

# Unit Two:

## SOIL

### I. Origins of Soil

#### i. Principal Rock Groups

##### a) Igneous Rock

The first rocks on Earth were formed billions of years ago when molten material on the earth's surface cooled to form a hard crust. To the present day, a similar process takes place when volcanic lava comes to the surface and cools to form solid rock. The resulting rock types are collectively known as **igneous rock** (Lat.: *ignis* = fire). Typical examples of igneous rock are granite and basalt.

Igneous rock is chemically complex and contains a variety of elements, combined in various compounds. In the order of their most common occurrence, they include oxygen, silicon, iron, calcium, sodium, potassium, magnesium, carbon, phosphorus and sulphur.

If silicon dioxide (also known as silica, SiO<sub>2</sub>):

- is plentiful (>65%), then the rock is acidic,
- amounts to <52%, then the rock is basic.

**Granite** is made up of three distinct components:


- **felspar** (sometimes spelt *feldspar*),
- **mica** and
- **quartz**.

These three minerals are really groups of related minerals and vary in colour, appearance and other properties according to their actual composition. However, some generalisations can be made.

Felspar is white or pink in colour and contains the elements potassium (K) or calcium (Ca), as well as aluminium (Al) and silicon (Si). Mica is usually dark and contains, in addition to the above, the elements iron (Fe) and magnesium (Mg). The third mineral, quartz, is in fact crystalline silica. It sometimes contains trace amounts of iron or other metal oxides, which may give it a colour other than its natural white. Its high quartz content makes granite an *acidic rock*.

**Basalt** contains very little quartz and is therefore a *basic rock*, although it is otherwise quite similar to granite. The difference in texture arises from the fact that granite cooled slowly to form large crystals, whereas basalt cooled quickly, resulting in very small crystals<sup>1</sup>.

<sup>1</sup> The fast cooling of lava when exposed to ambient temperatures on the earth's surface or on the sea floor after a volcanic eruption does not give basalt enough time to form large crystals. It is therefore very fine textured. Granite cools slowly, deep under the earth's surface, well insulated by overlying rock, hence its coarse-grained texture. The fact that granite is now exposed in places like the Wicklow Mountains is due to the erosion of overlying layers of older rocks over several hundred million years.

 Why is the most plentiful element not mentioned in the last two paragraphs?

##### b) Sedimentary Rock

After igneous rock has been broken down by the forces of heat, frost and rain, it is frequently carried into lower geographic regions by streams and rivers. Smaller particles are often carried out to sea and deposited on the sea floor. For instance, sand grains, resulting from the physical weathering of quartz, are deposited in the waters near the river estuary, where they form a sediment that will in time become cemented into a rock and form **sandstone**. The much smaller clay particles, resulting from the chemical breakdown of mica and felspar, remain in suspension for longer and are therefore carried further from the seashore before settling on the seabed and eventually solidifying into **shale**.

Deep in the oceans, far away from the seashore, the calcareous<sup>2</sup> skeletons of sea animals (from fish-bone down to the shells of microscopic plankton) accumulated over millions of years to form the various types of **limestone**<sup>3</sup>.

Because these rocks originated as sediments in the oceans, these rocks are collectively called **sedimentary rocks**<sup>4</sup>.

##### c) Metamorphic Rock

When sedimentary rocks are exposed to great pressure, or a combination of pressure and heat, they are changed significantly<sup>5</sup>. Thus shale is changed to slate, limestone to marble and sandstone to quartzite. The resulting rock types are collectively known as **metamorphic rock** (Gr.: *metamorphosis* = transformation).

### ii. Soil Formation

Soils are formed from weathered rock and organic matter.

Soils retain some of the characteristics of the rocks from which they originate<sup>6</sup>. Those formed

<sup>2</sup> Calcareous = made from calcium compounds

<sup>3</sup> Chalk is a relatively pure form of limestone. The grey colour of most limestones is due to an admixture of clay.

<sup>4</sup> Sedimentary rock does not always remain horizontal. Subsequent movement of the earth's crust can result in up-tilting layers, or even turning them upside down!

<sup>5</sup> The schist in the Wicklow Mountains shows the effects of prolonged exposure to the immense heat of the up-welling magma during the Caledonian folding four hundred million years ago. The formerly flat layers of the original sediment are often folded over and back into a Z-shape.

<sup>6</sup> This is certainly true for Ireland, where soils are relatively young. Repeated ice ages have scoured the rock surfaces clean of older soils, so all our soils are essentially less than 10,000 years old. Most Irish soils are formed from glacial deposits or from rocks "recently" exposed. In regions like the

 Using the information in the previous paragraphs, fill in the spaces of the table.

	<b>Acidic or Alkaline</b>	<b>Permeable or Impermeable</b>	<b>Chemical Elements contained in the Rock (Enter the Symbols)</b>
<b>Granite</b>			
<b>Basalt</b>			
<b>Limestone</b>			
<b>Sandstone</b>			

**Table 2.1:** Some important properties of commonly occurring rock types.

from granite tend to be acidic, while others formed from limestone tend to be alkaline or at least near-neutral (pH 6.5+). If the underlying rock is permeable (e.g. sandstone or limestone), the soil is usually free draining. If the rock is impermeable (e.g. granite, basalt), then the soil is likely to have a problem with waterlogging.

**a) The Weathering of Rocks**


Both physical and chemical forces are at work during the weathering of rocks. Rock surfaces absorb energy (heat) from the sun and expand as a result. On cooling down during the night they contract again. Since the outer layers expand and contract more than the interior, tensions arise within the rock, which over time result in cracks ('fissures'). Furthermore, dark mica particles in granite absorb more light and heat up more quickly than the reflective quartz, resulting in uneven expansion and consequently greater tension and increased cracking.

Water enters the smallest fissures and, in winter, freezes to ice. During freezing, it expands with great force (remember burst pipes, car engines without anti-freeze!), and opens the cracks further.

Water is also a powerful solvent and affects rocks by leaching more soluble constituents. This effect is enhanced by the mildly acidic nature of rain<sup>7</sup>. Although rainwater is normally an extremely weak acid, its effect over time can be powerful in high-rainfall regions, especially on alkaline rock, but also on alkaline components of complex rocks, like granite.

Mediterranean, which have not experienced any recent ice ages, soils bear little resemblance their parent materials and are more influenced by climatic factors.

7 When rain droplets form in the atmosphere, they dissolve small amounts of CO<sub>2</sub> and thus become slightly acidic (**carbonic acid**). After a thunderstorm, when lightning has burnt atmospheric nitrogen (N<sub>2</sub>) to become nitrogen oxides (NO, NO<sub>2</sub>, etc., abbreviated to NO<sub>x</sub>), this dissolves in rainwater to form **nitric acid**. Atmospheric SO<sub>2</sub>, from sources including volcanic activity, industrial and domestic pollution, also reacts with water to form **sulphuric acid**.

 It has been calculated that the limestone rock of the Burren in County Clare is being eroded by rain at the rate of 0.05 mm a year. If the upper regions at present are around 300 m above sea level, how long will it be before this unique landscape is gone completely?

Check the pH of the rain in your area. Compare, if possible, rain that has fallen over a rural area with rain from Dublin or downwind of Moneypoint power station. Also, collect rain during a thunderstorm.

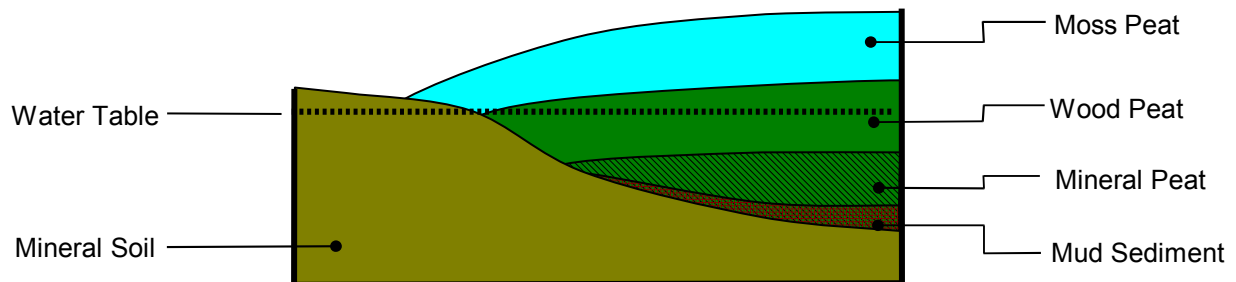
**b) Biological Factors**

Plant lifeforms appear on rock surfaces before proper soil is present and they play an important part in the process of soil formation. **Lichens** are simple plants that can survive on bare rock. Typical plant types get water and minerals from the soil, but lichens follow a different strategy.

A lichen is in fact not a single plant but an association of an alga and a fungus. The fungus stores water between showers and otherwise lives off the food that the alga manufactures from carbon dioxide, water and minerals with the help of sunlight (photosynthesis). Lichens obtain mineral nutrients by secreting acids onto the rock, dissolving the minerals and thus making them available as plant nutrients. The rock becomes brittle in the process and is subject to further decay. Lichens also trap airborne dust particles, which may contain vital mineral nutrients not available from the underlying rock. When they ultimately die, the humus formed from the decaying plant mixes with the weathered rock and the blown-in dust to form the first layer of true soil.

 Look out for lichens on old walls!

Mosses can grow where water lodges in hollows or depressions. They also break down rock, collect dust and provide humus like lichens, but are bulkier and therefore more efficient in soil formation.



**Figure 2.1:** Typical Profile of a raised bog

The water table corresponds to the surface of the former lake. The different layers represent succession during the growth of the bog.

As soon as the newly formed soil is a few millimetres thick, other, more demanding plants like grasses and other herbaceous plants begin to establish. These more efficient and more productive plant types speed up the soil-making process. Eventually, the soil becomes deep enough for shrubs and even trees to grow. Their roots, growing into any cracks or fissures, expand and break up the rock further (see also *Primary Succession, Unit Eight*).

### c) The Origin of Peat Bogs

At the end of the last Ice Age, some 10,000 years ago, melting glaciers deposited an uneven blanket of glacial till over vast parts of Ireland. Low-lying areas soon filled with melt- and rainwater and turned into shallow lakes.

Where a stream or river entered one of these lakes, surplus water soon found an outlet and gradually deepened its passage through the loose glacial material to a level where the lake was almost drained and eventually became part of the river plain.

Where no river entered the lake, water stagnated. Typically a floating mat of vegetation developed on the water surface, and a dense growth of reeds and other water plants encroached from the shore, gradually turning the lake into a **fen**. Slowly decaying plant material filled the former lake to surface level. At this stage, trees with a high tolerance for frequently waterlogged soil, notably willow, alder and silver birch, began to invade the fen, turning it into a **fen wood** or **carr**. When, in due course, these trees died, they, like the earlier water plants, didn't decay completely because of the anaerobic (= deprived of oxygen) conditions in the waterlogged soil.

Bacteria of decay, which normally carry out complete decomposition of organic matter, are *aerobic*, i.e. they require oxygen<sup>8</sup>.

When the pore spaces in the soil are filled with water, there is a shortage of oxygen, resulting in unfavourable living conditions for aerobic bacteria

Other bacteria, able to live and function under *anaerobic* conditions, then take over and decompose the dead plant matter, but only partially, turning it into **peat**.

Water, mainly rain, moves soil minerals downwards through the soil, concentrating them at the lake floor. There is almost no upward capillary action to bring these mineral nutrients to plants at the surface.

**Bog mosses** (*Spagnum* species) have the ability to grow and thrive where minerals are in short supply, which enables them to take over from other plants to become the dominant vegetation.

These mosses can soak up water like a sponge; they can in fact hold up to twenty times their dry weight in water<sup>9</sup>. This, combined with our humid Irish climate, where rainfall far exceeds evaporation, allows the mosses to grow several metres above the water table (which is at the level of the former lake surface). The result is the characteristic **raised bog** of the Midlands which typically rises 7.5 metres above the water table and can be up to 12 metres above the former lake floor.

Because raised bog forms in former lake basins, it is also known as **basin peat**.

A second type of bog common in Ireland is **blanket bog**, widely found in the west of Ireland and in hill regions. It requires high rainfall (>1,000 mm per annum) to develop, as well as an acidic rock base and a generally cool and damp climate.

Blanket bog gets its name from the fact that it covers the contours of the land surface like a fairly even blanket, instead of creating a dome shape like the raised bog. Its depth is usually between 1.5 and 2.5 metres. Blanket bog has less scope for agricultural development than raised bog.

