10

Soils

'To many people who do not live on the land, soil appears to be an inert, uniform, dark-brown coloured, uninteresting material in which plants happen to grow. In fact little could be further from the truth.'

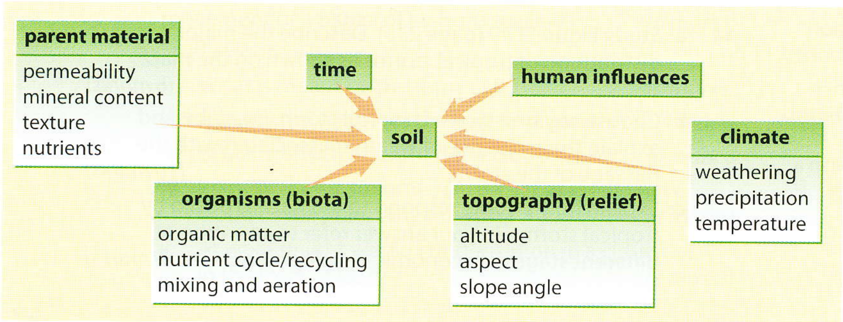
Brian Knapp, *Soil Processes*, 1979

Soil forms the thin surface layer of the Earth's crust. It can be defined as the unconsolidated mineral and organic material on the Earth's surface, often characterised by horizons or layers (Figure 10.5), that serves as a natural medium for the growth of plants and therefore the support of animal life on land. It has been subjected to, and shows the effects of, genetic and environmental factors of: climate (including water and temperature), macro- and micro-organisms, relief and the underlying parent rock (Figure 10.1). It develops over a period of time through the interaction of several physical, chemical, biological and morphological properties and characteristics.

The study of soil, its origins and characteristics (**pedology**) is a science in itself.

Figure 10.1

Factors affecting the formation of soil



Soil formation

The first stage in the formation of soil is the accumulation of a layer of loose, broken, unconsolidated parent material known as **regolith**. Regolith may be derived from either the *in situ* weathering of bedrock (i.e. the parent or underlying rock) or from material that has been transported from elsewhere and deposited, e.g. as alluvium, glacial drift, loess or volcanic ash. The second stage, the formation of **true soil** or **topsoil**, results from the addition of water, gases (air), living organisms (biota) and decayed organic matter (humus).

Pedologists have identified five main factors involved in soil formation (Figure 10.1). As all of these are closely interconnected and interdependent, their relationship may be summarised as follows:

soil = *f* (parent material + climate + topography + organisms + time)

where: *f* = function of.

Parent material

When a soil develops from an underlying rock, its supply of minerals is largely dependent on that rock. The minerals are susceptible to different rates and processes of weathering – see the example of granite, Figure 10.2. Parent material contributes to control of the depth, texture, drainage (permeability) and quality (nutrient content) of a soil and also influences its colour. In most of Britain, parent material is the major factor in determining the soil type, e.g. limestone, granite or, most commonly, drift.

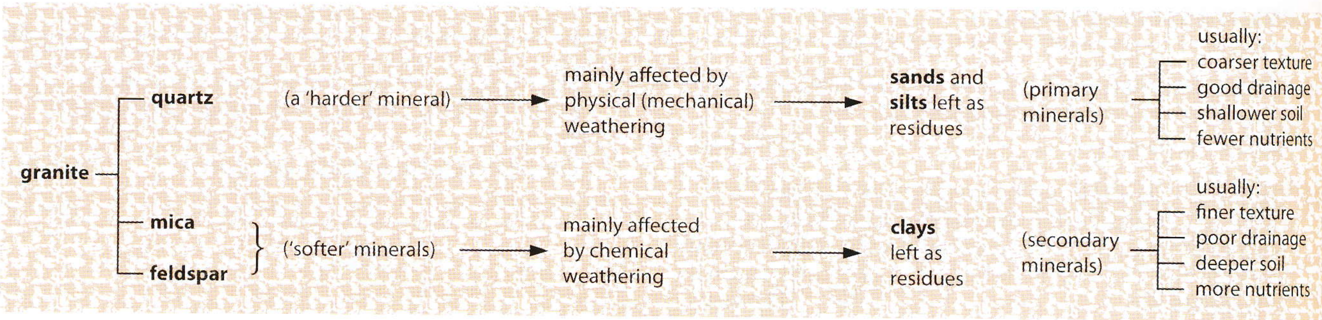


Figure 10.2

The influence of a parent rock – granite – on soil formation

Climate

Climate determines the type of soil at a global scale. The distribution of world soil types corresponds closely to patterns of climate and vegetation. Climate affects the rate of weathering of the parent rock, with the most rapid breakdown being in hot, humid environments. Climate also affects the amount of humus (organic material) in the soil. The amount is a balance between the input and output, the input and output being a function of the effects of temperature and moisture on biological activity. One might expect tropical rainforest soils to have more humus than tundra soils because of the greater mass of vegetation. However, it is possible for some tundra soils to have more humus accumulation due to a lower output, and some tropical rainforest soils to have less because of greater humus breakdown.

Rainfall totals and intensity are also important. Where rainfall is heavy, the downward movement of water through the soil transports mineral salts (i.e. soluble minerals) with it, a process known as **leaching**. Where rainfall is light or where evapotranspiration exceeds precipitation, water and mineral salts may be drawn upwards towards the surface by the process of **capillary action**.

Temperatures determine the length of the growing season and affect the supply of humus. The speed of vegetation decay is fastest in hot, wet climates as temperatures also influence (i) the activity and number of soil organisms and (ii) the rate of evaporation, i.e. whether leaching or capillary action is dominant.

Topography (relief)

As the height of the land increases, so too do amounts of precipitation, cloud cover and wind, while temperatures and the length of the growing season both decrease. Aspect is an important local factor in mid-latitudes (page 212), with south-facing slopes in the northern hemisphere being warmer and drier than those facing north. The angle of slope affects drainage and soil depth. Greater moisture flows and the increased effect of gravity on steeper slopes can accelerate mass movement and the risk of soil erosion. Soils on steep slopes are likely to be thin, poorly developed and relatively dry. The more gentle the slope, the slower the rate of movement of water through the soil and the greater the likelihood of waterlogging and the formation of peat on plateau-like surfaces at the top of the slope (Figure 10.3). There is little risk of soil erosion but the increased rate of weathering, due to the extra water, and the receipt of material moved downslope, tend to produce deep soils at the foot of the slope. A **catena** is where soils are related to the topography of a hillside and is a sequence of soil types down a slope. The catena (Figure 10.3) is described in more detail on page 276.

Organisms (biota)

Plants, micro-organisms such as bacteria and fungi, and animals all interact in the **nutrient cycle** (page 300). Plants take up mineral nutrients from the soil and return them to it after they die. This recycling of plant nutrients (Figure 12.7) is achieved by the activity of micro-organisms, which assist in nitrogen fixation (page 268) and the decomposition and decay of dead vegetation. At the same time, macro-organisms, which include worms and termites, mix and aerate the soil. Human activity is increasingly affecting soil development through the addition of fertiliser, the breaking up of horizons by ploughing, draining or irrigating land, and by unwittingly accelerating or deliberately controlling soil erosion.

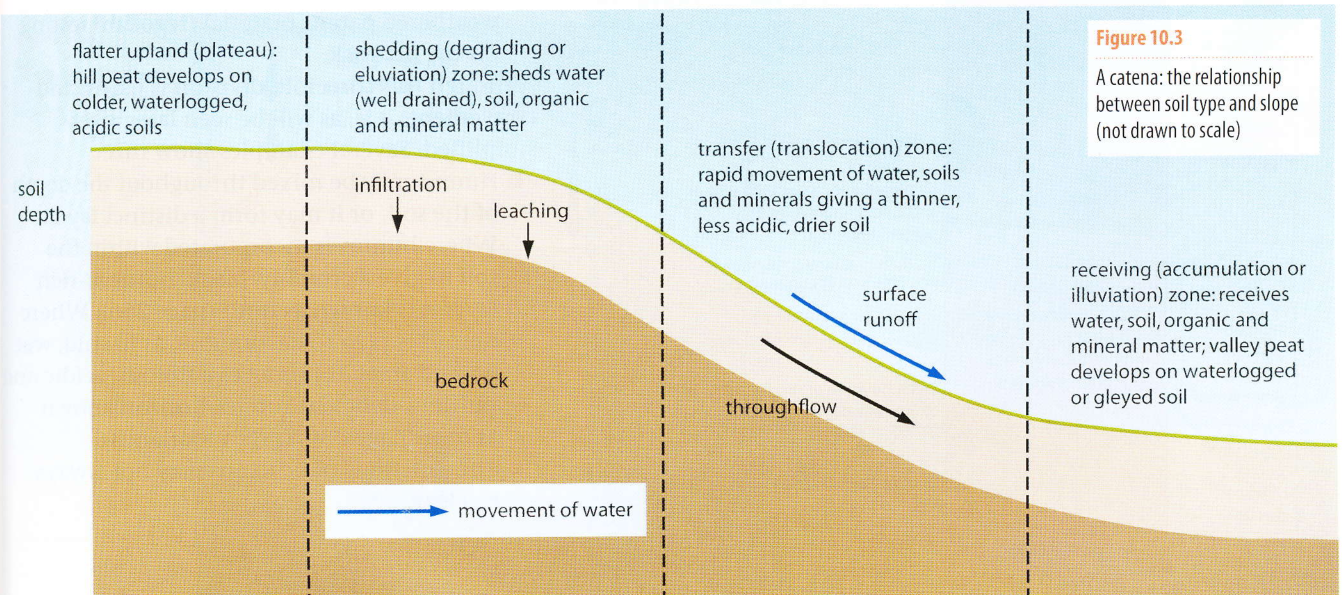


Figure 10.3

A catena: the relationship between soil type and slope (not drawn to scale)

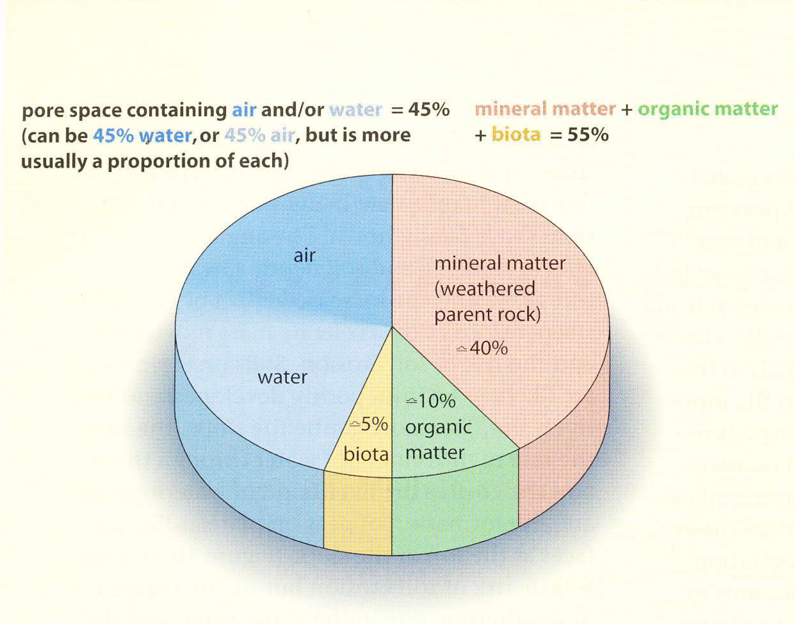


Figure 10.4

Relative proportions, by volume, of components in a 'normal' soil (*after* Courtney and Trudgill)

Time

Soils usually take a long time to form, perhaps up to 400 years for 10 mm and, under extreme conditions, 1000 years for 1 mm. It can take 3000 to 12 000 years to produce a sufficient depth of mature soil for farming, although agriculture can be successful on newly deposited alluvium and volcanic ash. Newly forming soils tend to retain many characteristics of the parent material from which they are derived. With time, they acquire new characteristics resulting from the addition of organic matter, the activity of organisms, and from leaching. **Horizons**, or layers (Figure 10.5), reflect the balance between soil processes and the time that has been available for their development. In northern Britain, upland soils must be less than 10 000 years old, as that was the time of the last glaciation, when any existing soil cover was removed by ice. The time taken for a mature soil to develop depends primarily on parent material and climate. Soils develop more rapidly where parent material derived from *in situ* weathering consists of sands rather than clays, and in hot, wet climates rather than in colder and/or drier environments.

A mature, fully-developed soil consists of four components: mineral matter, organic matter including biota (page 268), water and air. The relative proportions of these components in a 'normal' soil, by volume, is given in Figure 10.4.

The soil profile

The **soil profile** is a vertical section through the soil showing its different horizons (Figure 10.5). It is a product of the balance between soil system inputs and outputs (Figure 10.6) and the redistribution of, and chemical changes in, the various soil constituents. Different soil profiles are described in Chapter 12, but an idealised profile is given here to aid familiarisation with several new terms.

The three major soil horizons, which may be subdivided, are referred to by specific letters to indicate their genetic origin.

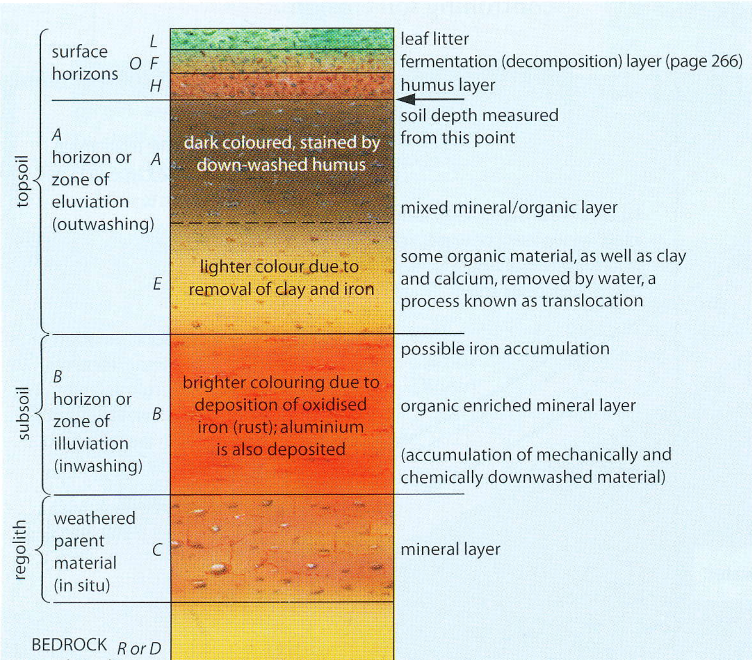
- The upper layer, or ***A* horizon**, is where biological activity and humus content are at their maximum. It is also the zone that is most affected by the leaching of soluble materials and by the downward movement, or **eluviation**, of clay particles. Eluviation is the washing out of material, i.e. the removal of organic and mineral matter from the *A* horizon (Figure 10.5).
- Beneath this, the ***B* horizon** is the zone of accumulation, or **illuviation**, where clays and other materials removed from the *A* horizon are redeposited. Illuviation is the process of inwashing, i.e. the redeposition of organic and mineral matter in the *B* horizon. The *A* and *B* horizons together make up the true soil.
- The ***C* horizon** consists mainly of recently weathered parent material (regolith) resting on the bedrock.

Although this threefold division is useful and convenient, it is, as will be seen later, oversimplified. Several examples show this:

- Humus may be mixed throughout the depth of the soil, or it may form a distinct layer. Where humus is incorporated within the soil to give a crumbly, black, nutrient-rich layer it is known as **mull** (page 266). Where humus is slow to decompose, as in cold, wet upland areas, it produces a fibrous, acidic and nutrient-deficient surface horizon known as **mor** (page 266) (peat moorlands).
- The junctions of horizons may not always be clear.

