Appendix 1. Glossary and index to glossary

Acidity: All soils with a pH below 7 are acid. However, the growth and yield of most plants is unaffected until the pH drops below about 5. As pH levels drop and the soil acidity increases, plant growth and yield decline.

Soil acidity occurs naturally in some soils, but agricultural practices have contributed to the increasing acidification of many naturally neutral to slightly acid soils. These practices include:

- use of ammonium fertilisers, particularly ammonium sulfate
- production of legumes that fix nitrogen, which is often leached, rather than taken up by plants
- removal of nutrients in the form of produce, without replacing them in the soil.

Aeration: Plant roots require oxygen to grow. In saturated soil, air cannot circulate from the atmosphere through the soil. Once the roots have used up the oxygen in the soil pores, it cannot be replaced. This means that under waterlogged conditions most plants will begin to suffer after a couple of days. The exceptions are plants like rice and mangroves, which have passages from the aerial organs to the roots, allowing the roots to live in waterlogged soils. In waterlogged conditions, anaerobic organisms (those that do not need oxygen) multiply and cause nitrogen to be lost as gas.

Aluminium: Aluminium (Al^{3+}) is a component of clay, and it becomes soluble in acid soils with a pH less than 5. Below pH 4.5 it becomes available in toxic amounts, and may severely restrict plant growth or even kill plants. The best way to control aluminium toxicity in soil is to maintain the soil pH above 5.

Anion: Anions are negatively charged particles (ions) such as chloride, sulfate and nitrate. See ‘Clay minerals’ and ‘Soil solution’.

Available nutrients: Available nutrients are nutrients that are in the soil solution (that is, the water in the soil), or are loosely attached to clay and organic matter as exchangeable ions. As such, they are readily available for plant use, unlike nutrients that are adsorbed or fixed in the soil and not available for plant use. See ‘Cation exchange capacity’ and ‘Clay minerals’.

Available water: See ‘Water’.

Calcium: Calcium is an important plant nutrient as well as an important cation in soils. Calcium has two positive charges, and is attracted strongly to clay. This attraction means that calcium holds clays together. It causes flocculation (clumping together) of wet clays, and this is important for good soil structure. Gypsum or lime, which are both calcium salts, are often used to obtain this effect. Calcium works against the dispersion that occurs when a soil is high in sodium. See ‘Cation exchange capacity’.

Cation exchange capacity (CEC): Cation exchange capacity is the term used to describe the capacity of the soil to hold ‘exchangeable’ cations. These cations can be held on the exchange sites of clay minerals, or by organic matter. CEC is therefore a measure of the soil’s ability to hold nutrients for later use by plants. In a soil with a low CEC, where there are not many exchange sites, nutrients are easily leached below the plant root zone, and lost to plant use. A soil with a high CEC is therefore more fertile than a soil with a lower CEC.

Cation: Cations are positively charged particles of atoms or molecules. The most important in soils are calcium, magnesium, sodium, potassium, aluminium, silicon, iron and hydrogen. The ratios of these cations, as well as the amounts of the various cations present, are important for plant nutrition and the structure of the soil. See ‘Sodicity’, ‘Cation exchange capacity’ and ‘Acidity’.

Clay: Clay is the smallest of the particles that make up soil. Clay particles are less than 0.002 mm in diameter. See ‘Clay minerals’ and ‘Texture’.

Clay minerals: Clay minerals are aluminium silicates that have a sheet or layer structure dominated by the anions oxygen and hydroxyl. The cations aluminium, magnesium, iron and silicon occupy the cavities between the anions. These minerals usually have a net negative charge because of the arrangement of the anions and cations. There are three broad groups of clay minerals that are important in soils: kaolins, illites and smectites. These do not normally occur alone; mixtures of clay minerals are very common.