The extensive raised bogs of Ireland are exploited for fuel and peat moss by Bord na Móna. Much of the peat is burnt as milled peat in power stations to generate electricity. The

<sup>8</sup> The complete decomposition of organic matter into carbon dioxide, water and minerals is called **mineralisation**.

<sup>9</sup> Gardeners appreciate this fact when they add peat moss to light garden soils to improve their water holding capacity.

shallower blanket bogs do not permit the efficient use of heavy machinery, but small, tractor-mounted machines are being put to good use and have largely replaced the traditional *slain* of the turf cutter<sup>10</sup>.

Much research has been carried out into future uses of cutaway bogs. It has been shown to have great potential -

- for grassland;
- for vegetable growing;
- for forestry;
- for wetland amenity areas, where the peat has been cut away to well below the water table;
- for wildlife reserves.

Their use for tillage is limited due to the danger of the soil surface blowing away under dry, windy conditions.

For agricultural or horticultural use, it is best to leave about 1.5m of peat. Wood peat, found at this level, makes the best soil. However, it also has the greatest value as a fuel, so deciding at what level to stop harvesting the peat is difficult.

Few raised bogs are now left intact, since even small-scale turf cutting can have a serious effect on the drainage of the bog and can change its characteristics and its ecology significantly. Some areas of midland bog that are still close to their natural state, like Mongan Bog near Clonmacnoise in Co. Offaly, are now being preserved.

#### d) The Soil Profile

A pit dug into the ground reveals the soil profile, which is typically made up of distinct layers or **soil horizons**. In simple terms, there are three horizons, the **A**, **B** and **C** horizons.

The **A horizon** broadly corresponds to what in everyday language is called the **top soil**. It is rich in

- humus (dark colour),
- roots,
- earthworms and
- bacteria.

In climates like our own, the A horizon is subject to leaching – surface water percolates downward and takes with it

- soluble minerals (Na, K, Ca, Mg compounds)
- (in time) less soluble minerals (Al, Fe compounds)
- clay particles and
- humus particles.

<sup>10</sup> Some of these machines extract peat from layers below the surface and deposit it on top. This causes little disturbance to the vegetation.


The **B horizon** is generally called the **subsoil**. It is sandwiched between A and C and has intermediate characteristics.


- It is the youngest of the three horizons, it owes its origin partly to
  - ❑ the activities of earthworms mixing materials from above and below, and partly to
  - ❑ the accumulation of leached materials from the upper layers.
- Where leaching has been a factor, the B horizon typically shows a strong colour
  - ❑ from the accumulation of iron and aluminium compounds, and
  - ❑ sometimes from the accumulation of humus.
- In certain soils the B horizon has a higher clay component than either A or C.

The A and B horizons combined make up the soil proper, the *solum*. The soil in the solum is structured to a varying degree, while the material in the C horizon is unstructured.

The **C horizon** is the parent material from which the overlying soil was formed.

- Where the soil was formed *in situ* (Lat.: on the spot), broken pieces of the underlying rock constitute the parent material.
- In the case of **derived soils**, the C horizon is made up of materials carried to the present location by
  - ❑ glacial ice sheets (glacial deposits),
  - ❑ rivers (alluvium) or
  - ❑ wind (loess).

 *Collect stones in a nearby tillage field or garden. Make your observations: are they round or angular? Of one rock type only or of several? If of different types, sort them and identify them (a drop of dilute acid makes limestone fizz – do you know why? Make a separate heap for 'unidentified' stones.*

 *Draw your conclusions: Is the soil formed in situ or derived? Have you obtained information about the underlying rock? Is the field well drained or subject to waterlogging? Would you expect the soil to be acidic, neutral or alkaline?*

*Check your conclusions: measure the pH. Dig a hole down to the underlying rock (with owner's permission!)*

The distinction between A, B and C horizons is only a very basic one. Where the A horizon has been subjected to leaching, its lower level has as a pale / bleached appearance, while the upper region is dark due to the continued presence of humus. The latter is then classed as A1 and the former, strongly leached layer, as the A2 horizon.


Unit Two: SOIL

An A3 horizon may be present; it represents a zone of transition to the B horizon.

The most characteristic division of the B horizon is the *B2 horizon*, B1 and B3 being transitional forms. B2 shows the greatest accumulation of leached substances, and depending on the nature of such materials may be suffixed

- B2t (textural; referring to a substantial increase in clay particles),
- B2h (humus) or
- B2ir (iron). In a case of advanced consolidation, B2ir becomes an **iron pan**.

If organic matter is found on the soil surface, this gives rise to an **O horizon**. If the organic matter is largely undecayed, it is called O1. Where it is at an advanced state of decay, it is called O2<sup>11</sup>.

 Which soil horizon corresponds broadly to the plough layer?

<sup>11</sup> Soil scientists may find it helpful to introduce further subdivisions. A deep A1 horizon under permanent grassland may have a shallow top layer of dark coloured soil, free of stones, and a deeper layer of more typical colour with a normal occurrence of stones. A distinction is then made between A11 and A12. The A11 horizon is thought to be the result of earthworms depositing worm casts on the surface.

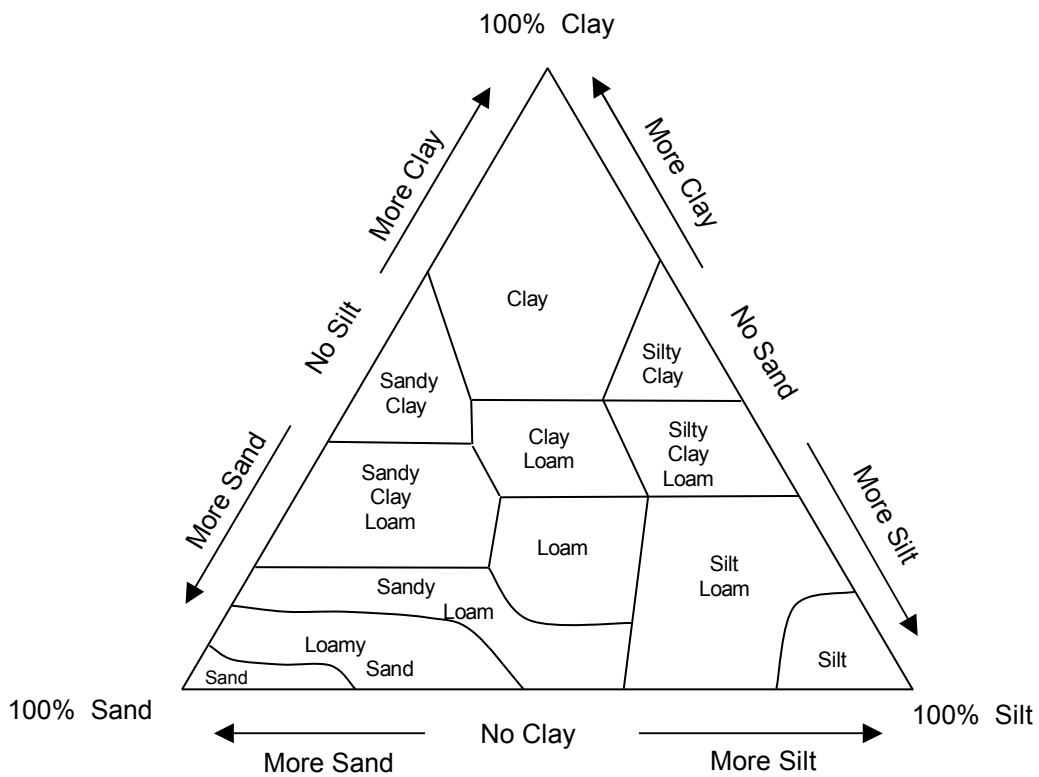


Figure 2.2: Soil Texture Triangle

	<b>Desirable Characteristics</b>	<b>Undesirable Characteristics</b>
<b>Sandy Soil</b>	<ul style="list-style-type: none"> <li>➤ has large air spaces</li> <li>➤ drains well</li> <li>➤ is easy to work with ('light' soil)</li> <li>➤ is a 'warm' soil</li> </ul>	<ul style="list-style-type: none"> <li>➤ tends to dry out quickly (does not hold water)</li> <li>➤ does not hold minerals (no electrical charges)</li> <li>➤ 'poor', 'hungry' soil (no nutrients in sand)</li> </ul>
<b>Clay Soil</b>	<ul style="list-style-type: none"> <li>➤ holds water over long periods</li> <li>➤ holds minerals against leaching (high base exchange capacity)</li> <li>➤ is naturally fertile (often contains P, K, and minor elements)</li> </ul>	<ul style="list-style-type: none"> <li>➤ becomes easily waterlogged (poor drainage)</li> <li>➤ is hard to work (heavy soil)</li> <li>➤ is a cold soil</li> </ul>

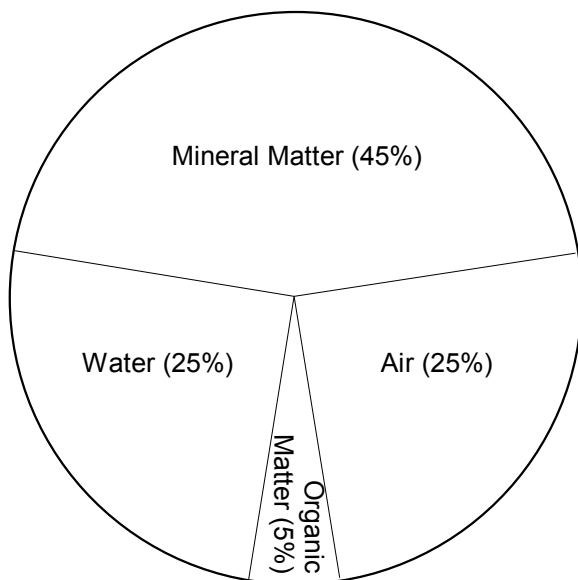
**Table 2.2:** Characteristics of sandy soil and clay soil

## II. Composition and Properties of Soil

### i. Soil Composition

Soils are composed of

- mineral particles (sand, silt and clay)
- dead organic matter (humus)
- living organic matter (plant roots, macro-and micro-organisms)
- water
- air
- mineral salts (macro- and micro-nutrients)




**Figure 2.3:** Ideal composition of soil.

The relative amounts of air and water will fluctuate. The total pore space, jointly occupied by the two components, should be c.50%.

#### a) Mineral particles : Soil Texture

Texture refers to the relative proportions of different-sized soil particles. Large particles of >2 mm diameter are not considered part of the soil and are referred to as pebbles or stones.

- Soil particles from 0.05 mm to 2 mm diameter are **sand particles**, but it is common to grade them further into coarse, medium and fine sand<sup>12</sup>.
- Particles from 0.002 mm to 0.05 mm diameter are **silt particles**.
- Particles smaller than 0.002 mm are called **clay particles**<sup>13</sup>.

 Why are clay particles smaller than sand / silt particles? Can you give a scientific explanation?

Apart from size, there are also important chemical differences between sand and silt on the one hand, and clay on the other. During the breakdown of granite, for instance, the quartz component is only broken down physically<sup>14</sup>. The ultimate particles are therefore relatively large in size. Felspar and mica, however, break down chemically and give rise to extremely small clay particles, which have rather interesting chemical properties, including the presence of a number of different nutrients that provide the soil with a degree of natural fertility.

The relative amounts of sand, silt and clay determine the texture of a soil. Soils may be classified according to their texture. A simple system of classification takes account of the clay content only:

<sup>12</sup> Definitions here vary between 0.02, 0.05 and 0.06. 0.05 is used by the U.S. Dept. of Ag. and has been adopted by the Irish Soil Survey. (0.06 is the figure from the Soil Survey of England and Wales).

<sup>13</sup> It is recommended that the term 'clay soil' should always be used where appropriate, and not be shortened to 'clay'. 'Clay' refers to that component of any soil type which is made up of particles less than 0.002mm in diameter. A further complication arises where the word 'clay' is commonly used in the sense of 'soil'. This should be avoided when speaking in a scientific context.

<sup>14</sup> Quartz is mainly silica. It has chemical properties similar to glass and is highly resistant to chemical attack.


0 – 5 % clay	sandy soil
5 – 10 % clay	sandy loam
10 – 20 % clay	loam
20 – 30 % clay	clay loam
30 – 40 % clay	clay soil
> 40 % clay	heavy clay soil

**Table 2.3:** Classification of soils by clay content only

While the system of classification in Table 2.3 is sufficient for most purposes, it obviously ignores the relative percentages of sand and silt. The soil texture triangle in Figure 2.2 gives a more detailed breakdown.

Soil characteristics vary according to their texture. The characteristics of sandy soil and clay soil are summarised in Table 2.2.