Figure 10.5

An idealised soil profile in Britain



- All horizons need not always be present.
- The depth of soil and of each horizon vary at different sites. Local conditions produce soils with characteristic horizons differing from the basic *A*, *B*, *C* pattern: for example, a waterlogged soil, having a shortage of oxygen, develops a gleyed (*G*) horizon (page 275).

The soil system

Figure 10.6 is a model showing the soil as an open system where materials and energy are gained and lost at its boundaries. The system comprises inputs, stores, outputs and recycling or feedback loops (Framework 3, page 45). Inputs include:

- water from the atmosphere or throughflow from higher up the slope
- gases from the atmosphere and the respiration of soil animals and plants
- mineral nutrients from weathered parent material, which are needed as plant food
- organic matter and nutrients from decaying plants and animals, and
- solar energy and heat.

Outputs include:

- water lost to the atmosphere through evapotranspiration
- nutrients lost through leaching and throughflow, and
- loss of soil particles through soil creep and erosion.

Recycling

Plants, in order to live, take up nutrients from the soil (page 268). Some of the nutrients may be stored until:

- either the vegetation sheds its leaves (during the autumn in Britain), or
- the plants die and, over time, decompose due to the activity of micro-organisms (biota, page 268).

These two processes release the stored nutrients, allowing them to be returned to the soil ready for future use – the so-called **nutrient** (or humus) **cycle**.

Soil properties

The four major components of soil – water, air, mineral and organic matter (Figure 10.4) – are all closely interlinked. The resultant interrelationships produce a series of 'properties', ten of which are listed and described below.

1. mineral (inorganic) matter
2. texture
3. structure
4. organic matter (including humus)
5. moisture
6. air
7. organisms (biota)
8. nutrients
9. acidity (pH value)
10. temperature.

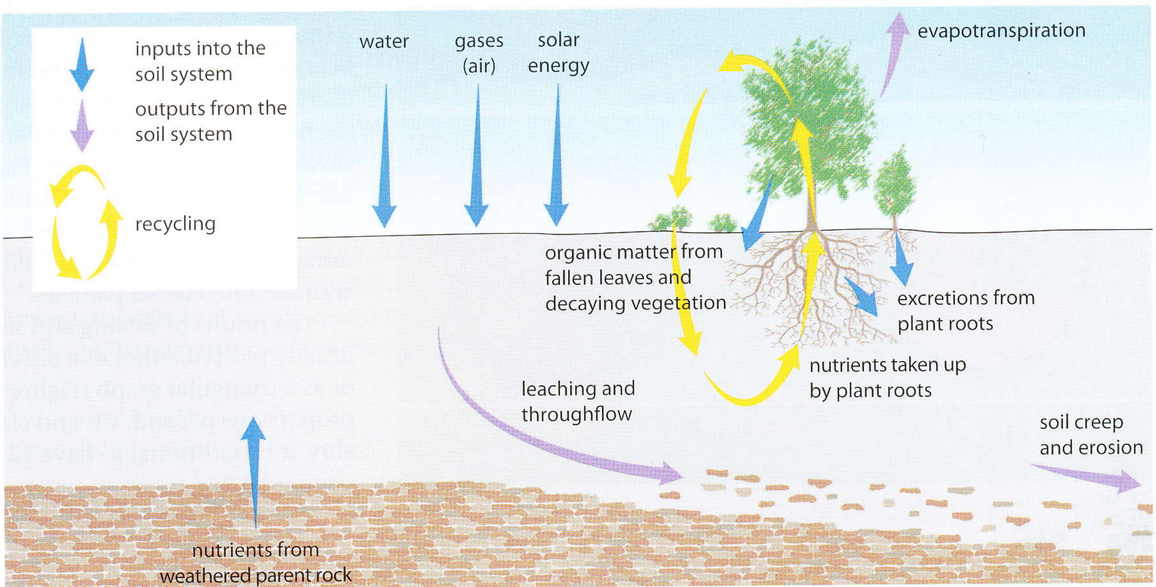
It is necessary to understand the workings of these properties to appreciate how a particular soil can best be managed.

1 Mineral (inorganic) matter

As shown in Figure 10.2, soil minerals are obtained mainly by the weathering of parent rock. Weathering is the major process by which nutrients, essential for plant growth, are released. **Primary minerals** are minerals that were present in the original parent material and which remain unaltered from their original state. They are present throughout the soil-forming process, mainly because they are insoluble, e.g. quartz. **Secondary minerals** are produced by weathering reactions and are therefore produced within the soil. They include oxides and hydroxides of primary minerals (e.g. iron) which result from the exposure to air and water (page 40).

Figure 10.6

The 'open' soil system



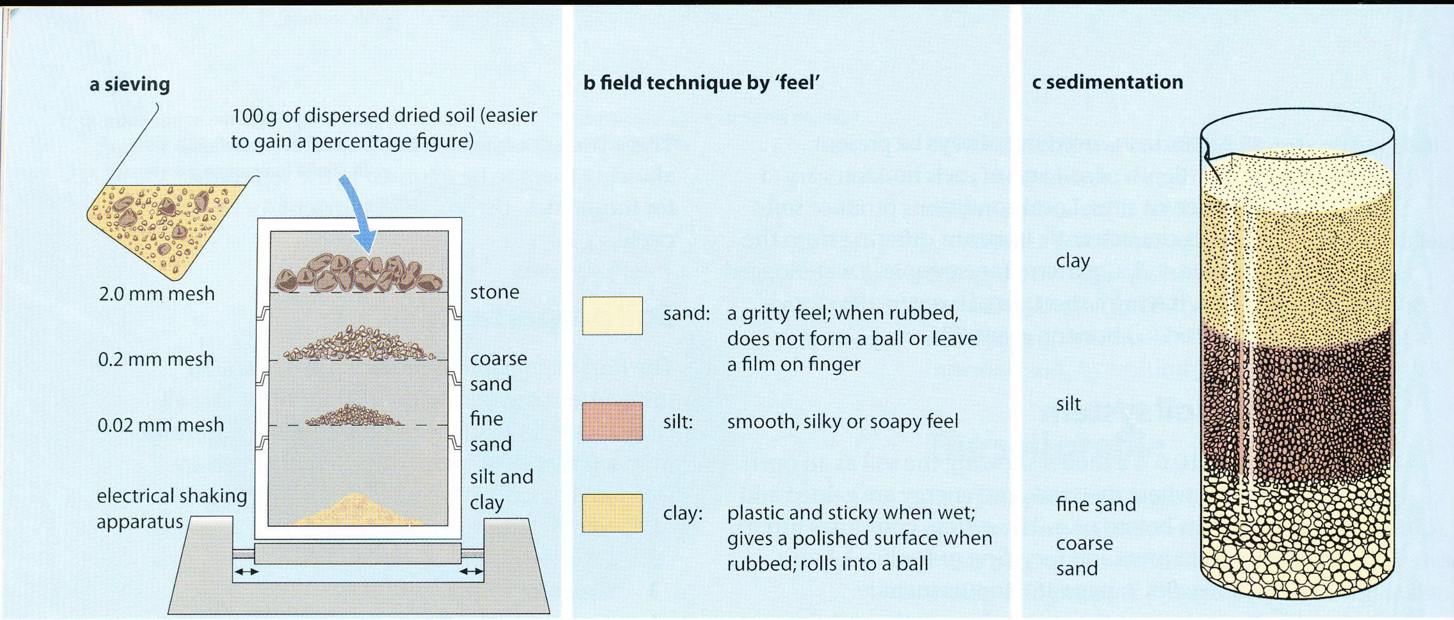


Figure 10.7

Measuring soil texture (*after* Courtney and Trudgill)

2 Soil texture

The term 'texture' refers to the degree of coarseness or fineness of the mineral matter in the soil. It is determined by the proportion of **sand**, **silt** and **clay** particles. Particles larger than sand are grouped together and described as stones. In the field, it is possible to decide whether a soil sample is mainly sand, silt or clay by its 'feel'. As shown in Figure 10.7b, a sandy soil feels gritty and lacks cohesion; a silty soil has a smoother, soaplike feel as well as having some cohesion; and a clay soil is sticky and plastic when wet and, being very cohesive, may be rolled into various shapes.

This method gives a quick guide to the texture, but it lacks the precision needed to determine the proportion of particles in a given soil with any accuracy. This precision may be obtained from either of two laboratory measurements, both of which are dependent upon particle size. The Soil Survey of England and Wales uses the British Standards classification, which gives the following diameter sizes:

Heading	Description from case study
coarse sand	between 2.0 and 0.6 mm
medium sand	between 0.6 and 0.2 mm
fine sand	between 0.2 and 0.06 mm
silt	between 0.06 and 0.002 mm
clay	less than 0.002 mm

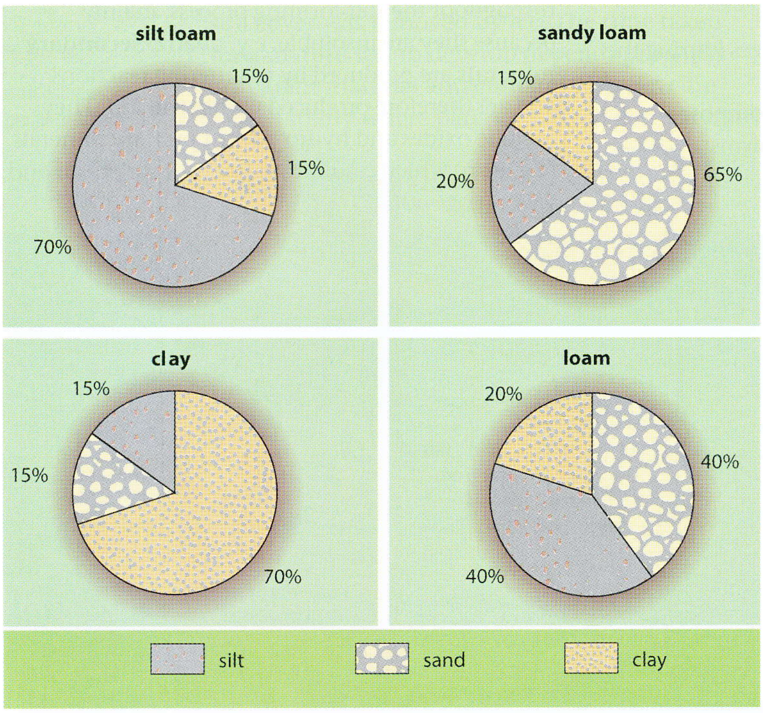
One method of measuring texture involves the use of sieves with different meshes (Figure 10.7a). The sample must be dry and needs to be well-shaken. A mesh of 0.2 mm, for example, allows fine sand, silt and clay particles to pass through it, while trapping the coarse sand. The weight of particles remaining in each sieve is expressed as a percentage of the total sample.

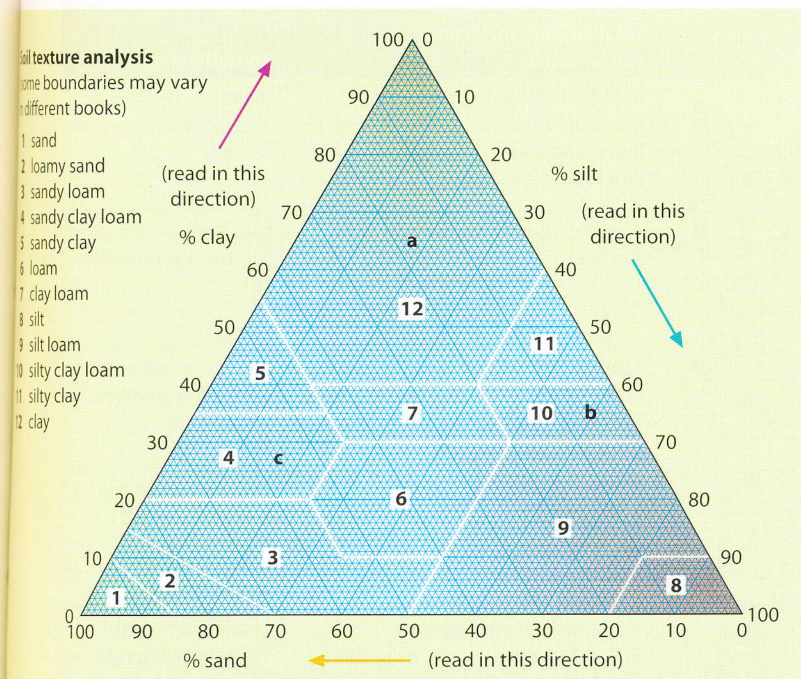
In the second method, sedimentation (Figure 10.7c), a weighed sample is placed in a beaker of water, thoroughly shaken and then allowed to settle. According to **Stoke's Law**, 'the settling rate of a particle is proportional to the diameter of that particle'. Consequently, the larger, coarser, sand grains settle quickly at the bottom of the beaker and the finer, clay particles settle last, closer to the surface (compare Figure 3.22). The Soil Survey and Land Research Centre tends to use both methods because sieving is less accurate in measuring the finer material and sedimentation is less accurate with coarser particles.

The results of sieving and sedimentation are usually plotted either as a pie chart (Figure 10.8) or as a triangular graph (Figure 10.9). As the proportions of sand, silt and clay vary considerably, it is traditional to have 12 texture categories (Figure 10.9).

Figure 10.8

The texture of different soil types





	% clay	% silt	% sand
a	65	18	17
b	35	59	6
c	27	17	56

Figure 10.9

Soil texture analysis: the use of a triangular graph

The importance of texture

As texture controls the size and spacing of soil pores, it directly affects the soil water content, water flow and extent of aeration. Clay soils tend to hold more water and are less well drained and aerated than sandy soils (page 267).

Texture also controls the availability and retention of nutrients within the soil. Nutrients stick to – i.e. are adsorbed onto – clay particles and are less easily leached by infiltration or throughflow than in sandy soils (page 268).

Plant roots can penetrate coarser soils more easily than finer soils, and 'lighter' sandy soils are easier to plough for arable farming than 'heavier' clays.

Texture greatly influences soil structure.

How does texture affect farming?

The following comments are generalised as it must be remembered that soils vary enormously.

Sandy soils, being well drained and aerated, are easy to cultivate and permit crop roots (e.g. carrots) to penetrate. However, they are vulnerable to drought, mainly because, due to their relatively large particle size (Figure 8.2a), they lack the micropores that would retain moisture (page 267) and partly because they usually contain limited amounts of organic matter. They also need considerable amounts of fertiliser because nutrients and organic matter are often leached out and not replaced.

Silty soils also tend to lack mineral and organic nutrients. The smaller pore size means that more moisture is retained than in sands but heavy rain tends to 'seal' or cement the surface, increasing the risk of sheetwash and erosion.

Clay soils tend to contain high levels of nutrient and organic matter but they are difficult to plough and, after heavy rain and due to their small particle size (Figure 8.2b) which helps to retain water (page 267), are prone to waterlogging and may become gleyed (pages 272 and 275). Plant roots find difficulty in penetration. Clays expand when wet, shrink when dry and take the longest time to warm up.

The ideal soil for agriculture is a **loam** (Figures 10.8 and 10.9). This has sufficient clay (20 per cent) to hold moisture and retain nutrients; sufficient sand (40 per cent) to prevent waterlogging, to be well aerated and to be light enough to work; and sufficient silt (40 per cent) to act as an adhesive, holding the sand and clay together. A loam is likely to be least susceptible to erosion.