Compaction: When a soil is wet it loses strength, and can behave like plasticine. For example, a wet harvest can easily leave a clay soil with wheel ruts 15 cm deep, complete with tyre tread marks. If the subsoil is wet, compaction can occur at depth even though the topsoil is dry. When a soil is compacted, there is often a near-complete loss of pore spaces, and the soil structure is severely damaged. Ploughing when the soil is too dry causes another form of compaction, particularly on loamy soils. (See ‘Texture’.) This operation may pulverise the soil, creating dust that packs into the soil pores after rain or irrigation. Again, the result is decreased pore space and damaged soil structure.

Consistence: Consistence refers to the way a soil behaves when you try to break it. Is it brittle, crumbly, labile or plastic? Consistence depends on the moisture content, so it is a good way to test whether the soil is the right moisture content to work without causing structural damage.

Crusting: Soil crusts are hard surface layers up to 1 cm thick, and with very fine or no shrinkage cracks. They occur mainly on bare soil when soil aggregates are broken down into particles by the force of raindrops, or by rain and wind erosion.

The particles fill the air spaces between the remaining aggregates and seal the surface of the soil. This reduces water and air entry, and restricts seedling emergence. Soils high in fine sand or silt, and low in cracking clay and organic matter, are most prone to crusting.

To avoid crusts, try to keep a cover on your soil such as pasture, crop or crop stubble. The vegetation breaks the force of raindrops, and prevents soil from breaking into particles. Adding organic matter helps the particles in crusted soils to form aggregates, allowing water and air to enter the soil pores. Reducing cultivation may also help to reduce the severity of crusts.

Cultivation: Our ancestors introduced the technique of soil cultivation from Europe. The principles of cultivation are to turn and break down the soil to a fine tilth, to eliminate weeds and to provide the ideal environment for the germination of seeds. This system has been used for centuries in Europe, where topsoils are deep, rainfall is high and organic matter takes much longer to break down in the cooler temperatures.

In Australia, regular intensive cultivation by this system has degraded the soil structure. Our soils are much older, our climate is hotter and drier, and organic matter breaks down quickly.

When you are considering cultivation it is important to consider the moisture content of the soil. This determines whether cultivation will produce a good soil tilth. A quick, simple test that can be carried out by hand is described under 'Moisture content'.

Advantages of cultivation

- **Controls pests and weeds.** Plants grow best in soils without weeds, insect pests and diseases. Strategic cultivation helps to control these and break the life cycles of harmful pests. Decide on the timing, type and depth of cultivation by knowing and monitoring the life cycle of the target pest or disease.
- **Breaks down plant residue.** Strategic cultivation breaks plant and animal matter into smaller pieces and mixes them into the soil, where micro-organisms can process them and release nutrients into the soil for plant use.
- **Breaks up crusts.** Strategic cultivation breaks up crusts and plough pans, and introduces channels and cracks that encourage the movement of water, air and roots through the soil.
- **Reduces soil strength.** Cultivation can reduce soil strength. This will greatly help to increase plant growth. Plant growth in harder soils (those with high soil strength) is slower than that in 'softer' soils (those with lower soil strength). This is partly responsible for the slow early growth in direct-drilled soils.
- **Creates a rough surface.** This can help to retain moisture.

Disadvantages of cultivation

- **Breaks down soil structure.** Too much cultivation can shatter the soil aggregates, so that fine soil particles break off and block soil pores. This causes the soil surface to crust or seal, thus preventing water from entering. This in turn decreases water storage and plant growth. By removing plant cover, cultivation exposes soil to the impact of raindrops and flood irrigation, which can cause aggregates to slake, again leading to surface sealing. Regular cultivation also reduces organic matter levels; this contributes to soil structural decline.
- **Forms plough pans.** Continued ploughing at the same depth, or ploughing when the soil is too wet, often leads to the development of a hard, compacted soil layer immediately below the plough depth. This plough pan restricts air and water movement and root growth, and may need expensive ripping or non-inversion cultivation to break it up.
- **Reduces the numbers of soil organisms.** Cultivation quickens nutrient cycling in the short term, but in the long term it runs down the total organic matter and reduces micro-organism activity. Continued cultivation depletes the numbers of earthworms and

mycorrhizal fungi, and destroys natural channels and cracks in the soil. Earthworm and micro-organism populations increase when pasture is grown for four to five years with a crop rotation.