Loam and other intermediate types have those characteristics to varying degrees, but on the whole have more of the advantages and fewer of the disadvantages than the two extremes. A good soil mixture would consist of 40% sand, 40% silt and 20% clay.

 Can you locate this mixture on the triangle in Figure 2.2?

Check below to see in what way humus mitigates the disadvantages of light and heavy soils.

**b) Humus**

Humus is the product of the breakdown of organic matter, the remains of once living plants and animals.

The decay of organic matter ultimately results in carbon dioxide, water and mineral salts (**mineralisation**); but frequently the breakdown is incomplete and produces instead a dark, sticky substance called *humus*. (also see Figure 2.17 **Error: Reference source not found**).

- Humus absorbs water and greatly improves the otherwise poor water-holding capacity of light (sandy) soils.
- It has chemical properties similar to clay and can hold minerals (cations) in the soil.
- Depending on its source, it contains various plant nutrients (esp. trace elements) which it releases very slowly for the benefit of the growing plant.
- This and its high cation exchange capacity (ability to hold minerals) makes it an ideal nutrient store in the soil.
- It improves and strengthens the crumb structure of heavy soils.

- Humus interacts physically and chemically with clay particles, thus forming stable clay-humus complexes.
- Its dark colour makes the soil warmer by absorbing more energy from the sun.

Fast decaying organic matter, usually the remains of the soft parts of plants whose carbohydrates are mostly in the form of **cellulose**, is an important food source for earthworms and micro-organisms (bacteria). ‘Fast’ here means that soil reserves are used up in a matter of months.

Slowly decaying organic matter (from hard stems whose cell walls have been fortified with a substance called **lignin**, (Lat.: *lignum* = wood), is more important for the improvement of the soil itself. Its breakdown leads to the formation of stable humus compounds which are quite resistant to further change and can stay in the soil for years.

Humus tends to make the soil more acidic, which is desirable in alkaline soils but has to be counteracted by liming in other soils. However, the acid nature of humus helps to release nutrients from the mineral fraction of the soil.

According to the organic matter content in their surface horizons, soils are grouped as in Table 2.4.

Peats must have a minimum thickness of 30 cm in the drained state, otherwise the peat layer will be considered an O horizon.

Mineral soils in Ireland usually contain 5 – 10% organic matter<sup>15</sup>.

< 10 % OM	mineral soil
10 – 17 % OM	humus soil
17 – 35 % OM	slightly peaty soil
35 – 50 % OM	peaty soil
> 50 % OM	peat

**Table 2.4:** Classification of soils according to organic matter (OM) content.

**c) Soil micro-organisms : Bacteria**

Soil micro-organisms include bacteria, fungi and algae, but bacteria are the most important group. Bacteria help in a number of ways to break down dead organic matter and to make nutrients available to growing plants. The specific tasks of some selected groups will be referred to in the context of the nitrogen and carbon cycles.

**d) Fungi**

An important association between tree roots and a fungus is known as **mycorrhiza**. The fungus

<sup>15</sup> Soil scientists work on the basis of organic carbon content instead of organic matter content.

organic carbon x 1.7 = organic matter

obtains organic food from the tree and assists it in the uptake of minerals from the soil.

### e) Soil macro-organisms : The Earthworm

It is arguable whether earthworms should be regarded as part of the soil or merely as its inhabitants, but they play such an important role that no soil could be considered complete without them. Some authorities have argued that the number of earthworms in the soil is the single best indication of soil fertility.

In a good soil, there may be as many as 500 earthworms per m<sup>2</sup>, which is equivalent to 5 million worms per hectare.



Figure 2.4: Worm casts

Earthworms can bring enough soil to the surface to create an entire new horizon. In some old, permanent pastures this horizon can measure 10 - 12cm in depth. It is referred to as an A11 horizon (A-one-one, not A eleven!) and is free of stones.

Earthworms improve the soil by:

- literally eating their way through it, mixing the ingested soil with mucus in their guts and passing it out in nicely structured crumbs;
- depositing soil in different places, thus mixing different horizons and deepening the soil;
- improving drainage;
- aerating the soil;
- adding organic matter to the soil when they die, recycling the minerals in their bodies.

Apart from the earthworm, soil is inhabited by a number of other small animals, such as wireworms, nematodes, millipedes and springtails, but some of these are quite undesirable plant pests and unlike the earthworm, make no contribution to soil fertility.

### f) Soil Water

Water is very important for plant growth, as well as for the survival of bacteria and earthworms. All chemical processes that go on in the soil require the presence of water. Too little or too much water can be harmful.

The water holding capacity depends on

- the depth of the soil,
- its organic matter content and
- its texture: clay soil can hold three times as much water as sandy soil.

We distinguish four conditions in regard to soil water:

1. **Flooding:** All spaces between soil particles are filled with water, and water is also '**ponded**' on the soil surface. The condition is well known and is highly undesirable.
2. **Waterlogging:** All pore spaces are filled with water, but there is no water on the surface. The condition is equally undesirable, even when it is only temporary. Though water itself is not harmful, its presence in the soil's pore spaces leaves little room for soil air and the absence of air is the problem.

At some level below the surface, all soil pore spaces are filled with water. This level is called the **water table**.

3. **Field capacity:** When a soil is well drained, it does not lose all its water, but only loses its **gravitational water**, i.e. the water that is free to move downward with the pull of gravity. Some water will remain attached to the surfaces of soil particles and cover them with a moist film. Very small spaces ('**capillaries**', Lat.: *capilla* = a hair) are filled with **capillary water**, while larger spaces are drained empty and filled with air<sup>16</sup>. The soil is now said to be at **field capacity** and this is the *ideal condition*.

If there is less than the ideal amount of water in the soil, the quantity needed to bring the land up to field capacity is called the **soil water deficit**. Soil water deficit is measured in mm, the same as rainfall<sup>17</sup>.

Clay soil can hold more capillary water than sandy soil because it has greater surface area and contains more capillary spaces<sup>18</sup>. In addition to capillary water, clay and humus particles can also absorb **imbibitional water** into the particle themselves (to imbibe = to drink). Imbibitional water is not available for uptake by plants. Water adhering to the surfaces of soil particles is also difficult to obtain.

16 Capillary water in small spaces is best observed when you dip a tea sieve in water. Try to shake off the water that clings to the wires!

17 One mm is equivalent to one litre per square metre (10,000 litres / ha).

18 The capacity to hold capillary water is proportional to the total surface area of all particles in a given volume of soil. The smaller the individual particles, the greater the surface area. One gram of soil can contain a surface area of 40 - 200 m<sup>2</sup>!

**Figure 2.5:** Soil at field capacity (left) and waterlogged (right).

At field capacity the small capillary spaces are filled with water (black) while larger spaces are filled with air (white). A film of water also surrounds individual soil particles. In the waterlogged condition, all or most pore spaces are filled with water.

4. **Wilting point:** Plants begin to wilt when they have extracted all the **available water** from the soil. Available water is the water present at field capacity minus the water remaining at wilting point.

While the first three conditions can be discussed with reference to the soil alone, a definition of the wilting point must take into account the water requirements of a given crop. Different plants have different wilting points.

The point where plants die is known as **permanent wilting point**.

**g) Soil Air**

Air in the soil is essential for:

- the growth of roots;
- aerobic soil bacteria; and
- earthworms.

Roughly four fifths (78%) of atmospheric air is nitrogen and one fifth (21%) is oxygen (carbon dioxide, water vapour and some rare gases make up less than one percent). Both these major components must be available *in* the soil and not just in the atmosphere above the surface for successful plant growth.

Plant roots need oxygen for the uptake of minerals from the soil<sup>19</sup>. The desirable types of soil bacteria are aerobic, which means they also require oxygen. So do earthworms. Nitrogen fixing bacteria can use nitrogen gas from soil air and turn it into compounds that can then be used by plants as a nutrient.

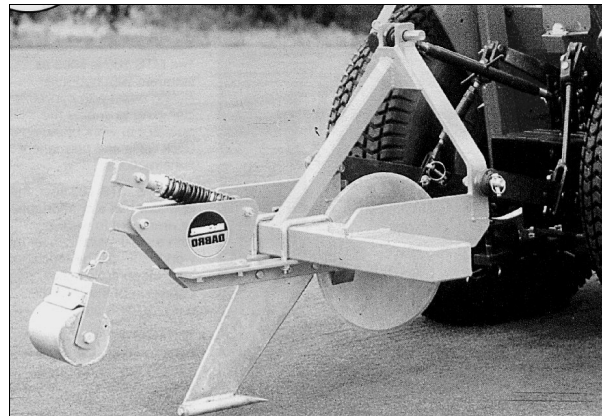
Sand particles are relatively large and have large spaces between them. In a well-drained soil, these spaces are filled with air. Clay particles are small and leave only small spaces between them. In addition, they absorb water internally which

<sup>19</sup> Minerals in the soil solution are often less concentrated than in the cell sap of plant roots. Therefore they cannot enter by simple diffusion but have to be "hauled in" by active transport. Active transport requires energy, which is made available only in the presence of oxygen (see active transport, and aerobic respiration, Unit Three)

makes them swell up, reducing the spaces between them even further.

To make sure that the soil contains sufficient air, it is vital to have good drainage. Where natural drainage is impeded, drainage channels must be provided. They may be

- open drains;
- pipe drainage systems; or
- mole drains.



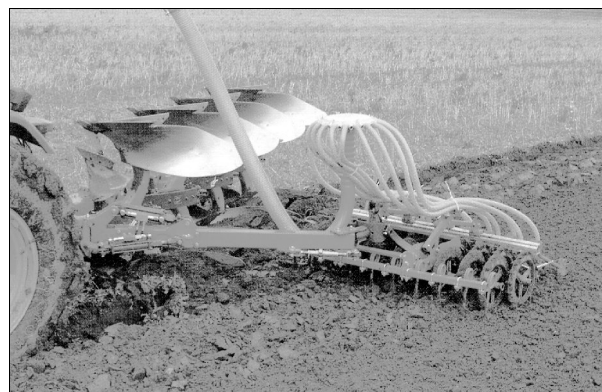
Source: McConnel

**Figure 2.6:** Mole Plough

Mole drainage is a semi-permanent solution to drainage problems.

The bullet at the bottom of the implement opens a tube through the soil that will serve as a drainage channel, but is only suitable for use on fairly heavy soil and level or consistently sloping land. On sandy soils the channel will collapse. The roller wheel at the back controls the depth of the mole.

Avoiding unnecessary soil compaction is essential. Even though up to 90% of compaction occurs with the first pass, one-pass equipment can avoid further damage. One-pass systems allow the performance of several operations in a single pass. The following pictures show one system that works off a ploughed field and one that carries out all operations from ploughing to seeding and final harrowing in one single action. Note that the tractor is mounted with twin wheels where it has to drive on ploughed land.



Source: Kverneland

**Figure 2.7:** A one-pass system that carries out all operations from ploughing to seeding

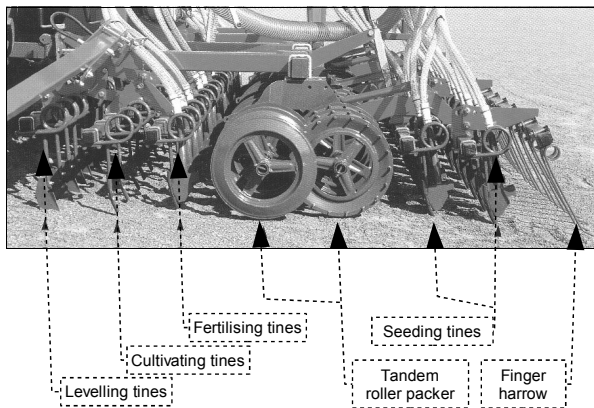


Source: Kverneland

**Figure 2.8a:** Combination seeding harrow

This one-pass implement needs a ploughed field. It then prepares the seed bed, places fertiliser and sows the seed. The seed hopper is front-mounted and the fertiliser hopper is rear-mounted. Twin wheels and the one-pass operation *reduce soil compaction*.

The close-up below shows the various attachments that carry out the different tasks:



Source: Kverneland

**Figure 2.8b:** Combination Seed Harrow Detail

Soil aerators are also available. Different designs use either straight or rotary knives that cut into the soil and at the same time vibrate to shatter compacted soil.



