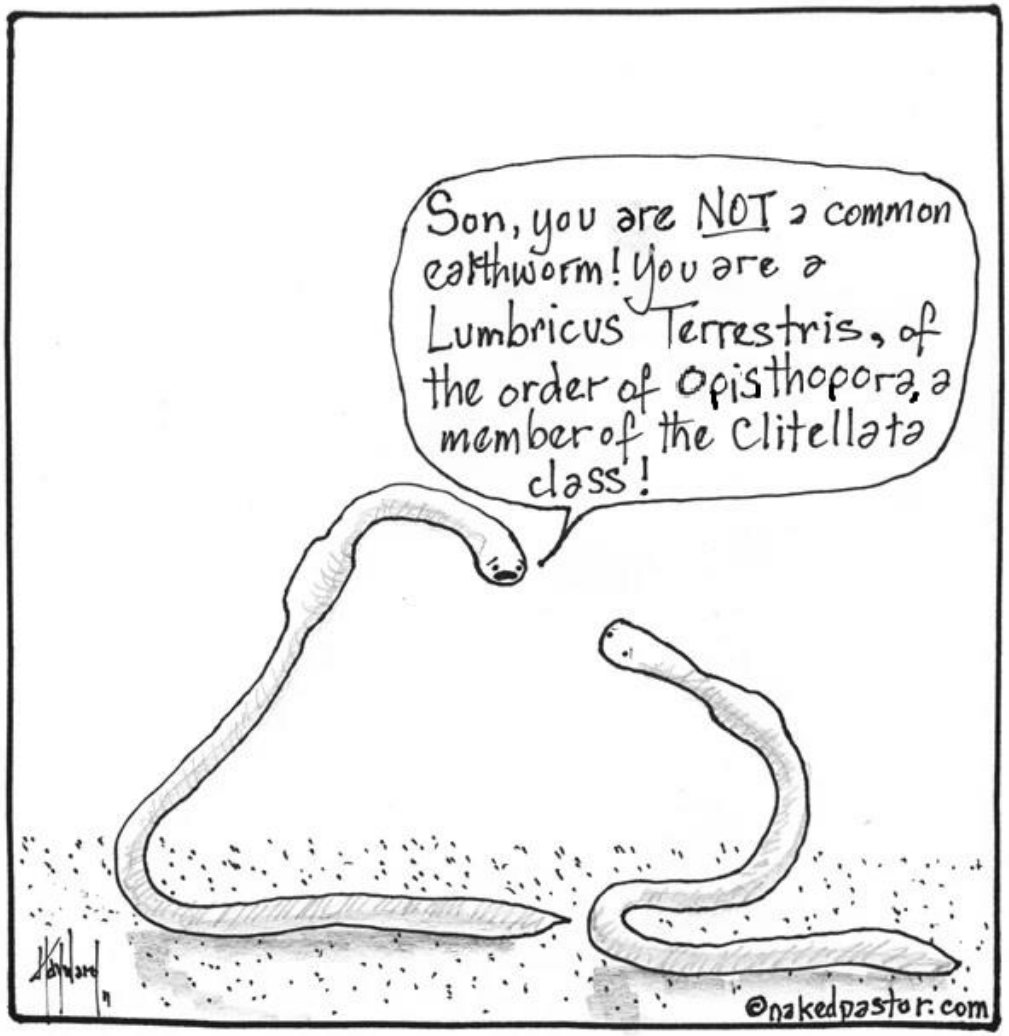
Earthworms in the UK

- Around 30 species of earthworms
- (they're the ones that crossed the channel before the UK became an island!)
- Longevity and fecundity depends on species but some species thought to live up to 10 years!