Alternatives

Cultivation may be needed initially to improve the soil's productivity, but it is not sustainable on a long-term, regular basis in most soils. You need to develop management techniques that keep cultivation to a minimum. Reduced cultivation results in better infiltration, root growth and water storage. The list below gives some options that can help you to keep cultivation to a minimum.

- Use 'gentle' cultivation methods. For example, use a roller to break down clods as opposed to dragging harrows. Avoid aggressive cultivation methods such as wideboards, scrapers and other implements that pulverise the soil.
- When you are using implements that invert the soil (that is, those that have sweeps or discs, keep cultivations shallow (< 5–7 cm).
- When cultivating below 7 cm, use non-inversion tillage.
- Grow plants that are not attacked by a particular pest or disease, so that cultivation is not needed to break the cycle.
- Use a pasture–crop rotation in which pasture is grown for four or five years and then followed by a crop.
- Use tined implements rather than discs. Discs reduce ground cover faster.
- Use reduced cultivation techniques, such as high clearance chisel ploughs, herbicides, rotations and sowing into pasture or standing stubble.
- Use planters that won't disturb the soil. Soil disturbance should be limited to the slot in which the seed or seedling is planted. Presswheels behind the planting boot firm the disturbed soil and give good contact between the seed or seedling and the soil.

Cultivation equipment:

Deep ripper

Deep rippers or subsoilers break up the compacted soil below the depth reached by conventional cultivation, and therefore improve drainage and aeration. There are several types of deep rippers, and they can reach 30 to 90 cm into the soil. Most have slanted tines or a sharply angled leading point to lessen the power required to pull them. This design also helps to lift and shatter the subsoil, breaking up any compacted layers.

Non-inversion ploughs are a type of deep ripper designed to rip through the soil without causing the aggressive disturbance and inversion of the soil that results from deep ripping. The ploughs usually have narrow, strong tines 30 cm apart that reach 10 to 30 cm into the soil. They include the Agrowplow®, the Paraplow® and the Agtill®.

Soil should be reasonably dry when it is deep ripped. (See the tests under 'Moisture content'.) Ripping wet soil does not shatter the subsoil and can smear and seal the soil beside the ripper tine. Smeared surfaces can prevent air, water and roots moving through the soil.

Chisel plough

Chisel ploughs are used to shatter but not turn the soil. They work on the same principle as rippers, but in the top 30 cm of the soil. Again, the soil must be dry to moist; otherwise the plough will smear and seal soil surfaces.

Disc ploughs and offset discs

Disc ploughs break up undisturbed soil by inverting it to bury surface weeds and trash. Regular use of disc ploughs reduces soil aggregates to small particles and produces a compacted layer or plough pan that prevents air, water and roots penetrating the subsoil. When it rains, soil particles on the surface collapse together to form a crust, which repels air and water and is difficult for seedlings to break through.

Mouldboard plough

The mouldboard plough is shaped to cut and turn over soil to bury surface residue. It is rarely used in Australia's shallow topsoils, because it brings up the less fertile subsoil. A shallow mouldboarding (to 10 cm) is sometimes a successful way of incorporating stubble. However, it has been used successfully where hardsetting or crusting occurs, to bring up swelling and shrinking clay subsoil in order to improve topsoil structure. This is an alternative when the clay subsoil is sodic. Gypsum is usually applied to the cultivated soil in these circumstances.

Harrows

Harrows are used for seedbed preparation and light surface cultivation to remove weeds after seeding. If they are used regularly they will break down and pulverise the soil structure. This is evident when large amounts of dust are produced while harrowing. A roller trailed behind cultivation implements does less damage to the soil structure than harrows.