Source: McConnel

**Figure 2.9:** Soil Aerator for Grassland

Other types have vibrating cutting knives penetrating the soil to a depth of up to 60 cm

## h) Mineral Nutrients<sup>20</sup>

In contrast to mineral particles, these are substances that are either dissolved in soil water or chemically bound to clay and humus particles. They are required by plants as nutrients. Some minerals are needed in relatively large quantities and are called **macronutrients** or **major elements** (N, P, K, Ca, Mg). Others are needed only in minute quantities and may be called **micronutrients**, **minor elements** or **trace elements** (e.g. Fe, Mn, Cu, Mo, B).

## i) Soil Temperature

1 kg of water requires ten times as much heat to raise its temperature by 1°C as does 1 kg of dry soil, which makes a wet soil a cold soil.

Wet soils warm up more slowly than well drained soils. In spring, after all gravitational water has drained away, clay soil retains much more capillary and imbibitional water than sandy soil. It is this extra water which slows down the warming-up process of clay soil and makes it a cold soil. On average, clay soil takes about 50% more heat to warm up by 1°C than sandy soil.

Other factors affecting soil temperature are **aspect** (whether it is sloping towards the sun or away from the sun), **colour** and **altitude**.

## j) Soil pH

The pH of a soil is an important factor as plants will grow well only within narrow limits of pH, and productivity will drop drastically if the pH deviates substantially from the optimum range. Earthworms and soil bacteria thrive in neutral or near-neutral conditions.


Though the pH scale extends from 1 to 14, a narrower range of values is encountered in the soil, and descriptive terms are applied as follows:

<sup>20</sup> The word *mineral* is a tricky one to use in Agricultural science. It originally meant a product of mining activities, so it could be a stone quarried for building or a metal ore. Geologists refer to feldspar as a mineral; they even refer to water as a mineral. So in soil science we often use the word in a loose geological sense. However, in plant and animal nutrition, minerals are essential *elements* that the plant or animal needs. To avoid confusion, the latter are usually called *mineral nutrients* in this text.

pH	Description
< 4.5	very acid
4.6 - 5.2	strongly acid
5.3 - 5.9	moderately acid
6.0 - 6.5	slightly acid
6.6 - 6.9	nearly neutral
7.0	neutral
7.1 - 7.5	slightly alkaline
7.6 - 8.3	moderately alkaline

**Table 2.5:** Classification of soils according to pH

Note that pH distribution is not symmetrical around the neutral point. In our climate, soils tend to become acidic due to constant leaching of cations, and therefore have to be limed every four years or so, according to need<sup>21</sup>.

 Not all plant species show the same pH preferences. Make a list of wild plants which prefer acidic conditions and which, when found in a field, are indicators of acid soil. Like wise of plants who love alkaline conditions.

Find out the optimum pH range and the tolerable ranges on either side of the optimum, for the following farm crops: Wheat, barley, oats, oil seed rape, sugar beet, fodder beet, turnips, perennial ryegrass, white clover.

Is there an 'ideal' pH range that suits all (or most) crops?

What about organic soils?

## ii. Chemical Properties of Clay and Humus

### a) Colloidal properties

Clay and humus are **colloids**. They can take in imbibitional water which makes their particles swell up. They feel sticky and slippery when rubbed between two fingers. They have electric charges (in both cases negative) on the outside and behave like oversized anions.

When shaken up with water, they form a **colloidal solution**. This is different from a **true solution** and different from a **suspension**.

- A true solution always appears clear and transparent, though it may be coloured.
- A suspension (e.g. starch in water), will clear up in time when suspended particles sink to the bottom in response to gravity.
- A colloidal solution remains permanently cloudy, because particles with like charges repel each other with a force greater than gravity. Adding divalent cations ( $\text{Ca}^{++}$ , as in

<sup>21</sup> The salt deserts in the arid [dry] regions of the western United States, like the Great Salt Lake in Utah, illustrate the opposite extreme.



**Figure 2.10a:** Compacted Soil



**Figure 2.10b:** Well structured soil

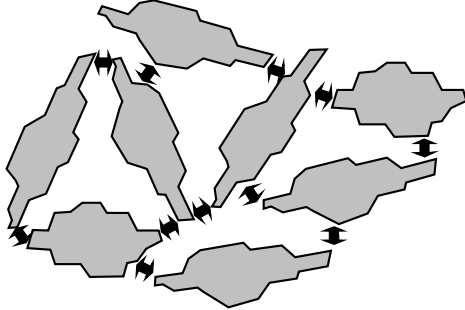
lime, or  $\text{Mg}^{++}$ ) will cause the formation of bridges or ties between suspended particles, resulting in heavier aggregates (crumbs) which gravity will then pull down (flocculation).

### b) Flocculation

Clay and humus attract cations (see Figure 1.2) and hold them so that they are not leached by gravitational water. In the absence of metal ions or ammonium ions, the particles surround themselves with hydrogen ions ( $\text{H}^+$ ) which are always plentiful in soil water. Clay then behaves like a weak, insoluble acid. When all sites are taken up by metal ions, the clay is said to be **base saturated**<sup>22</sup>.

<sup>22</sup> Trivalent aluminium ions  $\text{Al}^{+++}$  will also attach to the clay / humus particles. Unlike the metal ions mentioned in the text, they render the soil acidic. They play only a minor part so they will be ignored from here on.

Divalent cations can do in the soil what they can do in a colloidal solution: they can link neighbouring particles together to form larger aggregates of clay, the desired crumb **structure**. The process is known as flocculation (Lat.: *flocculus* = a flake or crumb).



**Figure 2.11: Flocculation**

Individual clay particles are joined together by divalent cations, here shown as double-headed arrows. This changes clay from a sticky mass to a loose, crumbly, well-aerated structure.

**Flocculated clay**

- has larger air spaces,
- has better drainage,
- is warmer, and
- is easier to work

than de-flocculated clay. This explains why an adequate supply of lime is necessary to minimise the disadvantages of heavy soils.

**c) Base exchange**

Cations attached to clay particles can be exchanged for others if the latter arrive in sufficient concentration. The displaced cations then enter the soil water (soil solution) and may be lost by drainage and are **leached**.

**Base exchange** (or **cation exchange**) is of the greatest importance because it facilitates the storage in the soil of some important plant nutrients, notably potash ( $K^+$ ) and ammonia ( $NH_4^+$ ). Whenever one of these fertilisers is added

to the soil, however, it drives  $Ca^{++}$  ions out into the soil solution and thus makes them prone to leaching. In this way, lime is sacrificed to conserve other minerals.

To make good the losses, most soils periodically have to receive large quantities of lime.

Negatively charged ions, e.g.  $NO_3^-$  (nitrate), cannot be held by soil particles. This means :

- nitric nitrogen, i.e. nitrogen fertiliser containing N in the form of nitrate, must only be given to a growing crop;
- it can be applied in spring a short time before growth starts, but if there is a delay in the onset of growth, it is easily leached;
- applying more nitrate than the crop is able to use up at any time also leads to leaching;
- leaching results not only in a financial loss to the farmer but also causes pollution.

(The molecule of urea is uncharged, so it does not partake in base exchange and is readily leached)

The cation exchange capacity of a soil depends on its clay and humus content. A good supply of humus greatly increases the base exchange capacity of sandy soils and their ability to retain nutrients.

**d) Natural fertility of clay**

Sand is mostly silicon dioxide (silica) and contains no useful minerals for the growth of plants. Clays are chemically complex, but consist mainly of aluminium silicon oxides (aluminosilicates) with small but significant amounts of other elements chemically combined with them. These include Fe, Ca, Na, K, Mg, P and S, all of which are of greater or lesser importance as plant nutrients.



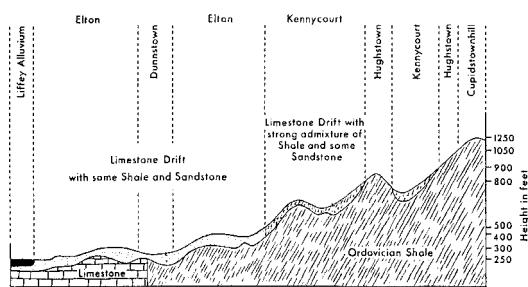
*Which important plant nutrient is conspicuous by its absence?*

**III. The National Soil Survey**

### i. Soil Maps and Bulletins

A nationwide soil survey was started by *An Foras Taluntas*, the Agricultural Institute in the 1960's, but was later suspended due to lack of funds. The purpose of the survey was to identify soils with similarities in their horizons, to classify them (according to similarities and differences) into **Great Soil Groups** and **Series**. Part of the brief was to determine the potential of each soil and its use range and suitability for **tillage**, **meadow**, **pasture** and **forestry**. The results were published in the form of soil maps accompanied by explanatory bulletins.

A **General Soil Map of Ireland** was first published in 1969, with a second edition in 1980. With the latter comes a bulletin titled *Soil Associations of Ireland and their land use potential*. The map shows associations between Great Soil Groups, i.e. two or more groups which are frequently found together in a given area. County maps (e.g. *Soils of Co. Kildare*) go into greater detail and show the distribution of *Soil Series* rather than *Great Soil Groups* or *Associations*. Both types of map and bulletin should be referred to when studying the characteristics of individual soil types and the detailed make-up of a particular soil profile.



Source: *The Soils of County Kildare*

**Figure 2.12:** Diagrammatic representation of soil series in relation to features and geology

### ii. The great soil groups

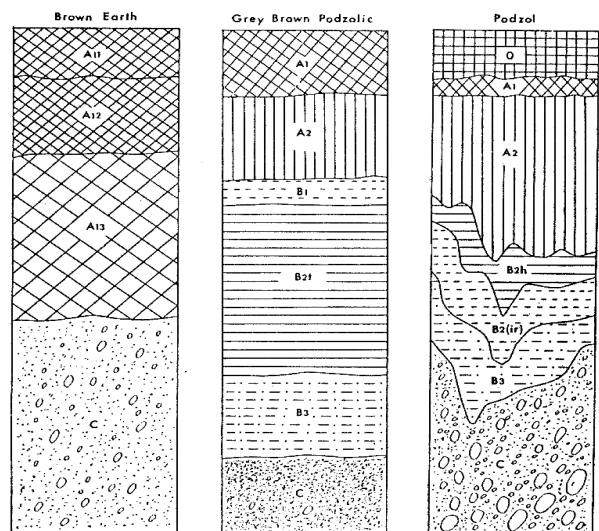
The following groups have been identified in Ireland:

- Podzols
- Brown Podzolics
- Grey-Brown Podzolics
- Brown Earths
- Gleys
- Rendzinas
- Regosols
- Lithosols
- Blanket Peats
- Basin Peats.

#### Podzolisation in steps

1. Leaching of bases, e.g.  $\text{Ca}^{++}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ .
2. A horizon becomes acidic.
3. When conditions are sufficiently acid, iron and aluminium salts are removed.
4. A pale, bleached ('eluvial') A2 horizon develops.
5. Fe and Al compounds are deposited in an 'illuvial' B horizon (B2ir).
6. B2 horizon may become cemented into an iron pan.
7. O horizon develops on the surface.
8. If O horizon > 30 cm, then peat develops.

The term *podzolisation* is sometimes used in a narrow sense to denote step 3 only.



Source: *The Soils of County Kildare*

**Figure 2.13:** Some examples of typical soil profiles

The main characteristics of selected groups are summarised below.

**a) The Podzols**

These soils have developed on acid parent material in areas of high rainfall (>1,000 mm) and cool climate. They have undergone substantial leaching of bases; iron, aluminium and humus compounds have been translocated into the B horizon. In cases of advanced podzolisation, iron oxides have accumulated in the B horizon and have been cemented together to form an impermeable **iron pan**.

Once the iron pan has formed, its major consequences are a severe restriction on drainage and on root penetration. Bad drainage causes anaerobic conditions (no oxygen), which are unfavourable to bacteria of decay and ultimately result in the accumulation of undecayed or semi-decayed organic matter on the soil surface (forming an "O" horizon). The soil is now referred to as a **peaty podzol**. When the O horizon exceeds 30 cm in thickness, it becomes a **blanket peat**. Podzols have a very limited use range due to their poor drainage and root penetration. An iron pan may even make the soil unsuitable for forestry. Also after reclamation, podzols soon revert back to their original state unless carefully managed.



**Figure 2.14:** Podzol profile

Note the strongly bleached A2 horizon and the dark O horizon on the surface.

**b) The Gleys**

Gley soils are mostly found in low-lying regions, where they have developed under conditions of permanent or frequent waterlogging. Waterlogging may have been caused by

- a high groundwater table;

- impermeable soil or parent material (a 'perched' water table); or
- excessive runoff from higher locations.

Accordingly, they are subdivided into groundwater gleys and surface water gleys. The process involved is known as *gleying* or *gleisation*<sup>23</sup>.