3 Soil structure

It is the aggregation of individual particles that gives the soil its structure. In undisturbed soils, these aggregates form different shapes known as **peds**. It is the shape and alignment of the peds which, combined with particle size/texture, determine the size and number of the pore spaces through which water, air, roots and soil organisms can pass. The size, shape, location and suggested agricultural value of each of the six ped types are given in Figure 10.10. It should be noted, however, that some soils may be structureless (e.g. sands), some may have more than one ped structure (Figure 10.11), and most are likely to have a distinctive ped in each horizon. It is accepted that soils with a good crumb structure give the highest agricultural yield, are more resistant to erosion and develop best under grasses – which is why fallow should be included in a farming crop rotation. Sandy soils have the weakest structures as they lack the clays, organic content and secretions of organisms needed to cause the individual particles to aggregate. A crumb structure is ideal as it provides the optimum balance between air, water and nutrients.

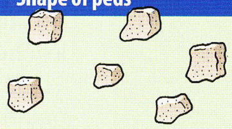
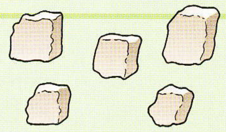
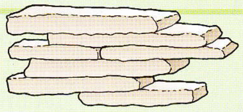
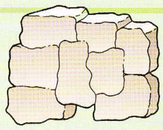
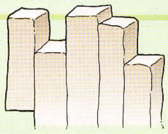
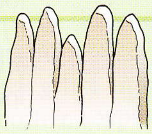
Type of structure (ped)	Size of structure (mm)	Description of peds	Shape of peds	Location (horizon: texture) and formation	Agricultural value
crumb	1–5	small individual particles similar to breadcrumbs; porous		*A* horizon: loam soil; formed by action of soil fauna (e.g. earthworms, mites and termites), high content of fibrous roots (grasses) and excretion of micro-organisms	the most productive; well aerated and drained – good for roots
granular	1–5	small individual particles; usually non-porous		*A* horizon: clay soil; formation as for crumb structure	fairly productive; problems with drainage and aeration
platy	1–10	vertical axis much shorter than horizontal, like overlapping plates; restrict flow of water		*B* horizon: silts and clays; formed by contraction by tree roots, especially when trees (e.g. Scots pine) sway in wind. Also due to ice lens, and compaction due to farm machinery	the least productive; hinders water and air movement; restricts roots
blocky	10–75	irregular shape with horizontal and vertical axes about equal; may be rounded or angular but closely fitting		*B* horizon: clay-loam soils; formation associated with wetting–drying and freeze–thaw processes	productive: usually well drained and aerated
prismatic	20–100	vertical axis much larger than horizontal; angular caps and sides to columns		*B* and *C* horizons: often limestones or clays; formation associated with wetting–drying and freeze–thaw processes	usually quite productive: formed by wetting and drying; adequate water movement and root development
columnar	20–100	vertical axis much larger than horizontal; rounded caps and sides to columns		*B* and *C* horizons; alkaline soils; formation associated with accumulation of sodium	quite productive (if water available)

Figure 10.10

Different soil structures

4 Organic matter

Organic matter, which includes humus, is derived mainly from decaying plants and animals, or from the secretions of living organisms. Fallen leaves and decaying grasses and roots are the main source of organic matter. Soil organisms, such as bacteria and fungi, break down the organic matter and, depending on the nature of the soil-forming processes (Figure 10.17), help develop up to three distinct organic layers at the surface of the soil profile (Figure 10.5):

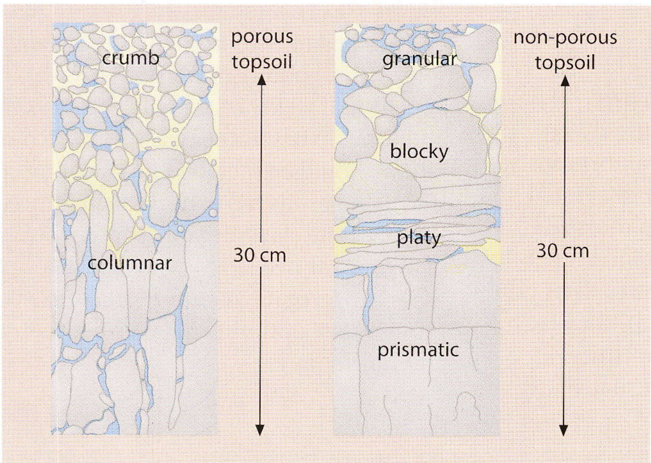


Figure 10.11

Differences in peds (*after* Courtney and Trudgill)

1 *L* or **leaf litter** layer: plant remains are still visible.
2 *F* or **fermentation (decomposition)** layer: decay, which biochemically involves yeast, is most rapid, although some plant remains are still visible.
3 *H* or **humus** layer: primarily organic in nature where, following decomposition, all recognisable plant and animal remains have been broken down into a black, slimy, amorphous organic material.

Wherever soil biological activity is low (due to one or a combination of acidity, low temperatures, wetness or the difficulty in decomposing organic matter), soil organism activity is greatly reduced or absent. As the litter layer cannot be mixed into the soil, then organic horizons build up to give the distinct *L*, *F* and *H* layers of a **mor**.

Where soil organisms are active, they will readily mix the litter into the soil, dispersing it throughout the *A* horizon where it decomposes into an *A* horizon rich in humus – the **mull** layer. Where organic material and mineral matter do mix, mainly due to earthworm activity, the result is the **clay–humus complex** (page 268). The clay–humus complex is essential for a fertile soil as it provides it with a high water- and nutrient-holding capacity and, by binding particles together, helps reduce the risk of erosion.

Humus gives the soil a black or dark-brown colour. The highest amounts are found in the **chernozems**, or black earths (page 327), of the North American Prairies, Russian Steppes and Argentinean Pampas. In tropical rainforests, heavy rainfall and high biological activity cause the rapid decomposition of organic matter which releases nutrients ready for their uptake and storage by plants (Figures 10.6 and 11.29c) or, if the forest is cleared, for leaching out of the system. In drier climates there may be insufficient vegetation to give an adequate supply.

5 Soil moisture

Soil moisture is important because it affects the upward and downward movement of water and nutrients. It helps in the development of horizons; it supplies water for living plants and organisms; it provides a solvent for plant nutrients; it influences soil temperature; and it determines the incidence of erosion. The amount of water in a soil at a given time can be expressed as:

$$W \propto R - (E + T + D)$$

(input) – (outputs)

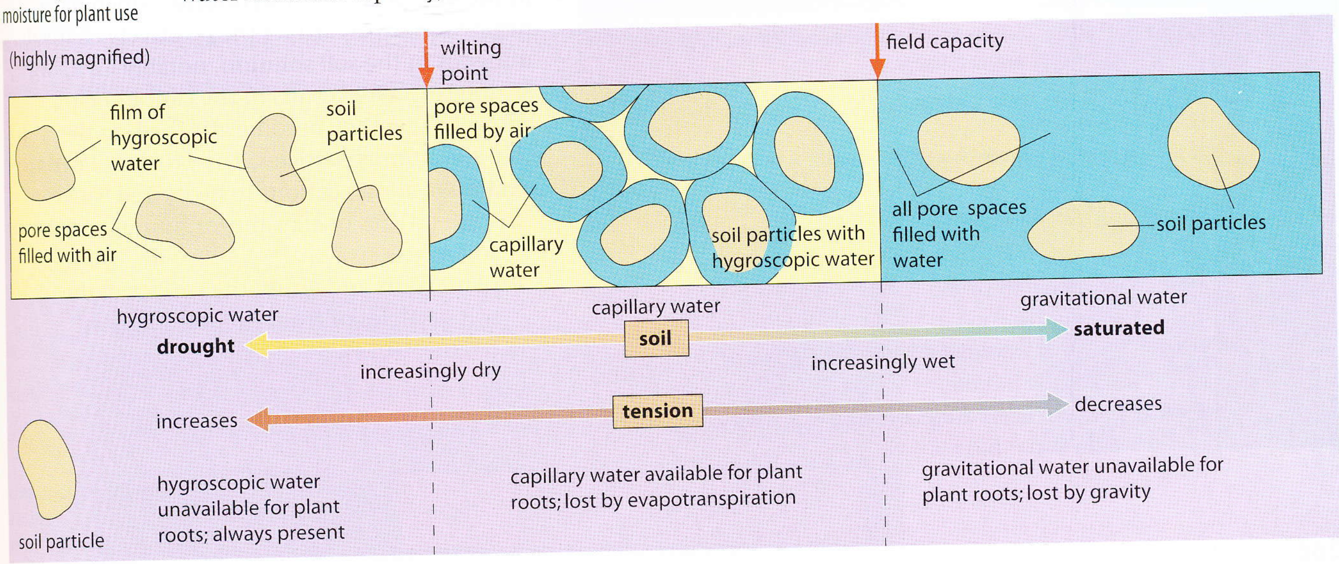
where: W = water in the soil
$\propto$ = proportional to
R = rainfall/precipitation
T = transpiration
E = evaporation
D = drainage.

Drainage depends on the balance between the **water retention capacity** (water storage in a soil) and the infiltration rate. This is controlled by porosity and permeability which in turn is controlled by the soil's texture and structure. It has already been shown how texture and structure affect the size and distribution of pore spaces. Clays have numerous small pores (**micropores**) which can retain water for long periods, giving it a high water retention capacity, but which also restrict infiltration rates (page 59). Sands have fewer but much larger **macropores** which permit water to pass through more quickly (a rapid infiltration rate), but have a low water retention capacity. A loam provides a more balanced supply of water, in the micropores, and air, in the macropores.

The presence of moisture in the soil does not necessarily mean that it is available for plant use. Plants growing in clays may still suffer from water stress even though clay has a high water-holding capacity. Soil water can be classified according to the tension at which it is held. Following a heavy storm or a lengthy episode of rain or snowmelt, all the pore spaces may be filled, with the result that the soil becomes saturated. When infiltration ceases, water with a low surface tension drains away rapidly under gravity. This is called **gravitational** or **free** water which is available to plants when the soil is wet, but unavailable when water has drained away. Once this excess water has drained away, the remaining moisture that the soil can hold is said to be its **field capacity** (Figures 3.3 and 10.12).

Moisture at field capacity is held either as **hygroscopic water** or as **capillary water**. Hygroscopic water is always present, unless the soil becomes completely dry, but is unavailable for plant use. It is found as a thin film around the soil particles to which it sticks due to the strength of its surface tension. Capillary water is attracted to, and forms a film around, the hygroscopic water, but has a lower cohesive strength. It is capillary water that is freely available to plant roots. However, this water can be lost to the soil by evapotranspiration. When a plant loses more water through transpiration than it can take up through its roots it is said to suffer **water stress** and it begins to wilt. At **wilting point**, photosynthesis (page 295) is reduced but, provided water can be obtained relatively soon or if the plant is adapted to drought conditions, this need not be fatal. Figure 10.12 shows the different water-holding characteristics of soil.

Figure 10.12
Availability of soil moisture for plant use



6 Air

Air fills the pore spaces left unoccupied by soil moisture. It is oxygen in the air that is essential for plant growth and living organisms. Compared with atmospheric air, air in the soil contains more carbon dioxide, released by plants and soil biota, and more water vapour; but less oxygen, as this is consumed by bacteria. Biota need oxygen and give off carbon dioxide by respiration and through the oxidation of organic matter. These gases are exchanged through the process of diffusion.

7 Soil organisms (biota)

Soil organisms include bacteria, fungi and earthworms. They are more active and plentiful in warmer, well-drained and aerated soils than they are in colder, more acidic and less well-drained and aerated soils.

Figure 10.13

Nutrients needed by plants

Macro-nutrients	Needed in large quantities	Carbon	C	Needed for basic cell construction. Obtained from air and water.
		Hydrogen	H	
		Oxygen	O	
		Nitrogen	N	Basis of plant proteins. Promotes rapid growth. Improves quality and quantity of leaf growth.
		Phosphorus	P	Encourages rapid seedling growth and early root formation. Helps in flowering and with seed formation.
	Needed in smaller quantities	Sulphur	S	Especially important for root crops.
		Potassium	K	Helps with production of proteins and in overcoming disease. Strengthens stems and stalks.
		Calcium	Ca	Reduces acidity. Helps with growth of roots and new shoots.
		Magnesium	Mg	Used in photosynthesis, being a basic constituent of chlorophyll. Important for arable crops.
Micro-nutrients (trace elements)	Needed in very small quantities	Sodium	Na	Helps to increase yields.
		Manganese	Mn	Used in respiration, protein synthesis and enzyme reactions.
		Copper	Cu	Reduces toxicity of other elements in soil. Helps enzyme reactions.
		Zinc	Zn	Helps in fruit production.
		Molybdenum	Mo	Needed in nitrogen fixation by activating enzymes.
		Silicon	Si	Important constituent of grasses.
		Boron	B	Helps growth.
		Chlorine	Cl	Can increase yields of some crops.
		Cobalt	Co	Helps fruit trees and bushes.

Organisms are responsible for three important soil processes:

- **Decomposition:** detritivores, such as earthworms, ants, termites, mites, woodlice and slugs, begin this process by burying leaf litter (detritus), which hastens its decay, and eating some of it. Their faeces (wormcasts, etc.) increase the surface area of detritus upon which fungi and bacteria can act. Fungi and bacteria secrete enzymes which break down the organic compounds in the detritus. This releases nutrient ions essential for plant growth (soil nutrients, Figure 10.13), into the soil while some organic compounds remain as humus.
- **Fixation:** by this process, bacteria can transform nitrogen in the air into nitrate, which is an essential nutrient for plant growth.
- **Development of structure:** fungi help to bind individual soil particles together to give a crumb structure, while burrowing animals create passageways that help the circulation of air and water and facilitate root penetration.

8 Soil nutrients

Nutrient is the term given to chemical elements found in the soil which are essential for plant growth and the maintenance of the fertility of a soil (Figure 10.13). The two main sources of nutrients are:

1 the weathering of minerals in the soil, and
2 the release of nutrients on the decomposition of organic matter and humus by soil organisms.

Nutrients can also be obtained through:

3 rainwater, and
4 the artificial application of fertiliser.

Nutrients occur in the soil solution as positively charged (+) ions called **cations** and negatively charged (-) ions known as **anions**. It is largely in the ionic form that plants can utilise nutrients in the soil. Both clay and humus, which have negative charges, attract the positively charged minerals in the soil solution, notably Ca^{2+}, Mg^{2+}, K^+ and Na^+. This results in the cations being adsorbed (i.e. they become attached) to the clay and humus particles. The process of **cation exchange** allows cations to be moved between:

- soil particles of clay and/or humus and the soil solution
- plant roots and either the surface of the soil particles or from the soil solution (Figure 10.14).