Rotary hoe

Rotary hoes aerate the soil and provide a fine seedbed. However, in the process, the rotating shoes compact the soil underneath the level they are aerating. They also seriously damage the soil structure by pulverising the seedbed. This leads to crusting and compaction if the soil is rotary hoed when wet. Frequent rotary hoeing is one of the quickest ways to cause soil structural decline.

Dispersion: Dispersion is the breakdown of soil clay minerals into single particles in solution. The opposite is flocculation. Dispersion occurs when the bonds in a soil are not strong enough to keep the particles together. This is usually because a soil has too great a proportion of exchangeable sodium in it, or is too low in organic matter. However, working a soil too wet or too dry can also increase its tendency to disperse on wetting. This is especially true of a soil that is low in organic matter. Salinity can mask the tendency of a soil to disperse. Check if your soil is dispersive by dropping small air-dry aggregates (3 to 5 mm diameter) into a saucer of rainwater. Be careful not to bump the dish, as movement will encourage dispersion. If the water turns cloudy within two hours, the soil is highly dispersive and will probably respond to gypsum or lime. Building up organic matter with, for example, a pasture phase, will also help to overcome dispersion in the soil. See also 'Sodicity' and 'Soil moisture'.

Drainage:

Drainage is an important issue, because most plants cannot survive waterlogging for more than a short time. Swamp plants such as rice are obviously exceptions, but most plants need at least 10% to 15% of the soil pore space to be filled with air to survive. Salinity is also an issue related to drainage, as it has an impact on rising watertables.

A soil becomes saturated when its pores fill with water. Once the soil is saturated, root growth in most plants can occur only on the surface. When there is more water than the soil pores can hold, the water will collect on the soil surface and drain by gravity to the lowest point. Surface drains merely remove this excess water.

Surface drainage

Surface drainage in irrigation should allow a paddock to be irrigated and then to drain away free water at the soil surface within 24 hours, (preferably 15 hours). Adequate surface drainage depends upon the slope, the run length (bay or furrow) and the irrigation layout. You may need to take any combination of these factors into account when you are planning for good surface drainage. Surface drainage is particularly important when soils have relatively poor permeability. Raised beds or hills used in irrigation are an effective method of improving surface drainage

Subsurface drainage

Subsurface drainage reduces the watertable below the root zone and is used for areas where surface drainage is not effective.

Tile drainage. The system uses slotted pipe ('tile') or other ready-to-use drainage systems. The pipes are surrounded by sand or gravel to prevent fine soil particles from being carried into the drain, and to improve the flow of water and bedding conditions for the pipes. The deeper the drain the better: it should be at least a metre below the surface, with a minimum grade of 1:1000, but preferably steeper. The spacing of the drains depends on the soil and the depth of drain.

Mole drainage. Mole drains are used to reduce waterlogging in heavy clay soils on flat country. They are unlined channels formed with a cylindrical foot attached to a vertical leg. The foot is pulled through the soil at a depth of about 60 cm below the surface with a trailing expander 9 cm in diameter, creating a smeared surface on the mole drain. The leg creates a slot that directs excess water into the mole drains and from there off the paddock. This system intercepts potential additions to the ground water, lowering the watertable in irrigation areas. Mole drains may not be stable in sodic soil, and only last for a couple of years under the best conditions. They also need interception drains to feed into, but they do drain quite good quality water compared with the deeper tile drains. They are used successfully in some irrigation areas, but are of limited use elsewhere.

Duplex soil:

A duplex soil is one that has a sand, silt or loam topsoil over a clay subsoil. These soils may have restricted drainage, or lateral drainage at the top of the subsoil because of this texture change. A red brown earth is an example of a duplex soil.

Earthworms:

Little is known about the behaviour of earthworms in Australia, but we do know that they benefit the soil. These benefits include increased nutrient availability, better infiltration and drainage, and a more stable soil structure. All of these benefits help to improve farm productivity.