The surface horizons of a gley are typically dark brown due to an accumulation of organic matter, while the lower mineral horizons are bluish grey with rusty-brown mottling.

Leaching is not a general feature of gleys.



Can you explain the causes of this rusty mottling? Use the following information:

*Iron can form ferrous and ferric compounds. In ferrous compounds it is divalent and in ferric compounds trivalent. Ferric oxides occur only under aerobic conditions (where oxygen is plentiful). Rusty spots are found close to earthworm channels or decayed roots.*

Gleys generally have a limited use range. They are unsuitable for tillage, being wet, cold, late soils. As pasture they are fair to good, but are liable to severe poaching in wet conditions. The grazing season is therefore short.

**c) The Grey-Brown Podzolics**

These well drained mineral soils are usually associated with a gently sloping topography, on calcareous (limestone type) parent material of glacial origin. Typically, the parent material contains a small proportion of Old Red Sandstone. Their most characteristic feature is an enrichment of clay particles in the B horizon, which have been translocated from the A horizon.

Though leaching is very much in evidence, the calcareous nature of the parent material counteracts its effects and has not allowed base depletion to proceed to a point where podzolisation would take its course. The A horizon consists of a deep A1 horizon and a pale A2 horizon may or may not be present. In some old pasture districts, the activities of earthworms may have resulted in the deposition of a stone-free layer of dark brown soil on the surface. Where this is the case, it is referred to as the A11 horizon. The B horizon is typically a B2t horizon, which means that its texture is heavier and its clay fraction greater than that of either A or C.

Grey-Brown Podzolics are good all-purpose soils, suited for tillage as well as intensive grazing.

**d) Brown Earths**

These are rather mature, well drained mineral soils. They have undergone very little leaching and therefore have a uniform profile with little differentiation into horizons. Most Brown Earths in

<sup>23</sup> In gleisation, ei is pronounced as in Eisenhower (or in Geissel).



amounts than N, P and K, but in larger quantities than all other plant nutrients (except sulphur). It stands in-between the two groups but is now generally considered a major element. **Sulphur** is difficult to classify but is sometimes included here.

The **minor elements** include **iron, copper, boron, molybdenum and manganese**, to name some of the more important ones. They should not be thought of as being less essential than the major minerals, for if even one of them is deficient it can have a serious effect on the crop. Often, however, the soil contains a sufficient supply of minor elements within the complex chemical structure of its clay particles. Dead and decaying organic matter (humus) also continuously releases small amounts of these chemicals.

## ii. Nitrogen

Nitrogen is needed by the plant for the manufacture of protein and many other organic substances, including chlorophyll (the green pigment in leaves). Symptoms of nitrogen deficiency are yellowing of the leaves (*chlorosis*) and stunted growth. Excess N produces rank growth which may cause lodging in cereals, delay ripening and render crops susceptible to disease (see Table 2.6).

Deficiency	Excess
Chlorosis	Rank Growth
Stunted Growth	Lodging (cereals)
Low levels of Protein	Delayed Seed Formation
	Delayed Ripening
	Long internodes (e.g. in coniferous trees)
	Susceptibility to disease

**Table 2.6:** Effects of nitrogen deficiency and excess

### a) The Nitrogen Cycle

Nitrogen is abundant in the atmosphere; about 80% of the air around us is nitrogen gas, N<sub>2</sub>. Yet it is not available to plants in this form – they can take in nitrogen only in the form of nitrate (NO<sub>3</sub><sup>-</sup>).

Plants combine nitrogen compounds with manufactured sugars to make proteins. If the plant is then eaten by an animal, the protein is digested and converted into animal protein. If not, it dies and decays and its N-component appears as **ammonia** in the soil. If the animal eats more protein than is required for growth and reproduction, the N in the surplus protein is excreted as **urea**, which soon decomposes to ammonia. Animal bodies, sooner or later, die and decay too, and their N-content shows up as

ammonia. Ammonia is now nitrified to **nitrite** and finally to **nitrate**.

The breakdown of dead plant and animal matter and of urea requires the help of bacteria of decay. Nitrification of ammonia to nitrite and nitrate is carried out by nitrifying bacteria.

Atmospheric nitrogen can be brought into this cycle through the process of nitrogen fixation. Nitrogen combines with oxygen only when exposed to very high temperature (e.g. lightning). This oxide dissolves in rainwater to form nitric acid and appears in the soil as nitrate ions.

There is also a group of bacteria capable of **fixing nitrogen**, i.e. they can form compounds from atmospheric nitrogen that may be utilised by plants. Some of these nitrogen-fixing bacteria are free-living in the soil while the majority are found in little lumps called *nodules* on the roots of legumes, e.g. clover, beans and peas. They depend on the plant for sugar (energy) and in turn supply it with fixed nitrogen.

<i>Azotobacter</i>	Free living nitrogen fixing bacteria
<i>Rhizobium</i>	Nitrogen fixing bacteria found in the root nodules of legumes
<i>Nitrosomonas</i>	Bacteria that convert ammonia to nitrate
<i>Nitrobacter</i>	Nitrifying bacteria that convert nitrite to nitrate

**Table 2.7:** The "Who's Who" of soil bacteria involved in the Nitrogen cycle.

### b) Nitrogen compounds as fertilisers

Nitrogen can be applied as fertiliser in any fixed form – as protein (including other forms of organic nitrogen compounds), urea, ammonium salt or nitrate.

- **Protein** is applied as ploughed-in beet tops, green manure, etc. It is highly resistant to leaching but may take many months before it is converted to nitrate and thus available for uptake by the crop. It provides a good nitrogen reserve in the soil.
- **Urea** occurs naturally in urine but is also available as a commercial high-nitrogen fertiliser. It is highly soluble in water and forms no cations, a fact that makes it very prone to leaching, especially during autumn. Recent research has shown that spring leaching is less serious than was previously thought. If a dry summer follows, water moves mostly upward and brings back the leached minerals to within reach of the plant roots. In warm weather, provided there is sufficient moisture in the soil (the top 25 mm should be moist), urea is soon changed by bacteria to ammonia and subsequently to nitrate.

### Where does the Nitrogen go?

Irish farmers spend hundreds of millions of Euro annually on fertilisers, of which 50% is spent on nitrogen fertilisers alone. On tillage land, 45% of the nitrogen is recovered, i.e. contained in the crops that are removed from the field, while 55% is lost in various ways. On grassland, only 15% is recovered as a component of milk or beef. As much as 85% is frequently lost, or at least made unavailable for a number of years.

 Check the figures:

Dairy cows per hectare	
Milk yield per cow	
Milk yield per hectare	
Protein in milk (%)	3.4%
Milk protein per hectare (kg)	
Nitrogen in protein (%)	16%
Milk nitrogen per hectare (kg)	
Fertiliser nitrogen per hectare (kg)	

#### A breakdown of the losses:

##### ➤ **Runoff.**

If heavy rains occur within one or two days after fertiliser application, 30 – 40% of the N applied (and corresponding amounts of P and K) are washed off the surface into rivers, ditches or low-lying areas of the field. This is a particularly serious problem on heavy soils where soakage is slow, and on hilly land. Runoff pollutes ditches, streams and rivers.

Farmers should consult weather forecasts and spread fertiliser only when heavy rains are not expected for at least a week.

##### ➤ **Losses to the atmosphere: Volatilisation and denitrification.**

Ammonia is a gas which in its liquid form is simply dissolved in water, and under drying conditions is very much susceptible to volatilisation (which for our purposes means about as much as evaporation).

In slurry and fresh FYM, ammonia is present mainly as ammonium -carbonate and -bicarbonate. Both compounds are very unstable and break up easily to yield ammonia gas, carbon dioxide and water.

Volatilisation also occurs when urea (as urine or as commercial urea) is applied under drying conditions. Urea is changed to

ammonia by bacterial action and then lost to the atmosphere. Other ammonium compounds, such as ammonium sulphate and ammonium nitrate (both found in commercial fertilisers) are quite stable and do not tend to break up and release the gas.

##### ➤ **Denitrification.**

Denitrification occurs from the breakdown of nitrates ( $\text{NO}_3^-$ ) by bacteria, which consume the oxygen for respiratory purposes, in the absence of free atmospheric oxygen.

Nitrate is reduced to nitrite and finally to elemental nitrogen. These processes take place under generally anaerobic conditions, i.e. in spring when the soil is wet, waterlogged and low in air content. Denitrification can cause losses of 10 – 20% when the soil is wet and nitrates are present.

##### ➤ **Leaching.** Minerals found in the soil solution will move downward at the rate of 3 mm per millimetre of rainfall in dry soils, and 2 mm per millimetre of rainfall in loam. Minerals, such as nitrates, when leached are not necessarily lost, provided they have not reached a depth of more than 60 cm before the end of spring – as soon as a soil water deficit arises in summer, the movement of water is generally upward, and dissolved minerals are brought back up to where the roots can reach them.

Leaching is a more serious problem in autumn. Especially after a dry summer the downward movement of water is very rapid and leaching is more severe than after a wet summer. Apart from the financial losses to the farmer, leaching has serious environmental consequences when it causes **groundwater pollution**. This may affect drinking water.

##### ➤ **Uptake by plants.** This is the purpose of all fertiliser use (with the exception of lime, which is primarily given as a soil conditioner). To ensure that the highest possible percentage of the fertiliser is indeed taken up by the plants, it is important to match the application to the requirements of the crop, to know the extent of the soil reserves and to optimise the conditions for bacterial activity (e.g. pH!). The best response to N is in May, when an increased yield of 25 kg DM can be expected per kg N applied. (10:1 in August; minimal economic response: 4:1).

##### ➤ **Uptake by soil micro-organisms.** When organic matter such as straw is ploughed into the soil, bacteria of decay will break it down. The more straw there is the more bacteria are required; so they multiply rapidly. Bacterial cells are largely made up of

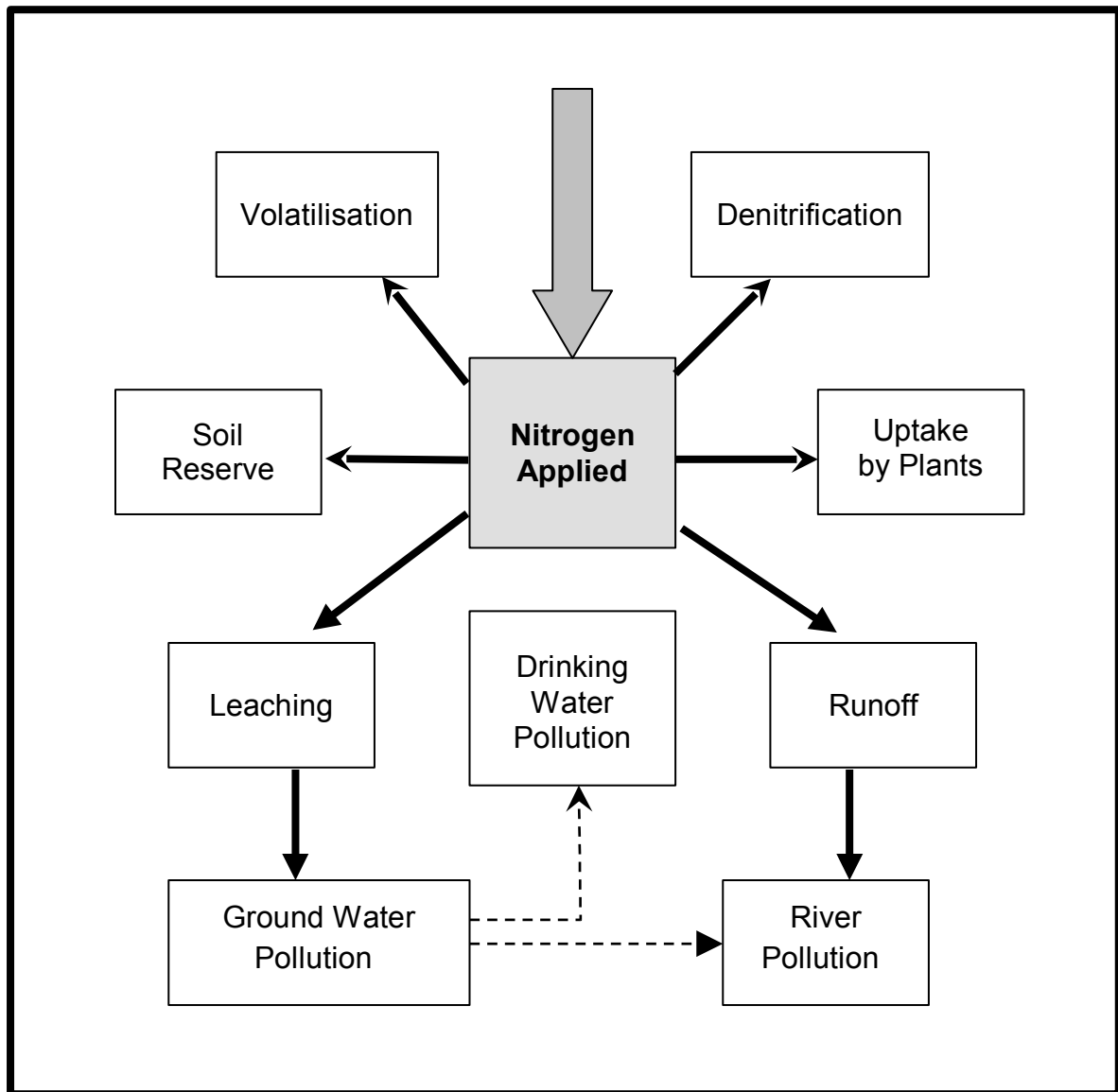


Figure 2.16: Where does the Nitrogen go?

proteins (containing the elements C, O, H and N), whereas straw is mainly carbohydrate (C, O, H). For bacteria to grow and reproduce, they use the straw as a source of C, O, H, but need a separate source of N to make proteins. If nitrates are present in the soil, bacteria will use them for this purpose, especially when the organic matter present is high in carbon but low in nitrogen (like straw).