Earthworms

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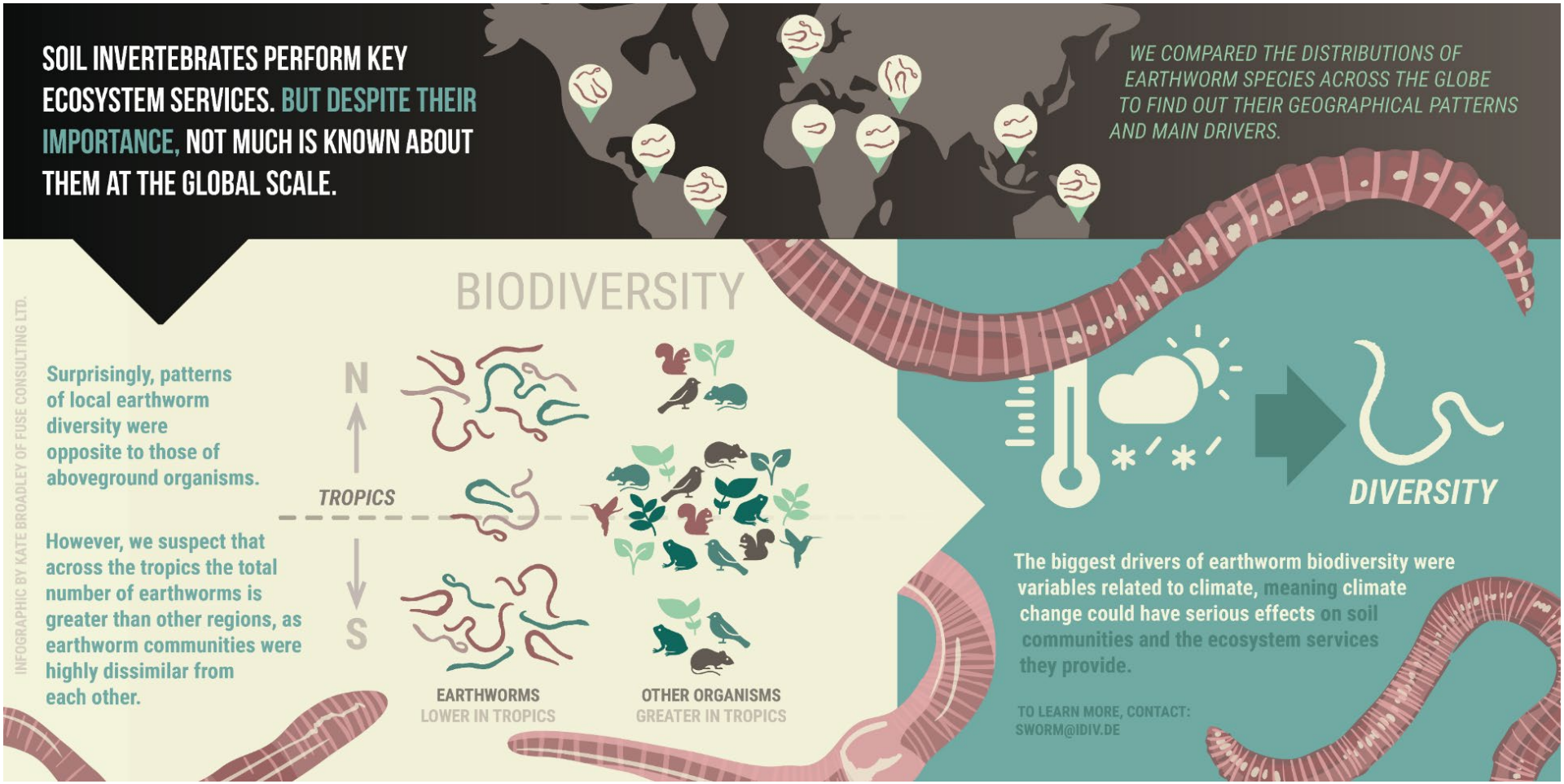
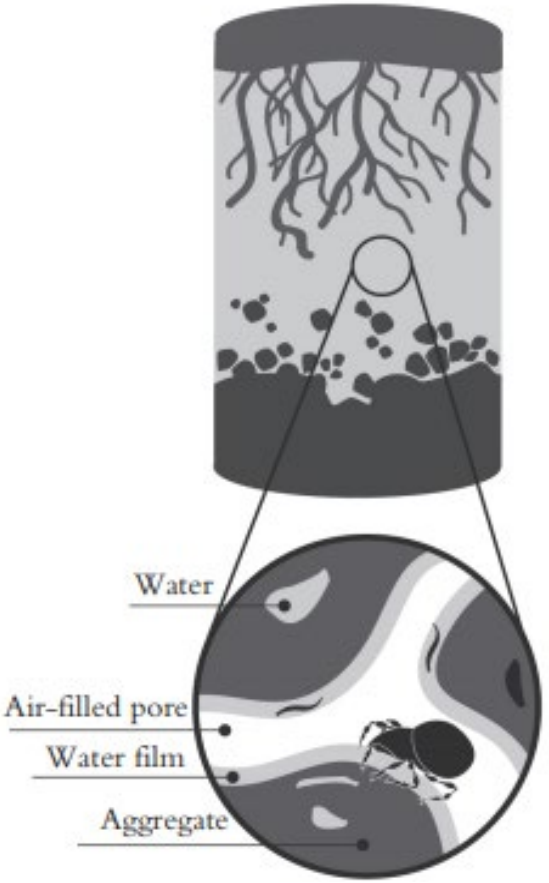