Earthworm casts cement the soil particles together in water-stable aggregates. These are able to store water without collapsing. Earthworms that leave their casts on the soil surface rebuild topsoil. In favourable conditions they can bring up about 50 t/ha annually, enough to form a layer 5 mm thick.

Electrical conductivity (EC): EC is a measure of the concentration of ions (both cations and anions) in the soil solution.

Another name for the concentration of ions in solution is salinity. EC units are microSiemens per centimetre (µS/cm). These units relate directly to deciSiemens per metre (dS/m) and parts per million (ppm) of total dissolved solids in mg/L. For example, 1 dS/m = 1000 EC (µS/cm) = 640 ppm.

Evaporation: Evaporation removes water from the soil by heating it and vaporising it into the air. If the soil is very wet, water loss by evaporation is rapid. However, as the soil dries, evaporation becomes increasingly slower. This is because it is more difficult to transmit water from the deeper layers to the surface, where evaporation occurs. Consequently, the surface layer of the soil becomes air dry, and the radiation, which would have caused evaporation, now heats the soil and the air above it. Living plants and mulches slow down evaporation. Ploughing exposes moist soil, increasing evaporation.

At times of high evaporation, it is better to have one large irrigation or rainfall event than a series of smaller ones. This is because when the soil surface is dry, small amounts of rainfall or irrigation penetrate only the surface layer, and so evaporate easily. A large rainfall event or irrigation penetrates deeper into the profile; some water evaporates, but the rest is available to plants.

Exchangeable sodium percentage (ESP): The exchangeable sodium percentage is simply the amount of exchangeable sodium in a soil expressed as a percentage of the total exchangeable ions in the soil. An ESP of more than 5 defines a sodic soil.

Fertilisers: ‘Fertiliser’ is the general term given to a product that adds nutrients to the soil. All fertilisers sold in New South Wales have to be registered with NSW Agriculture under the Fertilisers Act. (The Act also covers liming materials and gypsum.) Products that are not registered cannot be sold as fertilisers. This is to make sure that all fertilisers conform to minimum nutrient requirements.

Manufactured fertilisers

Manufactured fertilisers are produced synthetically in factories where raw materials are treated to create new chemical compounds. Superphosphate, for instance, is produced from rock phosphate and sulfuric acid. Most manufactured fertilisers contain inorganic nutrients that are readily available to plants.

Manufactured fertilisers short-circuit the nutrient cycle and can rapidly boost plant growth. Their big advantage is that the amounts of nutrients can be better controlled than in organic fertilisers. Their solubility, however, can cause problems. Nitrate, for instance, is easily leached through the soil into ground water.

Compound or NPK fertilisers contain nitrogen, phosphorus and potassium, and may contain useful amounts of other nutrients. The percentage of the three major elements is shown on the bag.

Special purpose blends are NPK compound fertilisers formulated to suit a particular crop's demands. Because our soils are generally low in phosphorus, fertilisers that provide phosphorus are the type most often used in Australia.

Organic fertilisers

Organic fertilisers are derived from the decomposition or digestion of plant or animal materials, including plant composts, composted manures and animal by-products. Nutrients in the organic form must be converted by micro-organisms in the soil to inorganic form before they can be taken up by plants. As a result they are often released at a slow and uneven rate. The nutrient content varies greatly, depending on the fertiliser source, so it is more difficult to predict the effectiveness of organic fertilisers. Slow nutrient release can be an advantage, especially in sandy soils that are easily leached.

Organic fertilisers can help to maintain the soil structure if they are used in sufficient quantities. As soil organisms break raw organic matter down, they produce a relatively stable form of organic matter called humus. Humus is important in binding soil aggregates and promoting water entry through pores. Humus also plays an important role in holding plant nutrients and controlling soil acidity changes.