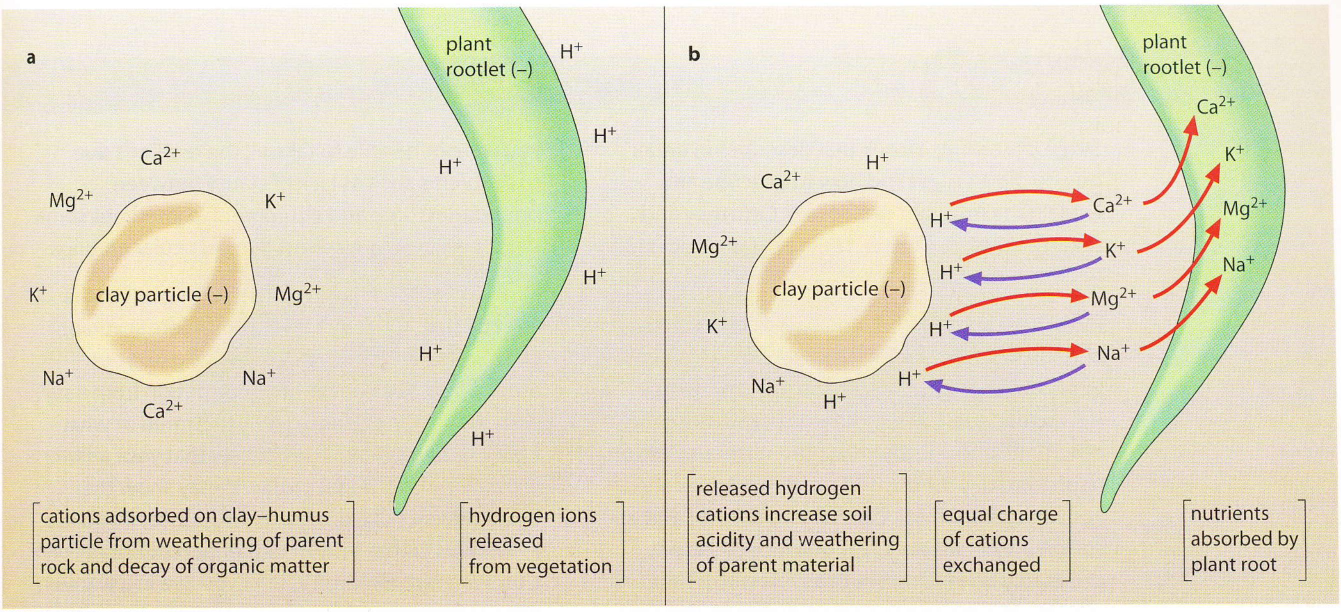


Figure 10.14

The process of cation exchange (*after* Courtney and Trudgill)

As well as providing nutrients for plant roots, the cation exchange releases hydrogen which in turn increases acidity in the soil (see below). Acidity accelerates weathering of parent rock, releasing more minerals to replace those used by plants or lost through leaching. The **cation exchange capacity** (CEC) is a measure of the ability of a soil to retain cations for plant use. Soils with a low CEC, such as sands, are less able to keep essential plant nutrients than those with a high CEC, like clays and humus; consequently they are less fertile.

9 Acidity (pH)

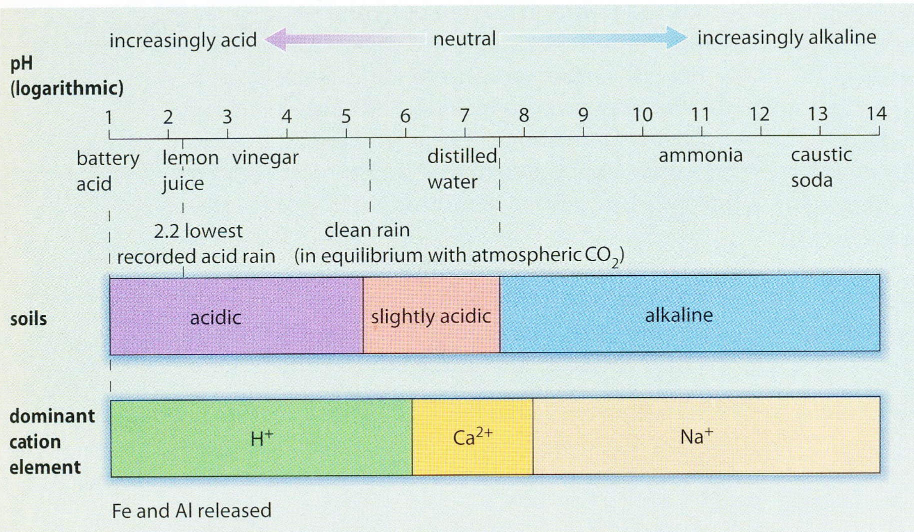
As mentioned in the previous section, soil contains positively charged hydrogen cations. **Acidity** or **alkalinity** is a measure of the degree of concentration of these cations. It is measured on the pH scale (Figure 10.15), which is logarithmic (compare the Richter scale, Figure 1.3). This means that a reading of 6 is 10 times more acidic than a reading of 7 (which is neutral), and 100 times more acidic than one of 8 (which is alkaline). Most British soils are slightly acidic, although in upland Britain acidity increases as the heavier rainfall leaches out elements such as calcium faster than they can be replaced by weathering. Acid soils therefore tend to need constant liming if they are to be farmed successfully.

A slightly acid soil is the optimum for farming in Britain as this helps to release secondary minerals. However, if a soil becomes too acidic it releases iron and aluminium which, in excess, may become toxic and poisonous to plants and organisms. Increased acidity makes organic matter more soluble and therefore vulnerable to leaching; and it discourages living organisms, thus reducing the rate of breakdown of plant litter and so is a factor in the formation of peat.

In areas where there is a balance between precipitation and evapotranspiration, soils are often neutral, as in the American Prairies (page 327); while in areas with a water deficiency, as in deserts (page 323), soils are more alkaline.

Figure 10.15

The pH scale showing soil acidity and alkalinity



10 Soil temperature

Incoming radiation can be absorbed, reflected or scattered by the Earth's surface (Figure 9.4). The topsoil, especially if vegetation cover is limited, heats up more rapidly than the subsoil during the daytime and loses heat more rapidly at night. A 'warm', moist soil will have greater biota activity, giving a more rapid breakdown of organic matter; it will be more likely to contain nutrients because the chemical weathering of the parent material will be faster; and seeds will germinate more readily in it than in a 'cold', dry soil.

Places 33 The soil pit: soil study in the field

Begin by reading a book that describes in detail how to dig a soil pit and how to describe and explain the resultant profile (e.g. Courtney and Trudgill, 1984, or O'Hare, 1988; see References at end of chapter).

First, make sure you obtain permission to dig a pit. The site must be carefully chosen. You will need to find an undisturbed soil – so avoid digging near to hedges, trees, footpaths or on recently ploughed land. Ideally, make the surface of the pit approximately 0.7 m^2, and the depth 1 m (unless you hit bedrock first). Carefully lay the turf and soil on plastic sheets. Clear one face of the pit, preferably one facing south as this will get the maximum light, to get a 'clean' profile so that you can complete your recording sheet. (The one in Figure 10.16 is a very detailed example.) Sometimes you will not be able to take all the readings due to problems such as lack of clarity between boundaries, time and equipment; sometimes some details will not be relevant to a particular enquiry.

Make a detailed fieldsketch before replacing the soil and turf. You may have to complete several tasks in the laboratory before writing up your description. You can gather information from a soil without needing to know how it formed or what type it is. Remember, it is unlikely that your answer will exactly fit a model profile. It may show the characteristics of a podsol (Figure 12.40) if you live in a cooler, wetter and/or higher part of Britain; or of a brown earth (Figure 12.34) if you live in a warmer, drier and/or lower part of the country – but you must not *force* your profile to fit a model.

Figure 10.16

Soil recording sheets

a soil site

Recorded by		Date	Locality	Six-figure grid reference
Parent rock (geological map)	Altitude (estimated from Ordnance Survey map)	Angle of slope (Abney level)	Aspect (bearing or compass point)	Relief (uniform, concave or convex slope, terrace)
Exposure (exposed, sheltered)	Drainage (shedding or receiving site, floodplain, terrace, boggy)	Natural vegetation or type of farming (tree species, ground vegetation, crops, animals)	Previous few days' weather (warm, cold, wet, dry)	Other local details (remember your labelled fieldsketch)

b soil profile

Horizon	Depth of horizon (cm)	Lower boundary of horizon	Colour	Texture	Stoniness	Structure (peds)	Consistency	pH	Moisture content	Porosity	Organic matter	Roots	Carbonates	Soil biota and/or animals
How to read, estimate and measure	measure from top of soil surface	sharp, abrupt, clear, indistinct, gradual, irregular, smooth, broken	use Munsell colour chart	percentage clay, silt or sand; 'feel'; sieves; sedimentation	size of stones, number of stones, shape of stones	structureless crumb, etc.	loose, friable, firm, hard, plastic, sticky, soft	pH paper or soil-testing kit	weigh sample, evaporate water, reweigh sample,or use a moisture meter	time taken for a beakerful of water to infiltrate	type, estimate percentage, measure depth	weigh, burn sample (and roots), reweigh sample, calculate percentage	add dilute (10%) hydrochloric acid; if it effervesces, sample is over 1% carbonate	number, types
A														
B														
C														

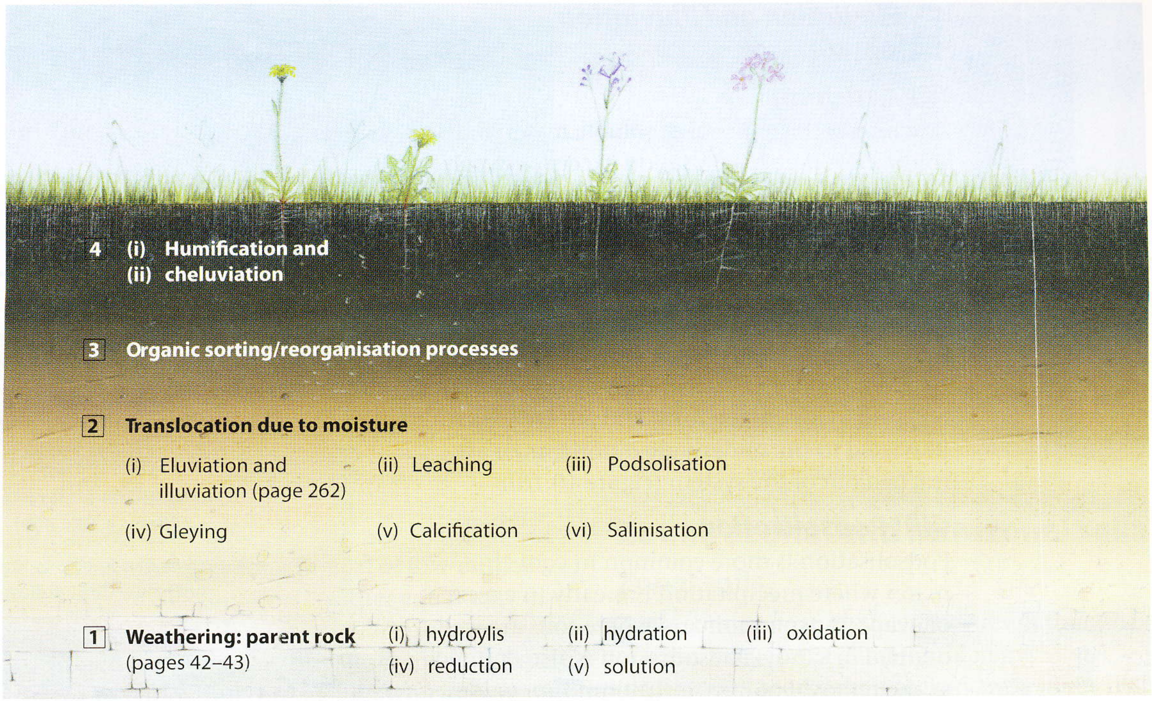


Figure 10.17

Soil-forming processes

Processes of soil formation

Numerous processes are involved in the formation of soil and the creation of the profiles, structures and other features described above. Soil-forming processes depend on all the five factors described on pages 260–262. Some of the more important processes are shown in Figure 10.17.

1 Weathering

As described on page 263 and in Figure 10.2, weathering leaves primary minerals as residues and produces secondary minerals as well as determining the rates of release of nutrients and the soil depth, texture and drainage. In systems terms, this means that minerals are released as inputs into the soil system from the bedrock store and transferred into the soil store (Figure 10.6).

2 Humification and cheluviation

Humification is the process by which organic matter is decomposed to form humus (page 266) – a task performed by soil organisms. Humification is most active either in the *H* horizon of the soil profile (Figure 10.5) where it can result in mull (pH 5.5 to 6.5), or in the upper *A* horizon where it can produce mor (pH 3.5 to 4.5) (page 266). Moder (pH 4.5 to 5.5) is transitional between the mor and mull (page 262).

As organic matter decomposes, it releases nutrients and organic acids. These acids, known as **chelating agents**, attack clays and other minerals, mainly in the *A* horizon, releasing iron and aluminium. The chelating agents then combine with the cations of the iron and aluminium to form organic-metal compounds known as **chelates**. Chelates are soluble and are readily transported downwards through the soil profile – the process of **cheluviation**. The iron and aluminium may be deposited in the lower profile as they become less soluble in the slightly higher pH levels found there (Figure 10.5).

3 Organic sorting

Several processes operate within the soil to reorganise mineral and organic matter into horizons, and to contribute to the aggregation of particles and the formation of peds.

4 Translocation of soil materials

Translocation is the movement of soil components in any form (solution, suspension, or by animals) or direction (downward, upward). It usually takes place in association with soil moisture.

In Britain, there is:

- usually a soil moisture budget surplus due to an annual excess of precipitation over evapotranspiration (water balance – Figure 3.3)
- locally, an increase in soil moisture due to poor drainage.

The increase in soil moisture, resulting from these two factors, can lead to:

- either the translocation processes of leaching and podsolisation, or
- gleying associated with areas of poor drainage.

(i) Eluviation and illuviation

See page 262.

(ii) Leaching

Leaching is the removal of soluble material in solution. Where precipitation exceeds evapotranspiration and soil drainage is good, rainwater – containing oxygen, carbonic acid and organic acids, collected as it passes through the surface vegetation – causes chemical weathering, the breakdown of clays and the dissolving of soluble salts (bases). Ca and Mg are eluviated from the *A* horizon, making it increasingly acid as they are replaced by hydrogen ions, and are subsequently illuviated to the underlying *B* horizon, or are leached out of the system (Figure 10.18).

(iii) Podsolisation

Podsolisation is more common in cool climates where precipitation is greatly in excess of evapotranspiration and where soils are well drained or sandy. Podsolisation is also defined as the removal of iron and aluminium oxides, together with humus. As the surface vegetation is often coniferous forest, heathland or moors, rain percolating through it becomes progressively more acidic and may reach a pH of 5.0 or less (Figure 10.15). This in turn dissolves an increasing amount and number of bases (Ca, Mg, Na and K), silica and, ultimately, the sesquioxides of iron and aluminium (Figure 10.19). The resultant **podsol soil** (Figure 12.40) therefore has two distinct horizons: the bleached *A* horizon, drained of coloured minerals by leaching; and the reddish-brown *B* horizon where the sesquioxides have been illuviated. Often the iron deposits form an **iron pan** which is a characteristic of a podsol.

(iv) Gleying

This occurs when the output of water from the soil system is restricted, giving **anaerobic** or **waterlogged** conditions (page 275). This is most likely to occur on gentle slopes, in depressions where the underlying rock is impermeable, where the water table is high enough to enter the soil profile (e.g. along river floodplains) or in areas with very heavy rainfall and poor drainage. Under such conditions the pore spaces fill with stagnant water which becomes de-oxygenised. The reddish-coloured oxidised iron, iron III (Fe^{3+} or ferric iron), is chemically reduced to form iron II (Fe^{2+} or ferrous iron) which is grey-blue in colour. Occasionally, pockets of air re-oxygenise the iron II to give scatterings of red mottles (Figure 10.26). Although many British soils show some evidence of gleying, the conditions develop most extensively on moorland plateaus.