Live within the soil pores

- Soil environment shows extreme variation in space (and time)
- Wide range of surface types, pore size, microclimate and resources for organisms to live in/on and utilise
- E.G. Roots use pores of >100 µm as points of entry, while root hairs, protists, fungi use pores of > 10 µm, whilst bacteria can move in water films of only 1 µm depth



Ecosystem services

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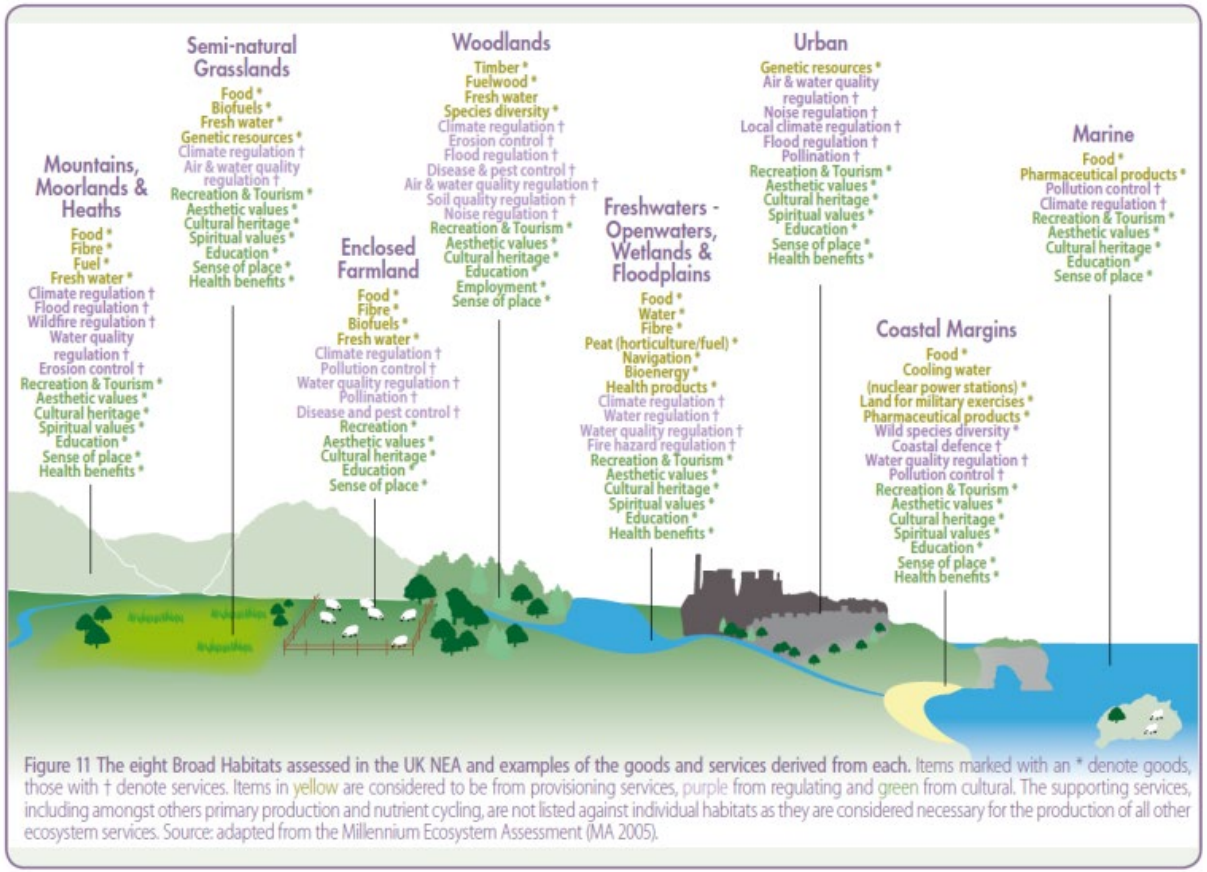
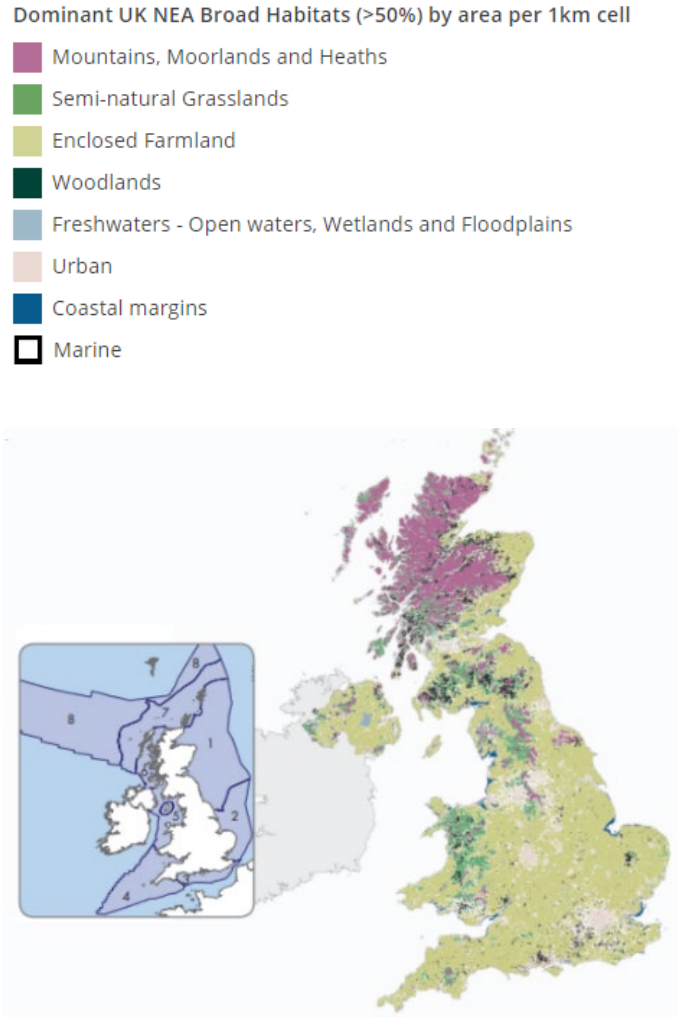