A balance is achieved when the C:N ratio is 15:1. In grassland, where among other plant remains, clover leaves and roots die and decay, the C:N ratio is more favourable and N is actually released in the process. Farmyard manure, though containing a substantial amount of N relative to P and K, has available nutrients only in the form of the latter two. The nitrogen is needed to break

down the straw and will be tied up in bacterial protein and humus compounds.

Yet this is not the full story. Humus and soil micro-organisms form an important nitrogen reserve, which is gradually broken down and made available to generations of plants over several years. About 1% of the soil reserve is made available each year.

Urea should not be applied when the soil is very dry, which under normal circumstances would rule out its use after the beginning of June. The danger here is *volatilisation* (loss into the atmosphere).

- **Ammonia** is not directly available to plants, but the positively charged ammonium ion is held by clay and humus particles in the soil and is not easily leached. Ammoniacal nitrogen must first be nitrified by bacteria and is therefore slower acting than nitric nitrogen (nitrate).
- **Nitrites** are of no practical importance.
- **Nitrates** are directly available to plants and therefore are the fastest acting form of nitrogen. They should only be given to a growing crop, i.e. around planting time or later as a top-dressing. On grassland, nitrate can be applied about two to three weeks before first growth is expected, and again at intervals during the growing season. No nitrogen fertiliser should be spread after the first week of September.

1	Small release of nitrogen
2	Medium release nitrogen
3	Large release of nitrogen
4	Very large release of nitrogen

**Table 2.8:** *The nitrogen index*

The nitrogen index is determined by looking at

- soil type,
- crop grown,
- amount of fertiliser and farm waste applied to soil
- last crop yield

### c) Commercial Nitrogen fertilisers

- **Calcium Ammonium Nitrate (CAN)** contains 25-27.5% N, half in nitric (= nitrate) and half in ammoniacal form. Its nitrate content makes it immediately active, while its ammonium fraction becomes available more slowly, and in this way, nitrogen is provided over a period of time. CAN contains about 20% lime.  
CAN is highly *hygroscopic*, i.e. it attracts moisture from the air and then sticks together in clumps. It should always be stored in a sealed plastic bag.
- **Urea** contains 46% N and is therefore the commercial fertiliser with the highest nitrogen content. It is now generally sold in prilled form. It is readily dissolved in water. Urea affects the germination of cereals, so it should not be applied by way of combine drilling.

It should be kept in mind that urea fertiliser contains only N (the missing 54% are carbon, oxygen and hydrogen which do not count as

minerals). Nor does it contain any "impurities", which are in fact valuable sources of trace minerals where they are present in other fertilisers.

- **Sulphate of Ammonia** (21% N) has an acidifying effect due to its sulphate content. It is more suitable for soils with a high pH (e.g. chalk soils) than for soils with a low pH. However, it can be useful where sulphur deficiency is suspected.

### iii. Phosphorus

Phosphorus is needed by the plant for fundamental growth processes, root development, seed formation and early ripening. Plants have their highest P requirements during early growth. Symptoms of phosphorus deficiency are stunted growth, reduction in tillering in cereals and a greyish-green colour of leaves with a brown or purple tint.

P is taken in by the plant as phosphate ion ( $\text{PO}_3^{---}$ )<sup>25</sup>. It is an anion and cannot therefore partake in base exchange or be held by soil particles. The degree of leaching depends on the solubility of the particular phosphorus compound contained in the fertiliser. Only water soluble phosphate fertilisers are easily leached.

#### Commercial Phosphate Fertilisers

- **Superphosphate** is available in different grades ranging from 8 – 16% P (actually, these are percentages of phosphoric acid, not of elemental P<sup>25</sup>). Most commonly available is 8% *Superphosphate*. 93% of the phosphate in *Superphosphate* is water soluble. It is the fastest acting phosphate fertiliser and is subject to leaching.  
8% *Superphosphate* contains 12% sulphur. Higher grades containing more than 16.7% P are known as *triple Superphosphates*.
- **Soft Ground Rock Phosphate** is slow acting. Its P content is not soluble in water but only in mineral acids, so it is not easily leached. It contains 11% P or more.
- **Basic Slag** is a by-product of steel manufacture. Its nutrient content varies but is usually around 6 – 7%. It is inexpensive and also contains lime.

<sup>25</sup> In agricultural language, the terms 'phosphate' and 'phosphorous' can be used almost interchangeably, though chemically, there is of course a great difference between the element and the salt (or ion) of phosphoric acid.



Soil Index	Soil P level (mg/l)	Plant Response
1	0 – 3	Definite
2	3.1 – 6	Likely
3	6.1 – 10	Unlikely
4	> 10	None

**Table 2.9:** Soil index and likely response to phosphorous

#### iv. Potassium

Potassium is necessary for the manufacture of sugars (carbohydrates) in plants. Satisfactory potassium levels in the soil are essential for nutrient movement within plants, and when soil potassium levels are low, the productive grasses and especially white clover tend to have very poor persistency.

The two commonly used fertilisers contain potassium in water-soluble form, but since the K<sup>+</sup> ion partakes in cation exchange, it is not easily leached. Potash<sup>25</sup> can be applied in autumn without fear of leaching; in fact on pasture it should be applied no later than January to allow it time to attach itself to a charged soil particle. If K is given to grass during active growth, plants can take it directly from the soil solution. This results in 'luxury uptake', which is wasteful of the nutrient and also causes high potassium levels in the grass and an increased risk of grass tetany.

- **Muriate of Potash** contains 50% K (actually, K<sub>2</sub>O), in the form of potassium chloride, KCl. It is a byproduct of the salt-mining industry and is relatively inexpensive.
- **Sulphate of Potash** (42% K) is much more expensive. It is used on potatoes and on certain horticultural crops sensitive to chlorine.

#### v. Compound fertilisers

Each of the 'straight' fertilisers discussed above contains only one of the elements N, P or K, while compound fertilisers contain at least two but usually all three of them.

- **10-10-20** contains 10% N, 10% H<sub>3</sub>P<sub>0</sub><sub>4</sub> and 20% K<sub>2</sub>O. The numbers printed on fertiliser bags are always read in the same order: N-P-K. Other popular compound fertilisers are 0-10-20 and 0-7-30, both fertilisers for autumn application, the nitrogen to be given separately the following spring. (The former is usually given to pasture ground and the latter to silage).
- **7-6-17** is a specially formulated potato fertiliser and contains sulphate of potash.

Specified amounts of magnesium or other elements may be included in some compound fertilisers, e.g. 13-4-14 + 5% Na + 4% S + 0.33% Boron, for sugar beet.

#### vi. Calcium

Calcium compounds are collectively known as lime. Ca is used by the plant to make cell walls and strong stems (straw) in cereals. It is also needed for the proper functioning of the cell wall and helps to neutralise waste acids.

However, the bulk of lime is applied, not as a plant nutrient, but as a soil conditioner, to raise the pH of acidic soil and to achieve flocculation.

Many Irish soils are naturally acidic due to high rainfall and leaching of bases. Liming is the best way of keeping soils at pH 6.0 – 6.5. Lime provides the basis of soil fertility and works in a number of ways. It

- corrects soil acidity;
- increases the activity of bacteria, including those involved in the nitrogen cycle;
- leads to the release of nutrients in the soil such as nitrogen, phosphorus and potassium;
- facilitates soil organisms in the breakdown of dead organic matter;
- improves earthworm activity;
- improves soil structure, which leads to increased soil pore size and thus improves drainage and aeration; and
- encourages the growth of 'sweet' grasses and white clover on grassland.

However, lime application should be restricted

- on soils with high molybdenum status;
- on peat soils (pH should not be raised above 5.5); and
- on heavy carboniferous soils where over-liming may lead to increased poaching.

Lime is usually applied once in a rotation (every four years or so), preferably to a crop like sugar beet or barley that prefers a high pH, or whenever tests indicate that it is needed (*see Figure 2.11*).

pH 8.0	over-limed
pH 7.0	optimum for white clover, beet, beans, peas, oil seed rape
pH 6.5	optimum for most cereals
PH 6.3	optimum for grass
pH 6.0	optimum for potatoes

**Table 2.10:** pH preferences of difference crops

### vii. Magnesium

Mg<sup>++</sup> ions are an integral part of the **chlorophyll molecule** and plants cannot manufacture chlorophyll without an adequate supply of magnesium. A shortage of the element therefore causes a lack of chlorophyll, a condition known as **chlorosis**. It shows up as a yellowing of the leaves (Gr.: *chloros* = green; *phyllon* = a leaf.). Since chlorophyll is essential for photosynthesis, the plant cannot manufacture food, resulting in poor growth.

An adequate supply of magnesium on pastures also helps prevent grass tetany.

### viii. Sulphur

Sulphur is taken up by the plant in relatively large amounts as it is needed for protein synthesis (two important amino acids contain sulphur). However, it is seldom deliberately applied as a fertiliser. High percentages of sulphur are found in sulphate of ammonia (24%), calcium sulphate (18%) and in Superphosphate (12%), and the use of one of these common fertilisers (aided perhaps by a little acid rain, which we would rather do without!) seems to take care of our crops' needs.

Nevertheless, there are some regions in Ireland where sulphur tends to be deficient. Sulphur deficiency in grassland produces symptoms similar to nitrogen deficiency.

### ix. Some Minor Elements

**Boron** - needed by beet and turnips. Deficiency causes **heart rot** (*'raan'*).

**Copper** - helps to control water balance in the plant.

**Iron** - needed for chlorophyll synthesis. Deficiency causes chlorosis.

**Manganese** - accelerates germination and maturation. Improves the uptake of P and Mg by the plant.

**Molybdenum** - needed by legumes. N fixing bacteria in root nodules require it for N fixation. Excess Mo inhibits the uptake of Cu by grazing animals, especially on soils of pH >6.

### x. Farmyard Manure (FYM)

*Farmyard manure is a mixture of straw, urine and faeces from different species of farm animals.*

FYM is a good source of organic matter, but it also contains substantial amounts of N, P, K and many minor elements. While phosphates are mainly contributed by the faeces, nitrogen and potash are more plentiful in urine. The composition of FYM can vary considerably.

It depends on

- the amount of straw (or other litter) used;
- the diet fed to the animals ;
- the type of animal from which it was collected;
- the age of the animals;
- in what manner and how long it was stored;
- whether most of the urine was soaked up or drained off.

### Faeces.

Some of the feedstuffs eaten by animals are not digested; they just pass through the alimentary canal and are eliminated as faeces. Any mineral nutrients contained in these feeds thus go back to the soil and eventually become available to plants. Undigested organic matter (roughage, fibre) makes up the bulk of the faeces.

### Urine.

The diet consumed by farm animals consists mainly of carbohydrates and proteins. While carbohydrates are intended primarily as a source of energy, protein is needed to make new (animal-) protein: flesh (growth), young animals (reproduction), milk, wool and eggs. For every animal there is an ideal ratio of proteins to carbohydrates which should be fed. In practice, this is difficult to achieve to any degree of perfection, and therefore animals always get either too little or too much protein. If they get too little, they will not perform to their full potential. If too much, the excess protein will be changed in the liver to carbohydrate and ammonia, and the latter will be excreted as urea. Urea mixed with other excretory products and diluted with water makes **urine**.