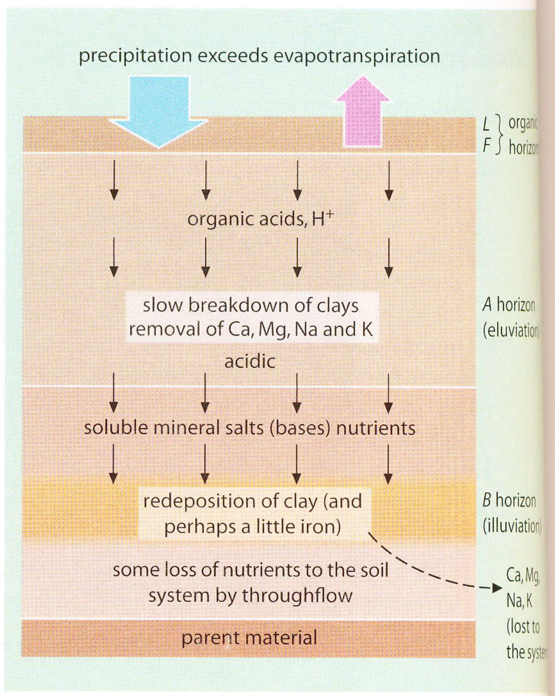


Figure 10.18

The processes of leaching

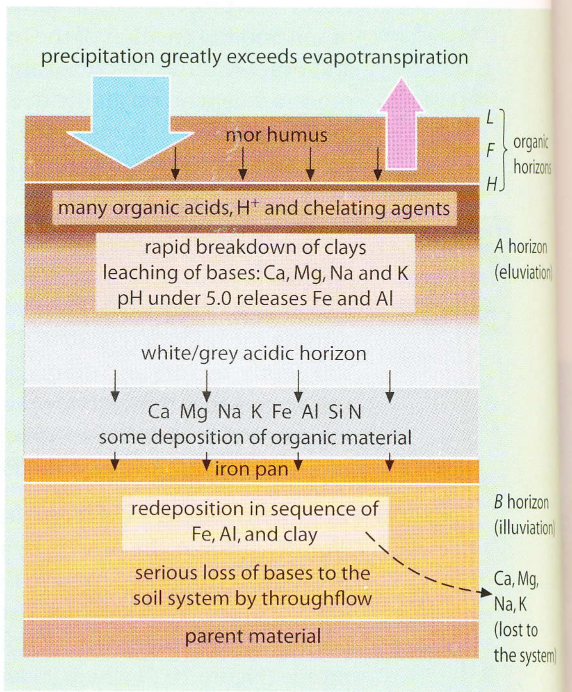


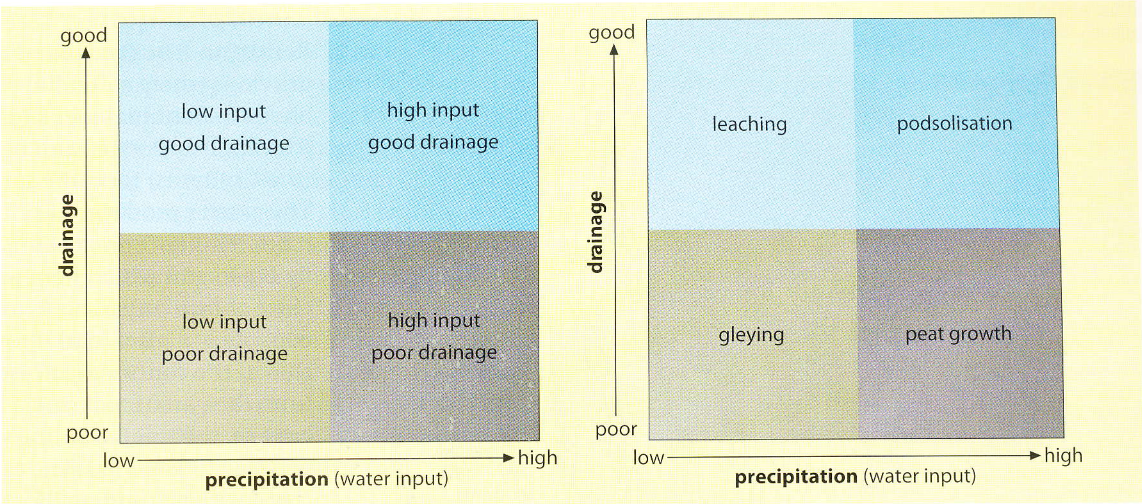
Figure 10.19

The process of podsolisation

Courtney and Trudgill (Figure 10.20) have summarised the relationship between leaching, podsolisation and gleying, and precipitation and drainage.

Figure 10.20

Soil-forming processes and the water balance (Figure 3.3) (*after* Courtney and Trudgill)



(v) Calcification

Calcification is a process typical of low-rainfall areas where precipitation is either equal to, or slightly higher than, evapotranspiration. Although there may be some leaching, it is insufficient to remove all the calcium which then accumulates, in relatively small amounts, in the *B* horizon (Figure 10.21; and chernozems, page 327).

(vi) Salinisation

This occurs when potential evapotranspiration is greater than precipitation in places where the water table is near to the surface. It is therefore found locally in dry climates and is not a characteristic of desert soils. As moisture is evaporated from the surface, salts are drawn upwards in solution by capillary action. Further evaporation results in the deposition of salt as a hard crust (Figure 10.22). Salinisation has become a critical problem in many irrigated areas, such as California (Figure 16.53).

Figure 10.21

The process of calcification

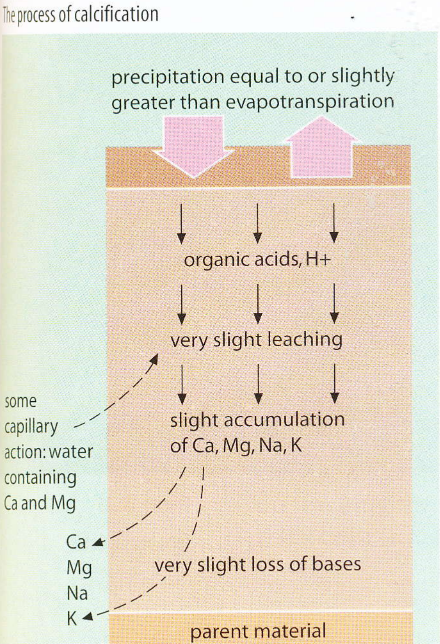
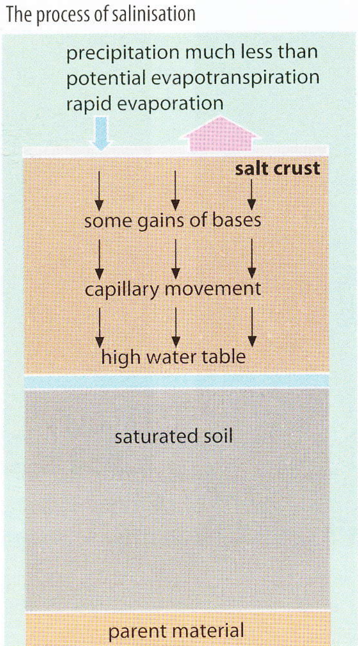


Figure 10.22

The process of salinisation



Zonal, azonal and intrazonal soils

Zonal soils

Zonal soils are mature soils. They result from the maximum effects of climate and living matter (vegetation) upon parent rock in areas where there are no extremes of weathering, relief or drainage and where the landscape and climate have been stable for a long time. Consequently, zonal soils have had time to develop distinctive profiles and, usually, clear horizons. However, it is misleading to imply that all zonal soils have distinct horizons; brown earths (page 329), chernozems (page 327) and prairie soils (page 328) have indistinct horizons which merge into each other. A description of the major zonal soils, and how their formation can be linked to climate and vegetation, is given in Chapter 12 and Figure 12.2. It should be stressed that this linkage is regarded by soil scientists as greatly outdated and a grossly simplified model – but it is still the one used in all the latest AS, A-level and Scottish Higher syllabuses that examine soils!

Azonal soils

Azonal soils, in contrast to zonal soils, have a more recent origin and occur where soil-forming processes have had insufficient time to operate fully. As a consequence, these soils usually show the characteristics of their origin (i.e. parent material, which may have resulted from *in situ* weathering of parent rock or have been transported from elsewhere and deposited), do not have well defined horizons, and are not associated with specific climatic–vegetational zones. Azonal soils, in Britain, include **scree** (weathering), **alluvium** (fluvial), **till** (glacial), **sands** and **gravels** (glacifluvial), **sand dunes** (aeolian and marine), **saltmarsh** (marine), and **volcanic** (tectonic) **soils**.

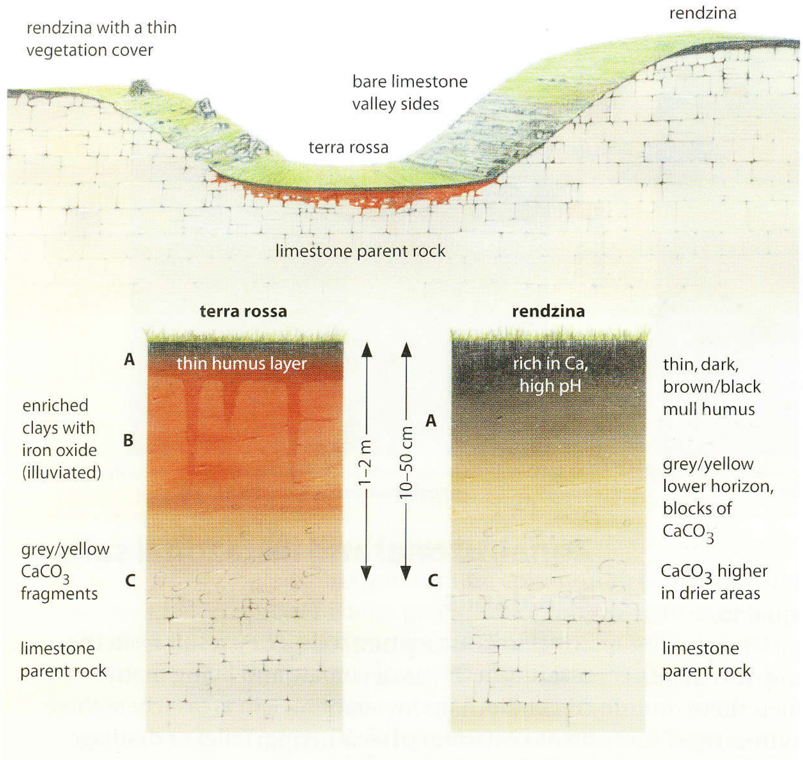


Figure 10.23

Calcimorphic soils: terra rossa and rendzina

Intrazonal soils

Intrazonal soils reflect the dominance of a single local factor, such as parent rock or extremes of drainage. As they are not related to general climatic controls, they are not found in zones. They can be divided into three types:

- **Calcimorphic** or **calcareous** soils develop on a limestone parent rock (rendzina and terra rossa, Figure 10.23).
- **Hydromorphic** soils are those having a constantly high water content (gleyed soils and peat – Figures 10.26 and 10.27).
- **Halomorphic** soils have high levels of soluble salts which render them saline.

Figure 10.24

A rendzina, Kent

Calcimorphic

1 **Rendzina** The rendzina (Figure 10.24) develops where softer limestones or chalk are the parent material and where grasses (the English Downs) and beech woodland (the Chilterns) form the surface vegetation. The grasses produce a leaf litter that is rich in bases. This encourages considerable activity by organisms which help with the rapid recycling of nutrients. The *A* horizon therefore consists of a black/dark-brown mull humus. Due to the continual release of calcium from the parent rock and a lack of hydrogen cations, the soil is alkaline with a pH of between 7.0 and 8.0. The calcium-saturated clays, with a crumb or blocky structure, tend to limit the movement of water and so there is relatively little leaching. Consequently there is no *B* horizon. The underlying limestones, affected by chemical weathering, leave very little insoluble residue and this, together with the permeable nature of the bedrock, results in a thin soil with limited moisture reserves.

2 **Terra rossa** As its name suggests, terra rossa (Figure 10.25) is a red-coloured soil (it has been called a 'red rendzina'). It is found in areas of heavy, even if seasonal, rainfall where the calcium carbonate parent rock is chemically weathered (carbonation) and silicates are leached out of the soil to leave a residual deposit rich in iron hydroxides. It usually occurs in depressions within the limestone and in Mediterranean areas where the vegetation is garrigue (Figure 12.24).

Figure 10.25

Terra rossa, Cuba

Hydromorphic

1 **Gley soils** Gleying occurs in saturated soils when the pore spaces become filled with water to the exclusion of air. The lack of oxygen leads to anaerobic conditions (page 272) and the reduction (chemical weathering) of iron compounds from a ferric (Fe^{3+}) to a ferrous (Fe^{2+}) form. The resultant soil has a grey-blue colour with scatterings of red mottles (Figure 10.26). Because gleying is a result of poor drainage and is almost independent of climate, it can occur in any of the zonal soils. Pedologists often differentiate between **surface gleys**, caused by slow infiltration rates through the topsoil, and **groundwater gleys**, resulting from a seasonal rise in the water table or the presence of an impermeable parent rock.

2 **Peat** Where a soil is waterlogged and the climate is too cold and/or wet for organisms to break down vegetation completely, layers of peat accumulate (Figure 10.27). These conditions mean that litter input (supply) is greater than the rate of decomposition by organisms whose activity rates are slowed down by the low temperatures and the anaerobic conditions. Peat is regarded as a soil in its own right when the layer of poorly decomposed material exceeds 40 cm in depth. Peat can be divided according to its location and acidity. **Blanket peat** is very acidic; it covers large areas of wet upland plateaus in Britain (Kinder Scout in the Peak District); and it is believed to have formed 5000 to 8000 years ago during the Atlantic climatic phase (Figure 11.18). **Raised bogs**, also composed of acidic peat, occur in lowlands with a heavy rainfall. Here the peat accumulates until it builds up above the surrounding countryside. **Valley**, or **basin**, **peat** may be almost neutral or only slightly acidic if water has drained off surrounding calcareous uplands (the Somerset Levels and the Fens); otherwise, it too will be acid (Rannoch Moor in Scotland). Fen peat is a high-quality agricultural soil.

Halomorphic

Halomorphic soils contain high levels of soluble salts and have developed through the process of salinisation (page 273 and Figure 16.53). They are most likely to occur in hot, dry climates where, in the absence of leaching, mineral salts are brought to the surface by capillary action and where the parent rock or groundwater contains high levels of carbonates, bicarbonates and sulphates, especially as salts of calcium and magnesium and some sodium chloride (common salt). The water, on reaching the surface, evaporates to leave a thick crust (e.g. Bonneville saltflats in Utah, page 188) in which only salt-resistant plants (halophytes, page 291) can grow.

Figure 10.26

Gleying: a hydromorphic soil

Figure 10.27

Peat in the Flow Country, Sutherland, Scotland

The soil catena

A **catena** (Latin for 'chain') is a sequence of soil types down a slope where each **soil type**, or **facet** is different from, but linked to, its adjacent facets (Figure 10.3). Catenas therefore illustrate the way in which soils can change down a slope where there are no marked changes in climate or parent material. Each catena is an example of a small-scale, open system involving inputs, processes and outputs. The slope itself is in a delicate state of dynamic equilibrium (Figure 2.12) with the soils and landforms being in a state of flux and where the ratio of erosion and deposition varies between the different slope facets. Soils on lower slopes tend to be deeper and wetter than those on upper slopes, as well as being more enriched by a range of leached materials. The thinnest and driest soils are likely to be found on central parts of the slope. It takes a considerable period of time for catenary relationships to become established and therefore the best catenas can be found in places with a stable environment, such as in parts of Africa, where there have been relatively few recent changes in either the landscape or the climate.