Figure 11 The eight Broad Habitats assessed in the UK NEA and examples of the goods and services derived from each. Items marked with an * denote goods, those with † denote services. Items in yellow are considered to be from provisioning services, purple from regulating and green from cultural. The supporting services, including amongst others primary production and nutrient cycling, are not listed against individual habitats as they are considered necessary for the production of all other ecosystem services. Source: adapted from the Millennium Ecosystem Assessment (MA 2005).



Without soil biodiversity huge reduction in ecosystem services

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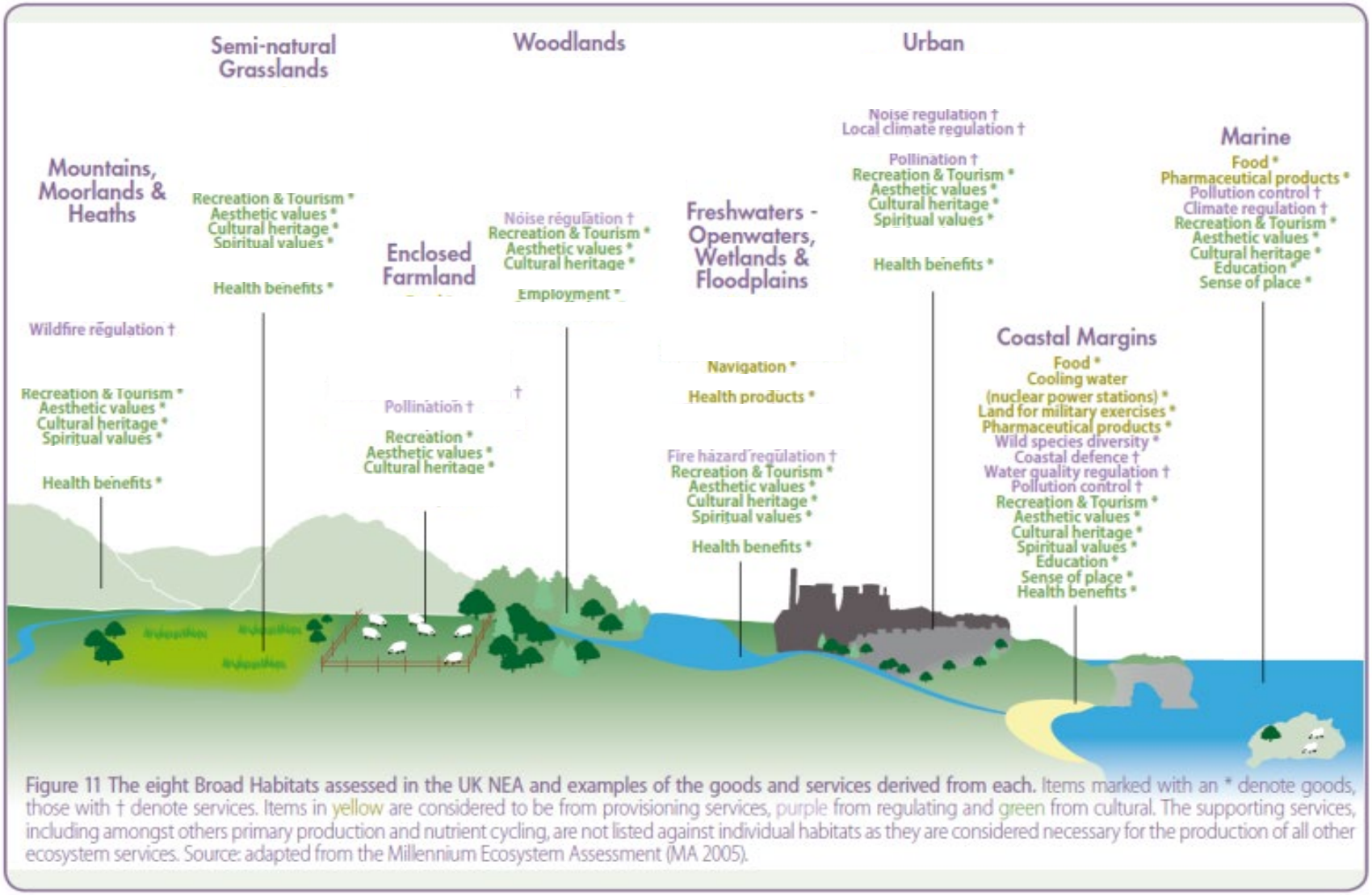