### Who excretes more nitrogen?

In cattle, the growth potential (daily weight gain) is quite similar for a few-months-old calf as for a yearling or a two-year-old, and therefore the protein requirements are about the same too. On the other hand, the daily carbohydrate requirements depend very much on the weight of the animal.



*If a similar diet (e.g. good silage) was fed to weanlings and to mature beef animals, which of them would excrete more nitrogen?*

*What about dry cows vs. lactating cows?*

*Who removes more nutrients from a pasture, old cattle or young cattle?*

*Are these questions relevant in regard to other minerals too?*

### What changes take place in FYM?

While fresh manure can vary widely in its composition, well-rotted manure turns out to be rather uniform in make-up. Changes take place as soon as manure is 'made':

- Urine not absorbed by straw or litter will drain away, taking with it valuable dissolved minerals.
- Urea is converted to ammonia, which evaporates easily ('volatilisation'), especially when the manure is exposed to drying conditions (and you can smell it!).
- In the longer term, bacteria break down carbohydrates to carbon dioxide and water, releasing the energy from it in the form of heat.
- Bacteria grow and multiply, using dissolved ammonia as a source of nitrogen to combine with carbohydrates and make bacterial protein.
- When the process is completed, a high percentage of the original mass of the manure will have been lost: as effluent, evaporated water, carbon dioxide and ammonia gas.
- What remains is a rather uniform black or brown mass of soluble and insoluble humus compounds. The percentage of nitrogen and other minerals is higher now than in fresh manure (as, on the whole, more other substances were lost [i.e. carbon, hydrogen and oxygen]). Most of the nitrogen is at this stage tied up in proteins and other organic compounds. An average sample of well-rotted FYM contains 0.5% N, 0.1% P and 0.5% K.

Like nitrogen, phosphorus and potassium have also become part of complex organic compounds and are in this form not readily available as plant nutrients.

If, however, manure is brought out fresh and immediately ploughed under, few nutrients are lost through drainage or volatilisation, and the minerals in their 'raw', inorganic state are more readily changed into a form that can be absorbed by the growing crop.

#### **xi. Examples of Organic Fertilisers**

- Ploughed-in plant debris, stubble, beet tops, etc.
- Ploughed-in pasture and ley.
- Green manure crops, particularly legumes (often grown as *catch crops*).
- Farm yard manure, consisting of straw, faeces and soaked-up urine.
- Slurry, consisting of faeces, urine and sometimes farmyard and silage runoff.
- Seaweed.
- Industrial organic wastes, e.g. dried blood, shoddy (wool waste), meat-, fish- and bone-meal.

#### **xii. Improving Soil Fertility**

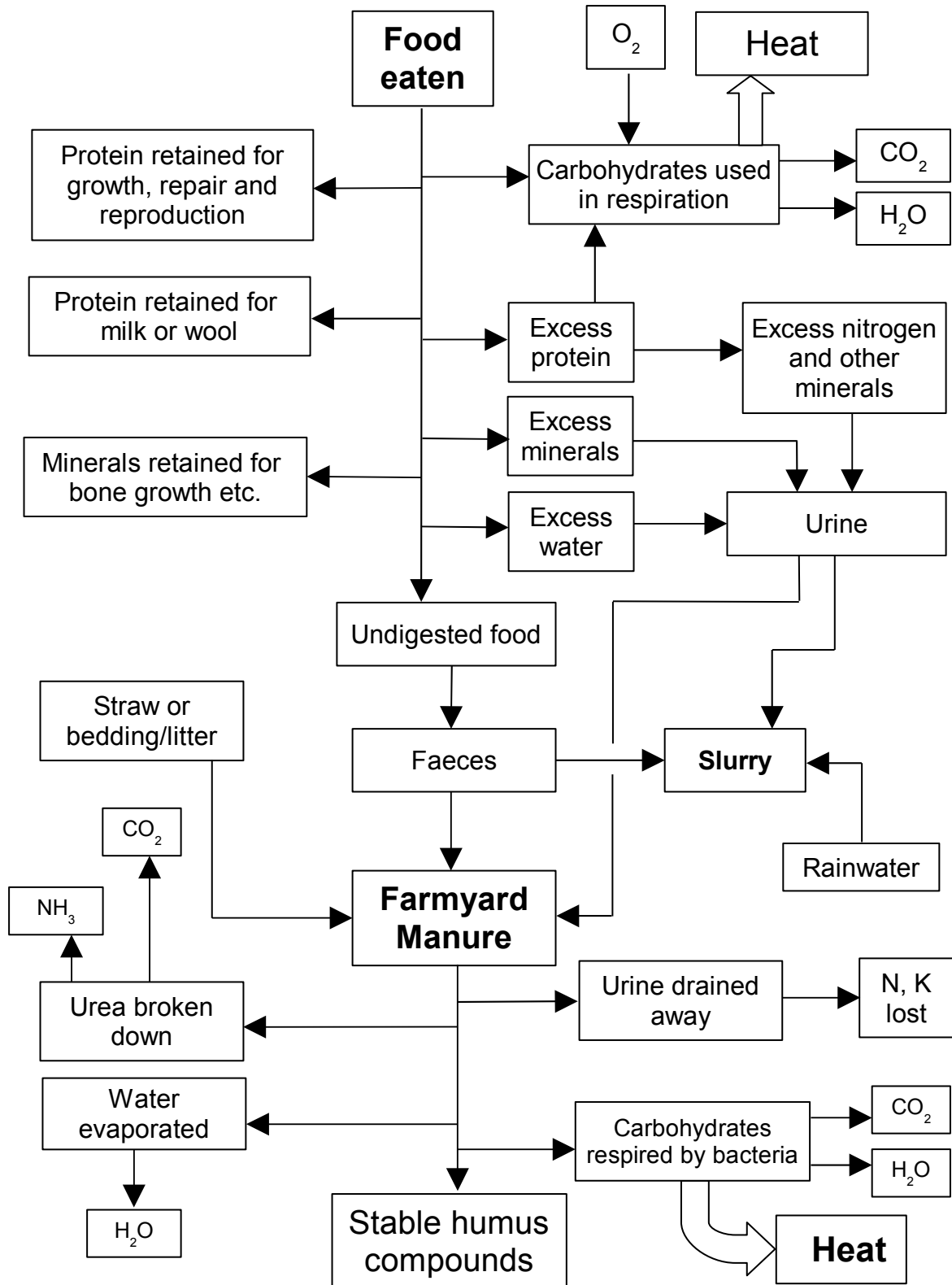
Improvement of infertile or neglected land should first aim at providing favourable conditions for soil micro-organisms and earthworms. Operations should be carried out in the following order:

1. Aerate the soil through drainage, if necessary
2. Apply lime if the pH is low
3. Plough in green manure (and / or FYM) to provide food for bacteria and worms
4. Apply commercial fertilisers according to crop requirement (include trace minerals if necessary)

When dealing with soils of high organic matter content, e.g. when reclaiming bog land, the same sequence applies, except that step 3 can be left out.

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#### **Notes:**



**Figure 2.17:** The "Making and Breaking" of Farmyard Manure

The flowchart outlines the utilisation of major food constituents in animals and goes on to summarise the changes taking place in farmyard manure.


The composition of FYM is influenced by diet, bedding, time of year, the manner in which it has been stored. Slurry composition can vary greatly according to the amount of rainwater, washings etc. that have entered the pit.

## V. Practical Work

### Experiment 2.1:

To determine the amount of water in a sample of soil.

1. Weigh an evaporating basin.
2. Note weight.
3. Fill basin with fresh garden soil, collected from a depth of about 5-10 cm.
4. Weigh again.
5. Calculate net weight of fresh soil.
6. Place in oven or incubator pre-set at a temperature of 105°C. Leave for two hours
7. Weigh twice, at twenty-minute intervals.
8. If no weight loss occurs between weighings, the soil is dry.
  - Alternatively, leave in oven until next day.
  - If there is no oven available, you can dry the soil by boiling a beaker of water on a Bunsen burner and placing the evaporating basin over the beaker.
9. Enter all results in the table below and calculate percentage of water.

 Find the water content of different soil samples, e.g. one at field capacity (feels moist but not wet), one at wilting point (air dried); or compare mineral soil with organic soil, which may give you an idea of the different water holding capacities.

1.	Weight of basin	g
2.	Weight of basin with fresh soil	g
3.	Net weight of fresh soil (2 – 1)	g
4.	Weight of basin with dried soil	g
5.	Net weight of dried soil (4 – 1)	g
6.	Amount of water lost (3 – 5)	g
7.	Percentage of water loss (6 * 100) / 3	%

### Experiment 2.2:

To determine the amount of organic matter in a sample of soil.

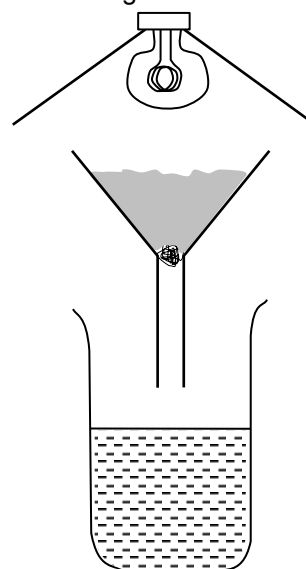
1. Place some dried soil in a pre-weighed crucible.
2. Weigh again and place in a pipe-clay triangle over a Bunsen burner.
3. Fill in the blank table (adjust your terms to suit this experiment).
4. Burn soil for 30 minutes.
5. Weigh the crucible at intervals until two successive weighings yield the same result.
6. Carry out calculations as before.

1.	Weight of basin	g
2.	Weight of basin with dried soil	g
3.	Net weight of dried soil (2 – 1)	g
4.	Weight of basin with burnt soil	g
5.	Net weight of burnt soil (4 – 1)	g
6.	Amount of organic matter (3 – 5)	g
7.	Percentage of organic matter (6 * 100) / 3	%

### Experiment 2.3:

To extract invertebrate animals from soil or leaf litter.

- The apparatus used for this experiment is known as the Tullgren funnel or dry funnel.



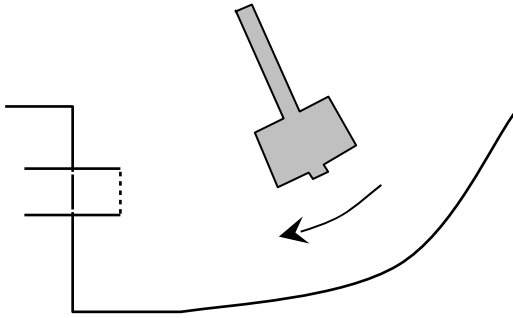
1. Loosely plug a large funnel with glass wool then fill it with soil.
2. Hold it in position over a beaker containing alcohol or chloroform.
3. Shine a strong light on the soil for 24 hours or so.
  - Invertebrates will move downward, away from the heat, and fall into the beaker.

### Experiment 2.4:

To determine the percentage of air in a sample of soil.

1. Prepare two tins (e.g. food tins) of identical size, both without a lid.
  - Tins with corrugated sides are not suitable. They buckle easily when hit with a mallet.
2. Puncture the bottom of tin A several times.

3. Measure the volume of the tins with a graduated cylinder.
4. Prepare a larger container (e.g. 5 litre plastic bucket) by sticking an adhesive label on the inside then drawing a horizontal mark, about one third from the top.
5. Fill with water to the mark, remove a tin-full (tin B) of water and mark the new level.
6. Dig a hole the depth of a spade. Gently drive tin A into a vertical face of the hole with a wooden mallet.



7. Keep about 5 cm down from the surface. When the bottom of the tin is flush with the soil face, dig out the tin and cut the soil flush with the top rim of the tin, using a blunt knife.
8. Empty contents into the prepared container.
9. Make good the water level to the original mark, using a graduated cylinder. The amount of water needed is equivalent to the volume of air in the soil sample.
10. Calculate the percentage of air.

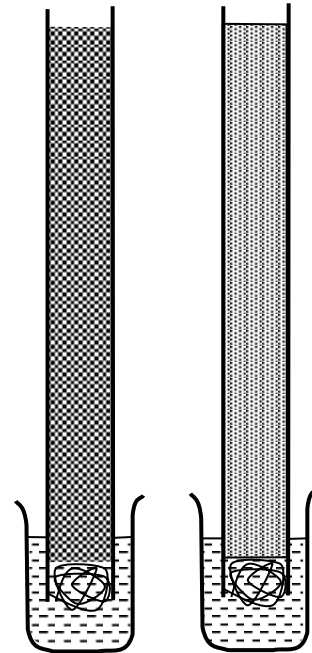
### Experiment 2.5:

*To investigate the permeability of different soils to water.*

1. Fill two Buchner funnels, one with heavy clay soil (dried and pulverised) and the other with light, sandy soil, both to 1 cm from the top.
2. Hold in position over two beakers with retort stands. Pour water in both, trying to keep the water levels even.
3. After one minute, remove beakers and measure the amounts of water collected in each.