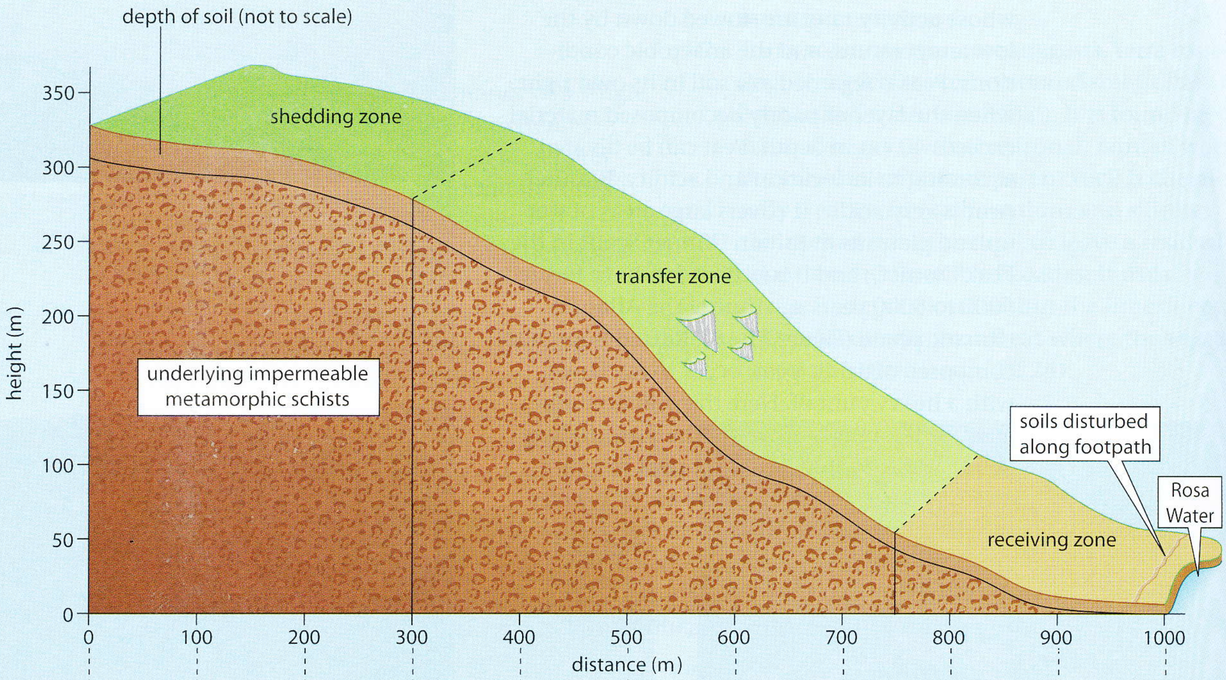
Places 34 Arran: a soil catena

Figure 10.28 shows a catena based on fieldwork conducted on the Isle of Arran. The transect was taken from a relatively flat, peat-covered upland area above the glaciated Glen Rosa valley, down a steep valley side to the Rosa Water (parallel to, and south of, the Garbh Allt tributary located on Figure 4.37).

Notice, with reference to Figure 10.3, the location on the transect of the shedding (eluviation or input), transfer (translocation) and receiving (illuviation or output) zones, and the relationships between the angles of slope and (i) soil depth, (ii) pH and (iii) soil moisture.

Figure 10.28

Readings taken along a catena in Glen Rosa



	A	B	C	D	E	F	G	H	I	J	K
Soil depth (cm)	170	110	45	42	24	18	28	20	21	70	90
pH	4.4	3.8	4.4	4.7	5.0	5.6	5.9	5.7	5.8	4.5	4.2
Soil moisture/ moisture meter	6.0	5.2	3.5	2.0	2.2	2.0	2.5	1.5	1.5	3.5	4.8
	input zone (includes heavy rainfall)				transfer zone				output zone (excludes the action of the river)		

Framework 9 Geographic Information Systems (GIS)

For centuries cartographers and geographers have been drawing and analysing maps by hand but, with recent technological developments, this work is increasingly being carried out by computers. Advances in geomatics – the science of handling geographic information – mean that huge amounts of data can be combined with digital maps and computer graphics in Geographic Information Systems (GIS).

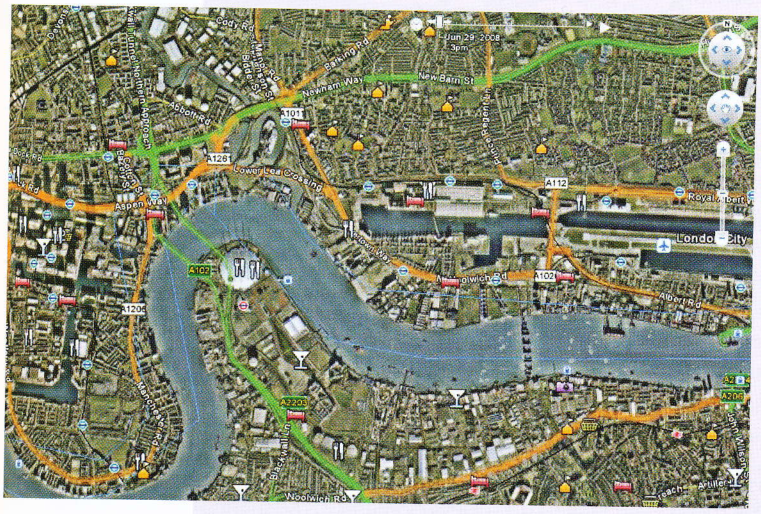


Figure 10.29

Google Earth image of London, overlain with geographic information

It is estimated that around 80 per cent of all digitally stored information has a spatial element or is tied to a certain place. Powerful GIS software packages enable geographers to view, analyse, interpret, question and display this data in order to reveal relationships, patterns and trends that may otherwise be hidden.

Increasing numbers of businesses now use GIS to make decisions about a wide range of subjects. Examples include:

- where to site gas and electricity services
- the optimal place to build a wind farm
- the most efficient way to route emergency vehicles
- how to protect and conserve sensitive wetland areas.

In the home, through basic internet-based packages such as Google Earth (Figure 10.29), many people use GIS to learn about the world and to plan their leisure time and holidays.

A computer-based GIS needs three main components:

- a computerised map – used as a backdrop on which to place all the other information; this can be a conventional map, an aerial photograph or a satellite image
- a GIS software package – this will contain the tools for manipulating the map and the information
- the information itself – contained in a database, as photographs, text or any other kind of digital data.

The base map can be made up of a number of layers showing geographical components such as height, soils, settlement patterns or vegetation. These maps come from many different sources including remote sensing companies or mapping organisations such as Britain's Ordnance Survey.

The GIS software is the link that enables data to be positioned on the base map (Figure 10.30) and contains tools to manipulate the base map, add information layers and display the results. The data added can be tailored to fit the end users of the GIS. Public utilities such as electricity, gas and water companies, for instance, can add information layers showing the locations of their cables and manholes. Data is not just limited to the surface but can include features such as underground pipelines, and computers can display the information as a three-dimensional representation of reality. Technicians can enter this virtual environment on their screens, walking underneath the streets of our cities to analyse the problems that occur within such complex networks (Figure 10.31).

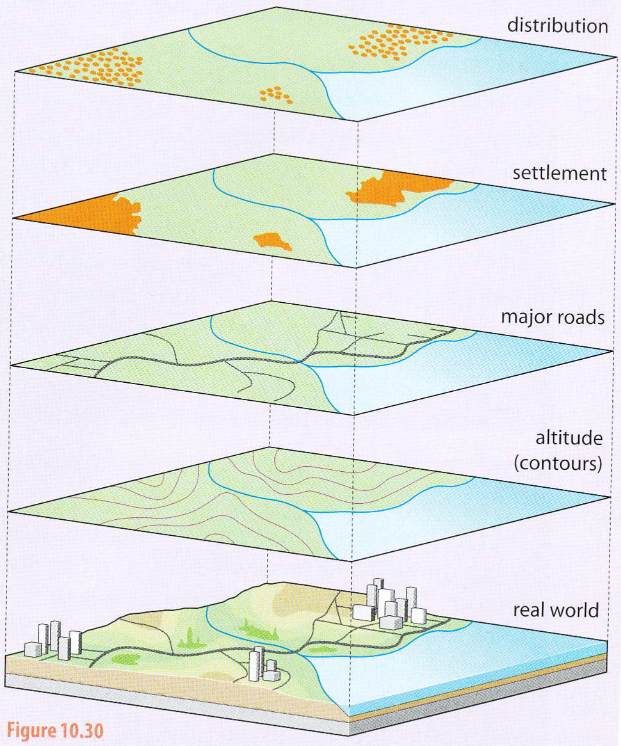


Figure 10.30

Linking layers through a Geographic Information System

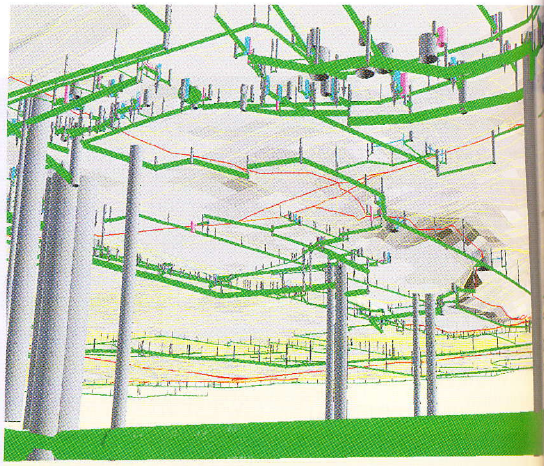


Figure 10.31

Underground water pipe network in Ballerup, Denmark shown in ArcGIS

GIS in the real world

'The application of GIS is limited only by the imagination of those who use it.'

Dr Jack Dangermond, President of pioneering GIS company ESRI

Across the globe, governments, local councils, the military, private companies and individuals use GIS daily to provide the services we take for granted. Problems such as finding the best position for a new power station or where to build a new cinema or housing estate are all analysed using GIS. At an individual level, self-employed businessmen can use home PC-based systems to improve their productivity. Farmers, for instance, log on to analyse information on weather patterns, soil type and economic trends in order to determine the best time to plant crops.

GIS in the future

'Imagine looking down a street but instead of simply seeing houses, shops and offices, your view has added extras like travel news, tours and even games.'

Ordnance Survey website

As the capability of computers increases, software developers are looking at ways in which GIS can provide information in the future. Businesses are constantly on the lookout for more digital data, especially if it is available in real time, and many are looking to run increasingly complex simulations through GIS before spending huge sums of money on big building projects. Governments and international organisations, meanwhile, are using systems to model the effects of climate change, sea-level rise, pollution incidents and other environmental disasters.

For personal users, the Ordnance Survey is developing The Magic Window, a handheld device that will superimpose geographic data on real-world images using a virtual 1:1 scale map of Great Britain (Figure 10.33). Developments in the sharing of data through the internet will also influence the availability of free GIS packages, bringing the easy-to-understand analysis of geographic information to millions of homes around the world.

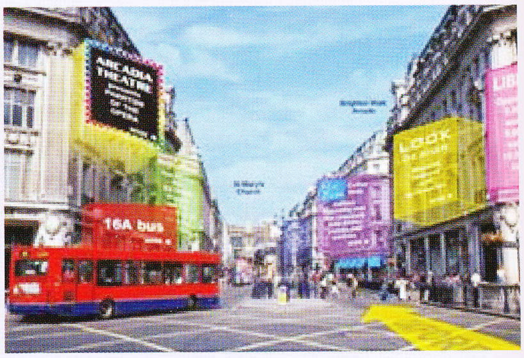


Figure 10.33

The Magic Window

Figure 10.32

How the emergency services and the police use GIS

Emergency services

Avoiding delays when sending an ambulance on an emergency call can be a matter of life or death. When operators take a phone call they ask for the location where help is needed and input the information into a GIS. The system quickly identifies the nearest available ambulance (sometimes by receiving data from satellites), builds a picture of expected traffic patterns based on the time of day and analyses the data to determine the quickest route the ambulance crew should take.

Mapping crime

Criminal analysts working for the police use GIS to locate, track and analyse incidents and help the police predict where and when crimes are likely to take place. Car thefts, for instance, often happen at night but are not reported until the morning when the owners wake up. By looking at patterns on their databases of abandoned cars, overlain with information on known offenders, the police are able to target resources and have had notable successes in catching criminals.

Further reference

DeMers, M. (2009) *GIS for Dummies*, John Wiley and Sons.

Sommer, S. and Wade, T. (2006) *A to Z GIS: An Illustrated Dictionary of Geographic Information Systems*, ESRI Press.

http://mapzone.ordnancesurvey.co.uk/mapzone/giszone.html

www.gis.com/whatisgis/index.html

www.gis.rgs.org/whatisgis.html

As we have seen (page 262), soil can takes thousands of years to become sufficiently deep and developed for economic use (exceptions include alluvium deposited by rivers and ash ejected from volcanoes). During that time, there is always some natural loss through leaching, mass movement and erosion by either water or wind. Normally there is an equilibrium, however fragile, between the rate at which soil forms and that at which it is eroded or degraded. That natural balance is being disturbed by human mismanagement with increasing frequency and with serious consequences.

Recent estimates suggest that 7 per cent of the world's topsoil is lost each year. The World Resources Institute claims that Burkina Faso loses 35 tonnes of soil per hectare per year. Other comparable figures are Ethiopia 42, Nepal 70, and the loess plateau of North China 251 (Figure 10.35). Soil removed during a single rain storm or dust storm may never be replaced. The Soil Survey of England and Wales claims that 44 per cent of arable soils in the UK, an area once considered not to be under threat, are now at risk (Figure 10.34).

UK soil degradation

Soil degradation involves both the physical loss (erosion) and the reduction in quality of topsoil. Currently, 2.2 million tonnes of topsoil is eroded annually in the UK and over 17 per cent of arable land shows signs of erosion. Degradation can result from one or more of several factors:

- Physical degradation is when soil erosion results from the action of the wind or water. It is a natural process, accelerated by human activity. Erosion by wind is less widespread and less frequent than erosion by water but when it does occur it is often more severe. Estimates suggest that 44 per cent of arable land is at risk of being eroded by physical processes.
- Chemicals carried by water can cause diffuse pollution, while biological degradation is when organic matter, in the form of plant remains or organic manure, is washed out of the soil.
- Climate change suggests that Britain will experience more seasonal extremes with wetter, stormier winters and warmer, drier summers [page 255]. Wetter winters may mean waterlogged soils and an increase in water erosion, while drier soils are more likely to be susceptible to wind erosion.
- Land use can affect the soil, for example when grass is removed to expose the soil and, without roots to bind it together, the soil becomes unstable.