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Soil health is important all year

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HOW FARMERS IMPROVE SOIL HEALTH ALL YEAR ROUND

WINTER

BUFFER STRIPS ON FIELD MARGINS

- Act as a barrier to reduce wind erosion in bare soils.

LIVESTOCK HOUSED INDOORS OVER WINTER

- Reduces soil erosion and poaching in wetter months.

ANNUAL CROP ROTATION

- Maintains soil fertility.
- Helps replenish nutrients.
- Helps to control weeds.
- Reduces crop specific pest and disease problems.

SPRING

SPREADING OF SLURRY AND FARM YARD MANURE

- Less requirement for artificial fertilisers.
- Helps increase organic matter and encourages earthworms.

COW TRACKS AND MULTIPLE GATEWAY ENTRY

- Multiple gateways helps reduce soil compaction.
- Cow tracks avoid poaching.

GRASS LAND SOIL CAN BENEFIT FROM AERATION

- Aeration improves soil drainage & helps keep soil aerobic.

SOIL SAMPLING AND VISUAL ASSESSMENTS

- By monitoring, measuring & managing soil health, farmers ensure that plants get the nutrients needed and earthworms are encouraged.

58% OF AGRICULTURAL LAND IS PERMANENT GRASSLAND & MEADOW

Acting as a permanent carbon storage area, this locks in greenhouse gases otherwise emitted to the atmosphere.

SUMMER

CONTROL TRAFFIC FARMING, GPS & REDUCTIONS IN TYRE PRESSURES

- Reduces soil compaction, fuel consumption and the need for traditional cultivation methods.

477,000 KM OF HEDGES IN THE UK

- Hedges act as a barrier to help reduce wind erosion.

STRAW CHOPPING AT HARVEST TIME

- Helps increase the soils organic matter content to help for the next crop.

AUTUMN

COVER CROPS AND CATCH CROPS

- Prevent post-harvest soil erosion, helps increase organic matter and rooting systems.
- Improves soil structure and infiltration.

DIRECT DRILLING OF WINTER CROPS FOLLOWING HARVEST USES A MINIMUM-TILLAGE METHOD

- Min-till or no-till methods mean fewer soil disturbances & increases in organic matter at the top level of soil.

BACK BRITISH FARMING

NFU

In conclusion

- If soil biodiversity is to be used as an indicator of soil health than food availability and crop establishment methods need to be considered.

- The more stable the environment is (less digging) and more food provided (organic matter) the more likely soil biodiversity populations will grow; and potentially the soils health will improve

- Healthier a soil is, the more resilient it will be to future weather extremes.

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Farming Advice Service

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