### Experiment 2.6:

*To investigate capillarity in soil.*



1. Hold up two open-ended tubes with retort stands in a vertical position
2. Plug the lower ends of both tubes with glass wool
3. Run some dried sand through a 2 mm sieve to eliminate all pebbles etc.
4. Pass through a 0.125 mm sieve to separate coarse and medium sand from fine sand, silt and clay.
5. Fill tube A with the coarser and tube B with the finer aggregate.
6. Lower both tubes into beakers of water and observe. In which tube does the water rise faster initially?
7. In which tube does it rise higher?
  - More meaningful results can be obtained when sandy soil is used vs clay soil, but the principle is more easily demonstrated by the above method.

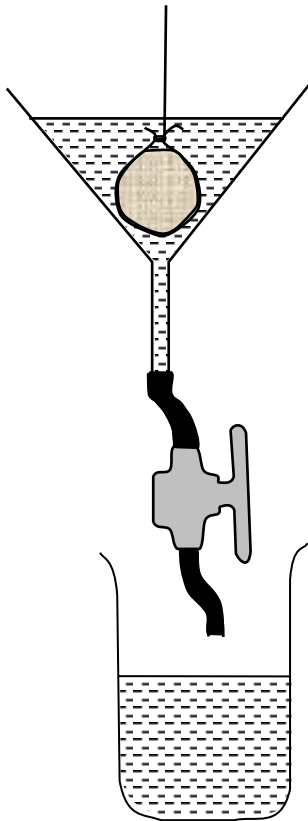
### Experiment 2.7:

*To measure the pH of a sample of soil.*

- Soil pH can be measured using indicator paper, indicator solution or electronic pH meters. The instructions for the user are supplied with the various kits or instruments.

### Experiment 2.8:

To extract nematodes from soil.



- The apparatus used for this experiment is known as Baermann funnel or wet funnel.
- 1. Take a short length of rubber tubing and attach it to a funnel.
- 2. Close the end of the tube with a clip.
- 3. Fill the funnel with water.
- 4. Fill a small bag (muslin or any other loosely woven material) with soil.
- 5. Lower the bag into the water.
- 6. Draw a drop of water after a day or two and examine it under a microscope.
- Some larger worms may be visible to the naked eye.

### Experiment 2.9:

To separate the sand, silt and clay fractions by mechanical analysis.

- A set of soil sieves is needed for this experiment.

Which mesh sizes will you use?

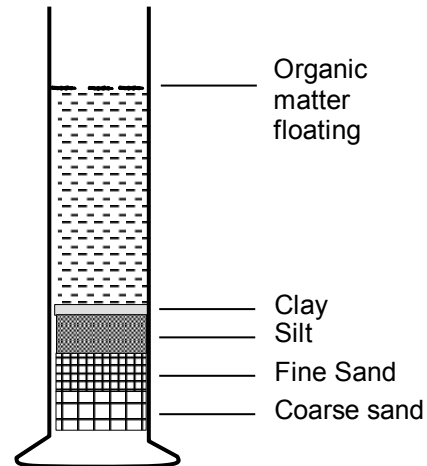
Is the finest mesh fine enough to separate silt from clay?

- If not, refer to Experiment 2.10.

Use plenty of water to wash soil through sieves, pour off when settled then dry the soil

### Experiment 2.10:

To separate the sand, silt and clay fractions by sedimentation.



1. Pass a small amount of soil through a 2 mm sieve to remove large objects.
2. Fill a graduated cylinder to one third with this soil and add a similar amount of water.
3. Shake vigorously and allow settling.
4. Identify sand (individual particles visible – distinguish between coarse and fine sand), silt (textured appearance, particles not visible individually) and clay (un-textured appearance) .

Does all the clay settle?

Which of the three components has a different colour? Why?

Where is the humus?


- Most textbooks will state that the humus floats on top. However, it was shown in a Young Scientist project a few years ago that the organic matter floating on the water surface was only in the order of 5% of the total humus (depending on soil type etc.). The bulk of the humus is tied up in clay-humus complexes or coating sand/silt particles and will not float to the top, but will settle with those particles.

### Experiment 2.11:

To demonstrate flocculation.

1. Shake up a handful of heavy clay soil with one half litre of water to make a colloidal solution.

- Leave for ten minutes to allow larger soil particles to settle.
- Fill three graduated cylinders, A, B and C. Add  $\text{Ca}^{++}$  ions (calcium chloride solution or lime water) to A, add  $\text{Na}^+$  ions (sodium bicarbonate or sodium hydroxide solution) to B, and add water to C to bring it up to the same level.
- Mix well and allow to settle.

 Which cylinder clears first, and why?

Look at the sediment under the clear liquid and compare it with the sediments in other cylinders.

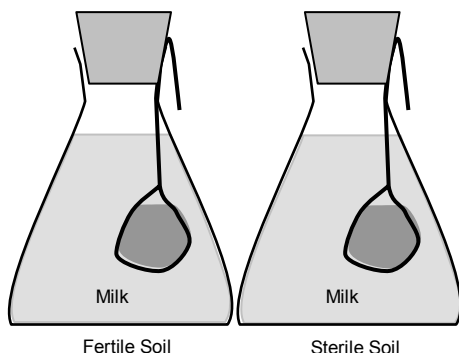
### Experiment 2.12:

To count the earthworms in a field.

- Dissolve two heaped teaspoonfuls of potassium permanganate in 20 litres of water.
  - Place a quadrant frame (1 m<sup>2</sup>) on the ground and clear away all vegetation inside frame.
  - Pour on the solution with a watering can.
  - Collect all earthworms as they come to the surface and count them.
  - When finished, return them to an area covered with high grass.
  - Calculate the earthworm population per hectare.
- The quadrant can be placed randomly by throwing it back over the shoulder, or it can be placed deliberately into selected areas (e.g. in an area that has been compacted by regular traffic, to compare it with an area not so affected).

### Experiment 2.13:

To demonstrate the presence of micro-organisms in soil (Effect on Milk).



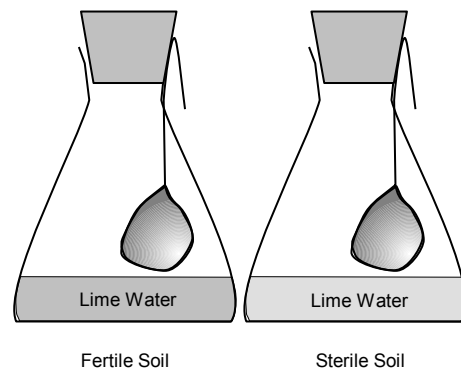
- Weigh two quantities of soil, 5g each.
- Place lot A in an oven at 250°C for two hours to kill all organisms in it.
- Keep lot B in a covered beaker.

- Suspend each lot in a muslin bag in a flask containing boiled or pasteurised milk.
- Stopper the flasks and incubate at 30°C for a day.
- Test pH of both milk samples

 Can you observe any other changes?

### Experiment 2.14:

To demonstrate the presence of micro-organisms in soil (Production of Carbon Dioxide).

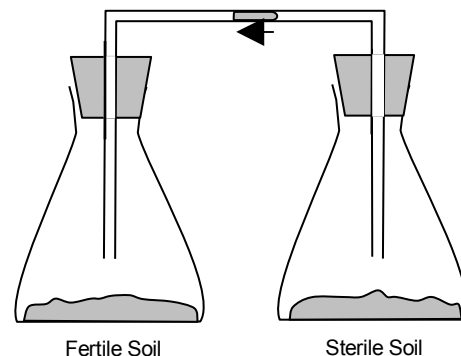


- Put some lime-water in a conical flask.
- Suspend some soil in a muslin bag over the lime water, stopper the flask.
- Set up a control with sterile soil (see Experiment 2.13). Leave in an incubator until the next day.
- Observe the changes in the lime-water.

 Explain the changes observed.

### Experiment 2.15:

To demonstrate the presence of micro-organisms in soil (Uptake of Air).



- Weigh out two equal amount of soil and sterilise sample A (see Experiment 2.13).
- Fill into two conical flasks, both stoppered and connected by a glass tube.

## Unit Two: SOIL

- Put a small drop of a coloured liquid (e.g. methylene blue) into the tube, halfway between the two flasks (mark its position).
- When kept in a warm room or incubator, the coloured liquid should be seen to have moved after a day or so.

### Practical Microbiology

This experiment shows the growth of bacterial colonies and makes it possible to isolate different types.

A knowledge and practice of sterile techniques is required to carry out the experiment successfully. It is also of vital importance to observe safety precautions. Bacterial colonies may contain a hundred million active bacteria, and even if they are not normally considered to be of the pathogenic (disease causing) type, when they get a chance to invade the human body in such numbers they can create a serious health hazard.

The lid of the Petri dish (*see below*) should be taped to its base with adhesive tape and not be opened once bacteria are seen to grow. Nowadays, plastic Petri dishes are used in preference to glass Petri dishes; as they can be incinerated after use.

Agar is a jelly-like substance, derived from seaweed. When set, it behaves like a solid, yet there is liquid water trapped between the large protein molecules of the jelly, so that micro-organisms which would normally require a liquid environment, can live and grow on the surface of the agar. Agar comes in the form of granules; it is mixed with hot water and will set when cooled. Agar contains no nourishment for micro-organisms. If intended for the growth of bacteria, it has to be mixed with meat extract (or any suitable substance available from laboratory suppliers). It is then called a nutrient agar. For the growth of fungi, agar is often mixed with malt extract (malt agar).

### Experiment 2.16:

*To demonstrate the presence of micro-organisms in soil (Agar Plate).*

- Prepare nutrient agar and sterilise it in an autoclave.
- Pour into sterile Petri dish and cover immediately. Allow to set.
- Place 1cm<sup>3</sup> of soil in a test tube and add 10 cm<sup>3</sup> of water.
- Shake vigorously.
- Pour (roughly) 1 cm<sup>3</sup> the suspension into a new test tube and again add 10 cm<sup>3</sup> of water.
- Repeat two more times to obtain a total dilution of about one in ten thousand. Dip a sterile wire loop into the suspension, half open the lid of the Petri dish and run the loop over the surface of the agar plate in a recognisable pattern, e.g. a squiggle.
- Seal the Petri dish with adhesive tape and place in an incubator set between 25 and 35° C.

- Observe over a series of days. Any growth appearing outside your pattern is due to contamination.



*Design a control for this experiment.*

### Experiment 2.17:

*To demonstrate that soil contains mineral salts.*

- Add distilled water to a sample of soil.
  - Shake vigorously and filter.
  - Divide up the filtrate into a number of evaporating basins and dry in oven at 105°C.
- When the water is evaporated, crystals of minerals will remain in the basin.

### Experiment 2.18:

*To test for the presence of phosphate.*

- Dissolve a small quantity of the crystals prepared in Experiment 2.17 in dilute nitric acid.
  - Add some ammonium molybdate solution.
- Yellow colour indicates a positive result.

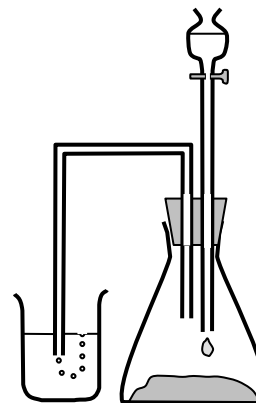
### Experiment 2.19:

*To test for the presence of nitrate.*

- Dissolve some crystals from Experiment 2.17 in water.
  - Add a few drops of 0.5% solution of diphenylamine in concentrated sulphuric acid.
- Blue colour indicates a positive presence.

### Experiment 2.20:

*To test for the presence of carbonate*



- Fill some soil into a large conical flask (about one third full).
- Fit a thistle funnel through a rubber bung.
- Fit a U-shaped glass tube to the rubber bung and stopper the flask.

4. Lead the free end of the glass tube into a beaker containing lime-water.
  5. Fill the funnel with dilute acid.
  6. Allow acid to drip on the soil in a slow succession of drops.
- If carbonate is present in the soil, the nitric acid will displace carbon dioxide, which will

escape through the tube and turn the lime-water milky.

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**Notes:**