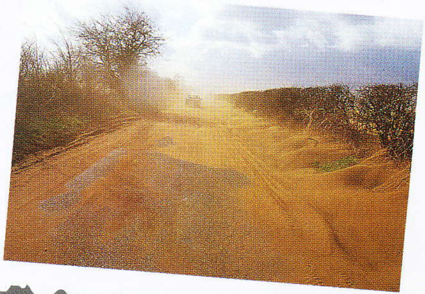


Figure 10.34

Soil erosion in Britain

Soil degradation

Degradation is the result of human failures to understand and manage the soil. The major cause of soil erosion is the removal of the natural vegetation cover, leaving the ground exposed to the elements. The most serious of such removals is deforestation. In countries such as Ethiopia (Places 76, page 520), the loss of trees, resulting from population growth and the extra need for farmland and fuelwood, means that the heavy rains, when they do occur, are no longer intercepted by the vegetation. Rainsplash (the direct impact of raindrops, Figure 2.12) loosens the topsoil and prepares it for removal by sheetwash (overland flow). Water flowing over the surface has little time to infiltrate into the soil or recharge the soil moisture store (pages 59–60). More topsoil tends to be carried away where there is little vegetation because there are neither plant roots nor organic matter to bind it together. Small channels or rills may be formed which, in time, may develop into large gulleys, making the land useless for agriculture (Figure 10.35).

Even where the soil is not actually washed away, heavy rain may accelerate leaching and remove nutrients and organic matter at a rate faster than that at which they can be replaced by the weathering of bedrock and parent material and the decomposition of vegetation (e.g. the Amazon Basin, Figure12.7 and Places 66, page 480). The loss of trees also reduces the rate of transpiration and therefore the amount of moisture in the air. There are fears that large-scale deforestation will turn areas at present under rainforest into deserts.

Although the North American Prairies and the African savannas were grassland when the European settlers first arrived, it is now believed that these areas too were once forested and were cleared by fire – mainly natural due to lightning, but partly by the local people (Case Study 12B). The burning of vegetation initially provides nutrients for the soil, but once these have been leached by the rain or utilised by crops there is little replacement of nutrients. Where the grasslands have been ploughed up for cereal cropping, the breakdown of soil structure (peds) has often led to their drying out and becoming easy prey to wind erosion (Figure 10.34). Large quantities of topsoil were blown away to create the American Dust Bowl in the 1930s, while a similar fate has more recently been experienced by many of the Sahel countries. In Britain, the removal of hedges to create larger fields – easier for modern machinery – has led to accelerated soil erosion by wind (page 495).

Loess plateau of North China

Figure 10.35 Loess in China

This region, more than 2.5 times the size of the UK, experiences the most rapid soil loss in the world. During and following the ice age, Arctic winds transported large amounts of loess and deposited this fine, yellow material to a depth of 200 m in the Huang He basin. Following the removal of the subsequent vegetation cover of trees and grasses to allow cereal farming (especially under the directions of Chairman Mao), the unconsolidated material has been washed away by the heavy summer monsoon rains, or blown by yellow dust storms, at the rate of 1 cm per year. It is estimated that 1.6 bn tonnes of soil reach the Huang He River during each annual summer flood. This material, the most carried by any river in the world, has given the Huang He its name – i.e. the 'Yellow River'. A further problem is that 6 cm of silt settles annually on the river's bed so that it now flows 10 m above its floodplain. Should the large flood banks be breached, the river can drown thousands of people (over 1 million in the 1939 flood) and ruin all crops.

Ploughing can have adverse effects on soils. Deep ploughing destroys the soil structure by breaking up peds (page 265) and burying organic material too deep for plant use. It also loosens the topsoil for future wind and water erosion. The weight of farm machinery can compact the soil surface or produce platy peds, both of which reduce infiltration capacity and inhibit aeration of the soil. Ploughing up- and down-hill creates furrows which increase the rate of surface runoff and the process of gullying.

Overgrazing, especially on the African savannas, also accelerates soil erosion. Many African tribes have long measured their wealth in terms of the numbers, rather than the quality, of their animal herds. As the human populations of these areas continue to expand rapidly, so too do the numbers of herbivorous animals needed to support them. This almost inevitably leads to overgrazing and the reduction of grass cover (Case Study 7). When new shoots appear after the rains, they are eaten immediately by cattle, sheep, goats and camels. The arrival of the rains causes erosion; the failure of the rains results in animal deaths.

Where there is a rapid population growth, land that was previously allowed a fallow resting period now has to be cultivated each year (Figure 10.36) – as are other areas that were previously considered to be too marginal for crops. Monoculture – the cultivation of the same crop each year on the same piece of land – repeatedly uses up the same soil nutrients.

Burkina Faso

As the size of cattle and goat herds has grown, the already scant dry scrub savanna vegetation on the southern fringes of the Sahara has been totally removed over increasingly large areas. As the Sahara 'advances', the herders are forced to move southwards into moister environments where they compete for land with sedentary farmers who are already struggling to produce sufficient food for their own increasing numbers. This disruption of equilibrium further reduces the land carrying capacity [page 378] – i.e. the number of people that the soil and climate of an area can permanently support when the land is planted with staple crops. These farmers have long been aware that three years' cropping had to be followed by at least eight fallow years in order for grass and trees to re-establish themselves and organic matter to be replenished. The arrival of the herders has brought a land shortage resulting in crops being grown on the same plots every year, and the nutrient-deficient soil, typical of most of tropical Africa, is rapidly becoming even less productive. This overcropping, a problem in many of the world's subsistence areas, uses up organic matter and other nutrients, weakens soil structures and leaves the surface exposed and thus susceptible to accelerated erosion.

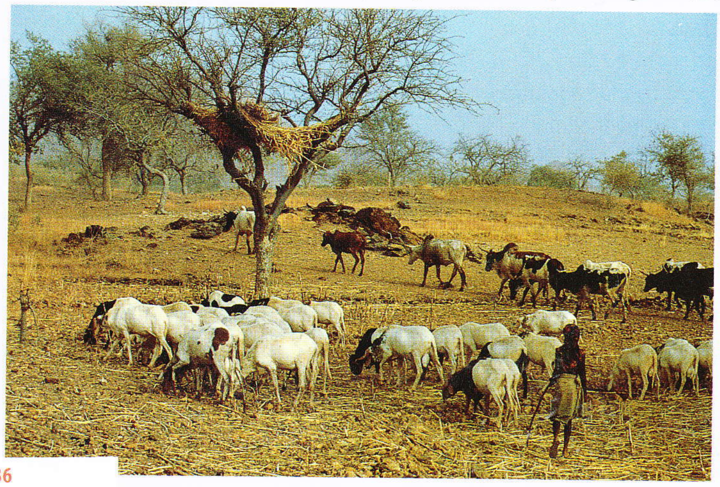


Figure 10.36 Overgrazing: Burkina Faso

The Soil Protection Review is carried out by Britain's farmers as part of cross-compliance. It involves identifying soil issues, deciding on measures to manage and protect soils, and then reviewing the results. The 2006 review concluded with the following recommended options to protect the soil from physical decline and erosion:

- reducing mechanical operations on wet ground
- planting crops early in autumn to protect the soil during the winter from water erosion
- ploughing across slopes where it is safe to do so (compare Figure 10.38)
- using low ground-pressure set-ups on machinery
- shepherding livestock and rotating forage areas
- planting and/or maintaining hedges or shelter belts to reduce wind erosion

and measures to protect the soil's organic matter:

- leaving straw and other crop residues on the land after a crop has been harvested
- including grass in crop rotations
- applying animal manure, compost and sewage sludge
- using reduced or shallow cultivation to maintain or increase near-surface organic matter.

Many farmers suggest that these options are often already adopted but need better co-ordination together with continued targeted advice, information and monitoring.

Figure 10.37

Mitigation strategies for soil degradation

In many parts of the world where livestock are kept and firewood is at a premium, dung has to be used as a fuel instead of being applied to the land. In parts of Ethiopia, the sale of dung – mixed with straw and dried into 'cakes' – is often the only source of income for rural dwellers. If this dung were to be applied to the fields, rather than sold to the towns, harvests could be increased by over 20 per cent.

Water is essential for a productive soil. The early civilisations, which grew up in river valleys (Figure 14.1), relied on irrigation, as do many areas of the modern world. Unfortunately, irrigation in a hot, dry climate tends to lead to salinisation, with dissolved salts being brought, by capillary action, into the root zone of agricultural trees and crops (Figure 16.53). Wells, sunk in dry climates, use up reserves of groundwater which may have taken many centuries to accumulate and which cannot be replaced quickly (fossil water stores, page 190). The resultant lowering of the water table makes it harder for plant roots to obtain moisture. The sinking of wells in sub-Saharan Africa, following the drought of the early 1980s, has unintentionally created difficulties. The presence of an assured water supply has attracted numerous migrants and their animals and this has accelerated the destruction of the remaining trees and exacerbated the problems of overgrazing (Places 65, page 479). Even well-intentioned aid projects may therefore be environmentally damaging.

Fertiliser and pesticides are not always beneficial if applied repeatedly over long periods. Chemical fertiliser does not add organic material and so fails to improve or maintain soil structure. There is considerable concern over the leaching of nitrate fertiliser into streams and underground water supplies. Where nitrates reach rivers they enrich the water and encourage the rapid growth of algae and other aquatic plants which use up oxygen, through the process of eutrophication, to leave insufficient for plant life (Figure 16.50). The use of pesticides (including insecticides and fungicides) can increase yields by up to 100 per cent by killing off insect pests. However, their excessive and random use also kills vital soil organisms, which means organic matter decomposes more slowly and the release of nutrients is retarded. Chemical pesticides are blamed for the decline in Britain's bee population.

Soil management

Fertility refers to the ability of a soil to provide for the unconstrained or optimum growth of plants. The capacity to produce high or low yields depends upon the nutrient content, structure, texture, drainage, acidity and organic content of a particular soil as well as the relief, climate and farming techniques. For ideal growth, plants must have access to nine macro-nutrients and nine micro-nutrients (Figure 10.13). Under normal recycling (Figure 10.6), these nutrients will be returned to the soil as the vegetation dies and decomposes. When a crop is harvested there is less organic material left to be recycled. As nutrients are taken out of the soil system and not replaced, there will be an increasing shortage of macro-nutrients, particularly nitrogen, calcium, phosphorus and potassium. Where this occurs, and when other nutrients are dissolved and leached from the soil, fertiliser is essential if yields are to be maintained. Soils need to be managed carefully if they are to produce maximum agricultural yields and cause least environmental damage (Figure 10.37).

If the most serious cause of erosion is the removal of vegetation cover, the best way to protect the soil is likely to be by the addition of vegetation. Afforestation provides a long-term solution because, once the trees have grown, their leaves intercept rainfall while their roots help to bind the soil together and reduce surface runoff. The growing of ground-cover crops reduces rainsplash and surface runoff, and can protect newly ploughed land from exposure to climatic extremes. Marram grass anchors sand, while gulleys can be seeded and planted with brushwood. Certain crops and plants, especially leguminous species such as peas, beans, clover and gorse, are capable of fixing atmospheric nitrogen in the soil, thus improving its quality. Trees can also be planted to act as windbreaks and shelter-belts. This reduces the risk of wind erosion as well as providing habitats for wildlife.

Soil can also be managed by improving farming methods. Most arable areas benefit from a rotation of crops, including grasses, which improve soil structures and reduce the likelihood of soil-borne diseases which may develop under monoculture. Many tropical soils need a recovery period of 5–15 years under shrub or forest for each 3–6 years under crops. In areas where slopes reach up to 12°, ploughing should follow the contours to prevent excessive erosion. On even steeper slopes (Figures 10.41 and 16.29), terracing helps to slow down runoff, giving water more time to infiltrate and thus reducing its erosive ability.

Strip cropping can involve either the planting of crops in strips along the contours or the intercropping of different crops in the same field. Both methods are illustrated in Figure 10.38. The crops may differ in height, time of harvest and use of nutrients.

Where evapotranspiration exceeds precipitation, dry farming can be adopted. This entails covering the soil with a mulch of straw and/or weeds to reduce moisture loss and limit erosion. In the Sahel countries, the drastic depopulation of cattle following the droughts of the 1980s has given herders a chance to restock with smaller (reducing overgrazing), better-quality (giving more meat and milk) herds so that incomes do not fall and the soils are given time to recover.

The addition of organic material helps to bind loose soil and so reduces its vulnerability to erosion (Figures 10.38 and 10.39). Soil structure and texture may be improved, theoretically, by adding lime to acid soils, which reduces their acidity and helps to make them warmer; by adding humus, clay or peat to sands, to give body and to improve their water-holding capacity; and by adding sand to heavy clays, so improving drainage and aeration and making them lighter to work. In practice, such methods are rarely used due to the expense involved.

Chemical (inorganic) fertilisers help to replenish deficient nutrients, especially nitrogen, potassium and phosphorus. However, their use is expensive, especially to farmers in economically less developed countries, and can cause environmental damage. Many farmers in poorer countries cannot afford such fertilisers and have to rely upon organic fertiliser. Animal dung and straw left after the cereal harvest are mixed together and spread over the ground. This improves soil structure and, as it decays, returns nutrients to the soil. Where crop rotations are practised, grasses add organic matter, and legumes provide nitrogen.

Organic milk has more healthy benefits

A study of organic milk, conducted by Professor Carlo Leifert of Newcastle University, has shown that drinking organic milk has greater health benefits than drinking normal milk. The study showed that organic milk contained 67 per cent more antioxidants and vitamins than ordinary milk and 60 per cent more of a healthy fatty acid called conjugated linoleic acid (CLA9) which tests have shown can shrink tumours. Similar levels of vaccenic acid, which has been shown to cut the risk of heart disease, diabetes and obesity, were also found as was an extra 39 per cent of the fatty acid Omega-3 which has also been shown to cut the risk of heart disease.

Gillian Butler, the livestock project manager, pointed out the health benefits even if consumers did not switch completely to organic milk. She pointed out that organic milk is more expensive to produce, as you get less milk per unit of land, and to buy, but because it is higher in all these beneficial compounds you do not need to buy as much to get health benefits.

Figure 10.39

Organic farming in Washington State, USA

Figure 10.38

Strip farming along contours in the southern USA

Stone lines in Burkina Faso

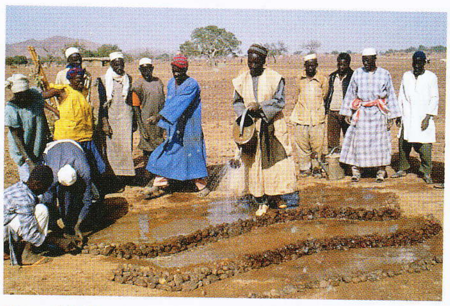


Figure 10.40

Stone lines in Burkina Faso

This project, begun by Oxfam in 1979, aimed to introduce water-harvesting techniques for tree planting. It met with resistance from local people who were reluctant to divert land and labour from food production, or to risk dry-season water needed for drinking.

Attention was therefore diverted to improving food production by using the traditional local technique of placing lines of stones across slopes to reduce runoff [Figures 10.40 and 16.64]. When aligned with the contours, these lines dammed rainfall, giving it time to infiltrate. Unfortunately, most slopes were so gentle, under 2°, that local farmers could not determine the contours. A device costing less than £3 solved the problem. A calibrated transparent hose, 15 m long, is fixed at each end to the tops of stakes of equal lengths and filled with water. When the water level is equal at both ends of the hose, the bottom of the stakes must be on the same contour. The lines can be made during the dry season when labour is not needed for farming. Although they take up only 1 or 2 per cent of cropland, they can increase yields by over 50 per cent. They also help to replenish falling water tables and can regenerate the barren, crusted earth because soil, organic matter and seeds collect on the upslope side of the stone lines and plants begin to grow again.

Since 2000, Practical Action has been financing the construction of crescent-shaped terraces which, built of earth along the contours of the land, last longer and hold on to vital rainwater more efficiently than traditional square dams. Crops grown here thrive in soil, rich in nutrients, that was previously washed away.

In Britain and North America, a growing number of farmers are turning to organic farming for environmental reasons (Figure 10.39 and page 497 and Case Study 16B).

Many soils suffer from either a shortage or a surfeit of water. In irrigated areas, water must be continually flushed through the system to prevent salinisation. In areas of heavy and/or seasonal rainfall, dams may be built to control flooding and to store surplus water. The drainage of waterlogged soils can be improved by adding field drains.

In several Sahelian countries, people use stones to build small dams which trap water for long enough for some to infiltrate into the ground; they also collect the soil carried away by surface runoff (Figures 10.40 and 16.64).

Soil conservation in northern Shaanxi (China)

According to historic records, the northern province of Shaanxi was once a region with plenty of water, fertile loess soil, lush grass and livestock. Since then, overcultivation and deforestation have led to severe soil erosion [Figure 10.35]. This has in turn caused serious desertification [Case Study 7], creating drifting sand dunes which have buried farmland and villages, while frequent droughts, floods and dust-storms have hindered the development of the local farming economy. Agriculture fell into a vicious circle: people, because of their poverty, reclaimed land but the more land they reclaimed, the poorer they became because this land was also subject to erosion.

Since the early 1980s, however, the central government has encouraged and supported a comprehensive programme for erosion control on the loess plateau. The two main aims have been to control and stabilise drifting sand in northern Shaanxi and to transform the soil throughout the province. This has involved the development of irrigation projects, the terracing of hillsides [Figure 10.41], the planting of trees as a shelter-forest network against the shifting sand [Figure 10.42] and the construction of check-dams [Figure 10.43].

Figure 10.42 The shelter-forest network

During the 1990s, the Loess Plateau Rehabilitation Project was set up with the twin aims of increasing the income of local farmers and reducing sediment flow into the Huang He. The project has involved engaging the local farmers and government officials in planting more trees, bushes and grasses that were previously native to the region; creating terraces for agriculture; planting orchards and vineyards; and constructing more sediment control dams and irrigation networks. At first the farmers and officials were sceptical about restoring so much land and leaving it for nature, but the desperate poverty of the plateau region led them to co-operate.

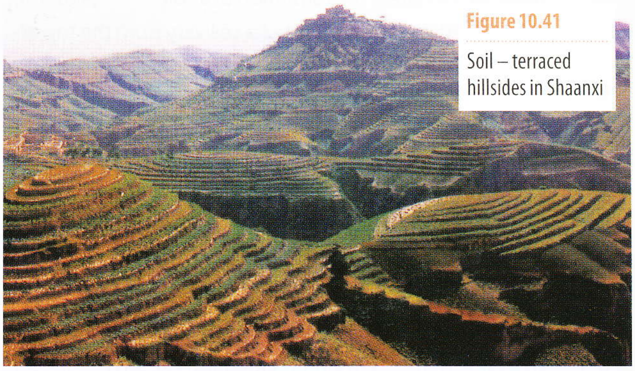


Figure 10.41 Soil – terraced hillsides in Shaanxi

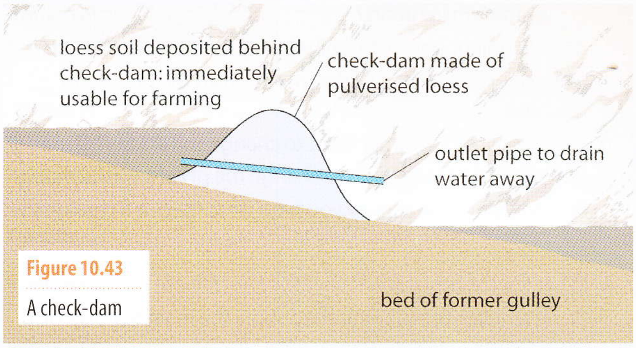


Figure 10.43 A check-dam

Each year more than 4 per cent of the eroded area is targeted for soil and water conservation projects.

The success of the Loess Project can be seen in the huge tracts of land that are now nurturing young forests; the crops grown in newly created fields along valley floors; the reduction in the amount of soil washed into the Huang He or blown towards Beijing in dust-storms; the restoration of an ecosystem; and, within a decade, the quadrupling of the income of local people. The project has helped promote sustainable and productive agriculture and improved the standard of living and quality of life of local people.

Further reference

Bridges, E.M. (1997) *World Soils*, Cambridge University Press.

Courtney, F.M. and Trudgill, S.T. (1984) *The Soil: An Introduction to Soil Study*, Hodder Arnold.

Ellis, S. and Mellor, A. (1995) *Soils and Environment*, Routledge.

Knapp, B. (1979) *Soil Processes*, Allen & Unwin.

O'Hare, G. (1988) *Soils, Vegetation and the Ecosystem*, Oliver & Boyd.

Trudgill, S. (1988) *Soil and Vegetation Systems*, Clarendon Press.

Department of Environment (Malaysia), controlling soil erosion: www.jas.sains.my/doe/new/index.html

Nature journal: www.nature.com/nature/

Soil salinity and erosion control in Alberta, Canada: www.agric.gov.ab.ca/app21/rtw/index.jsp – use search option

UN Convention to Combat Desertification: www.unced.int/main.php

UN Food and Agriculture Organisation, desertification: www.fao.org/desertification/default.asp?lang=eng

Questions & Activities

Activities

1 a i What are the two main components of a soil? *(2 marks)*
 ii Study Figure 10.1 (page 260) and describe how **two** of these factors affect the formation of a soil. *(4 marks)*
 iii Why does the water content of a soil vary from the top of a slope to the bottom? *(4 marks)*
 b What is a 'soil horizon'? *(4 marks)*
 c Choose **one** soil that you have studied.
 i Name the soil.
 ii Draw an annotated soil profile to show the main characteristics of the soil. *(6 marks)*
 d Why do farmers plough their arable land? *(5 marks)*

2 a What can happen to water when it lands on the surface of a soil? *(4 marks)*
 b i What does it mean when 'precipitation exceeds evapotranspiration'? *(4 marks)*
 ii What happens to the soil when leaching occurs? *(5 marks)*
 c Name and describe a soil that results from the process of leaching. *(4 marks)*
 d i Why would a farmer want to change soil acidity? *(2 marks)*
 ii What can a farmer do to change the pH of a soil? *(2 marks)*
 iii How does the activity you have described in **ii** change the pH? *(4 marks)*

3 a What is a 'soil horizon'? *(3 marks)*
 b Draw an **annotated** diagram to show the main features of a brown earth soil. *(5 marks)*
 c What natural vegetation type and climatic type is associated with formation of a brown earth soil? *(3 marks)*
 d Explain the processes by which a brown earth is formed. *(6 marks)*
 e In what type of area would you expect to find a brown earth within the British Isles? *(3 marks)*
 f What effect is a farmer trying to achieve when ploughing a brown earth? *(5 marks)*

4 Choose **one** example of soil you have studied in the field.
 a i Identify the aims and objectives of the study. *(3 marks)*
 ii Describe the main features of the area where the fieldwork was carried out. *(3 marks)*
 iii Explain how the fieldwork was planned before the trip took place. *(3 marks)*
 b Describe the methods used to collect the data (your response should include 'what', 'why', 'where', 'how' and 'how it was recorded'). *(8 marks)*
 c i For **one** piece of analysis you have carried out, explain how the data were sorted to prepare them for analysis. *(4 marks)*
 ii How were results prepared for presentation after the fieldwork trip? *(4 marks)*

5 a Identify and explain the **five** main factors affecting the formation of a soil. *(10 marks)*
 b What is:
 i soil texture
 ii soil structure? *(8 marks)*
 c For **either** soil structure **or** soil texture, describe how you would identify it in a soil. In your answer you should identify equipment used and explain how to interpret the results. *(7 marks)*

Exam practice: basic structured questions

6 a Study Figure 10.9 on page 265.
 i Identify the constituents of soils a, b and c, and suggest a name for each soil. *(3 marks)*
 ii Plot the soil textures from Figure 10.44 onto a triangular graph. *(5 marks)*
 b Explain how soil texture and soil structure can influence farming. *(9 marks)*
 c Identify **two** ways in which a farmer can improve the fertility of the soil. In your answer you should explain the effect of the activity on the farmer's output. *(8 marks)*

7 Study Figures 10.45 and 10.46 which show four soils and their locations.
 a i Describe how the depths of soil vary across this area. *(4 marks)*
 ii Account for the differences that you observed in **a i**. *(6 marks)*
 b Study soil profile B.
 i Describe the humus layer in soil B and explain how it has been formed. *(5 marks)*
 ii Describe the texture of the *A* horizon in soil B and explain how the texture affects farming. *(5 marks)*
 c Explain why a farm on the Charnwood Forest would be different from one on the Lincoln Edge. *(5 marks)*

Sample	Clay (%)	Silt (%)	Sand (%)
d	61	26	13
e	33	7	60
f	8	79	13
g	5	5	90
h	34	36	30

Figure 10.44
Five soil samples

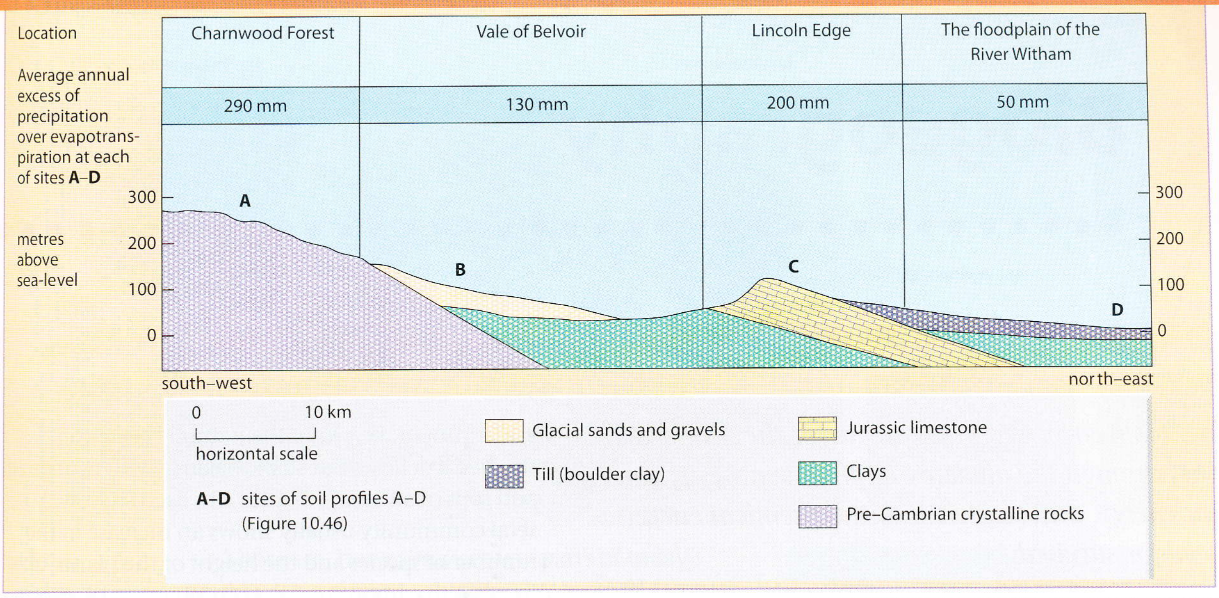


Figure 10.45 Cross-section through parts of Leicestershire and Lincolnshire

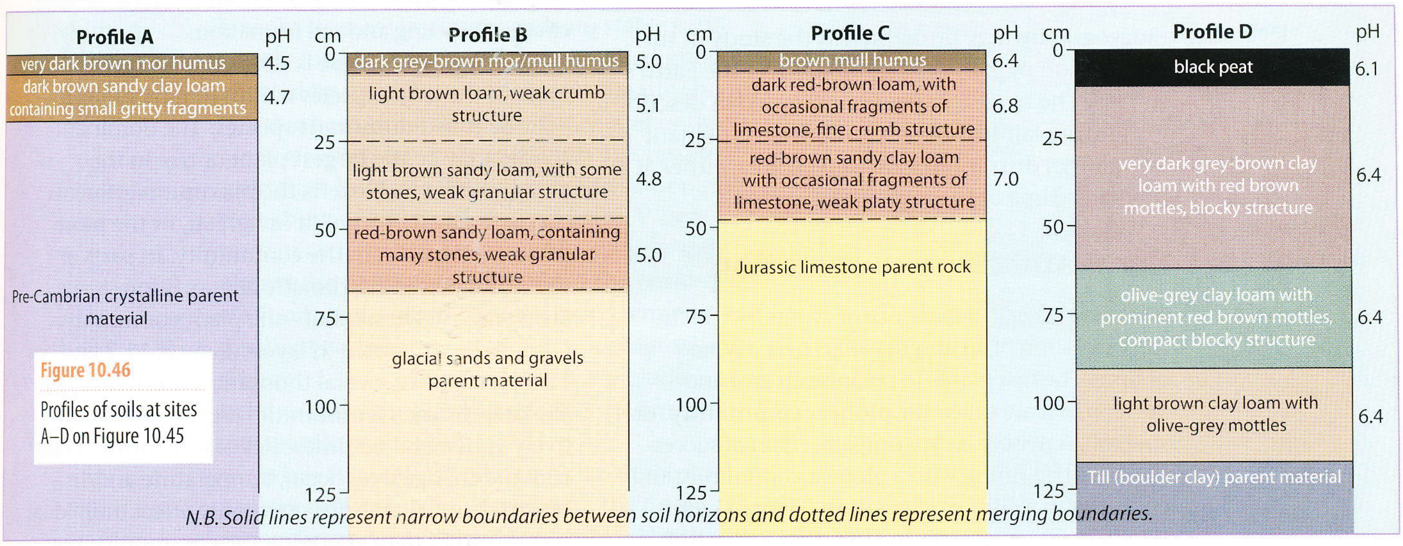


Figure 10.46 Profiles of soils at sites A–D on Figure 10.45

Exam practice: structured questions and essay

8 **a** Using Figures 10.45 and 10.46, identify which of the soils are zonal, azonal and intrazonal. *(4 marks)*

b Select either soil B or soil C.

i Describe the main characteristics of your chosen soil. *(4 marks)*

ii Account for the nature of the *A* horizon in your chosen soil. *(6 marks)*

c Soil D is a peaty gley. Explain **two** aspects of this soil that make it difficult for a farmer to cultivate. *(6 marks)*

d Suggest **two** reasons why soil A is a very shallow soil. *(5 marks)*

9 **a** Why does soil move downhill? *(5 marks)*

b Describe **two** unintended effects of human activity on soils. *(10 marks)*

c Explain **two** ways in which farmers can combat accelerated soil erosion. *(10 marks)*

10 **a** **i** Choose **one** azonal soil you have studied and draw an annotated diagram to show the characteristics of the soil. *(7 marks)*

ii Explain why it is classified as azonal. *(3 marks)*

b Why do geographers and others classify soils? *(5 marks)*

c Identify **one** scientific soil classification system you have studied. Making use of example soils, explain the basis on which the classification is made. *(10 marks)*

11 **a** What is a 'soil catena'? *(3 marks)*

b Explain how and why soil depth varies down the slope of a catena. *(7 marks)*

c Peat can develop in both the upland and the lowland areas of a soil catena.

Explain how this happens, making reference to the differences in the nature of the peat in the two areas. *(15 marks)*

12 With reference to countries at different stages of development, explain why farmers need to manage their soils more carefully if farming is to be sustainable. *(25 marks)*