Naturally occurring fertilisers

Naturally occurring fertilisers are minerals found in nature that contain valuable plant nutrients. Some naturally occurring fertilisers are found in rock form, for example, rock phosphate.

Selection and application

Before starting a fertiliser program you need to consider your soil type, the existing pH and nutrient status, and the form and amount of fertiliser required.

Test your soil regularly to check the pH and nutrient levels. This information will help you to decide what form and quantity of nutrients you need. Long-term use of fertilisers may affect pH and nutrient levels. High levels of organic matter buffer the effect of fertilisers on pH.

Soil can hold only a certain quantity of nutrients. This amount varies with the soil type: sandy soils hold less than clay soils. Negatively charged colloids of clay and organic matter hold positively charged nutrients (cations) with electrical forces. If there are too many cations for the colloids to hold, the rest stay in the soil water and drain away with the water (that is, leach). Some negatively charged nutrients (anions) such as nitrate also stay in the soil water and readily leach if they are not taken up by plant roots.

Nutrient movement

- Nitrogen converts to nitrate (NO_3^-) in the soil and is dissolved in solution, so it is easily leached away.
- Sulfur converts to sulfate (SO_4^{2+}) and also leaches.
- Potassium, calcium and magnesium are loosely held by clay and organic matter as exchangeable cations.
- Phosphorus reacts with clay very soon after application, so that it is fixed in the soil.

- The rule to remember with soluble fertilisers is to apply small amounts regularly, rather than a large amount occasionally. Plants can use only a fraction of any large amount applied, so most will be leached away. This is not only a waste of fertiliser and money, but it also possibly pollutes ground water and surface waters and may contribute to the development of algal blooms. Organic fertilisers can be applied in larger amounts less often, as they release nutrients more slowly, but you still need to be careful how you use them.

Flocculation: Flocculation refers to the clumping together of particles in solution, and is the opposite of dispersion. In soils, the presence of calcium tends to flocculate clays, maintaining structure, while sodium tends to disperse clays in solution. Gypsum and lime, both calcium minerals, are used to achieve flocculation in some sodic soils.

Gleying: 'Gleying' is a term used for the reduction of iron that removes the reddish and yellowish iron minerals and reveals the greyish colour of the clays. Gleying is a sign of severe waterlogging, and gleyed soils often have a bluish or greenish tinge.

Gypsum: Gypsum (calcium sulfate) occurs naturally as crystals in several areas in New South Wales and is mined. This gypsum is of variable quality and contains impurities. It is often quite lumpy nd coarse, and is therefore slow to dissolve and difficult to spread.

Gypsum is also available as a by-product of phosphate fertiliser production (phosphogypsum), or of hydrofluoric acid production (calcium sulfate anhydrite). These forms are generally of higher quality than mined gypsum. Phosphogypsum contains a small amount of phosphorus and is the most soluble form. However, it may have a high water content, which can cause spreading problems.

Calcium sulfate anhydrite has the highest purity of commercially available gypsum, but it tends to go lumpy if it is in contact with water before being mixed into the soil. It needs to be placed on dry ground, covered immediately and incorporated into the soil as soon as possible. This type of gypsum also contains small amounts of fluoride, mostly as the highly soluble calcium fluoride.

Gypsum is used as a soil-softening agent on sodic soils. It works in two ways:

- It creates a salt solution in the soil water, and clays tend not to swell or disperse as much in salt solutions. This is a short-term effect that occurs only until the gypsum is leached.
- The calcium cations in gypsum replace the exchangeable sodium cations on the clay. By this process a sodic clay is changed to a calcium clay, which is less prone to swelling and clay dispersion. The displaced sodium cations are leached below the plant root zone. This effect lasts long after the gypsum has dissolved.

The calcium effect can also be achieved with lime on acid sodic clays, but the lime has to be cultivated into the soil, and the soil should not be alkaline.

You can check if your clay soil is sodic by dropping small air-dried aggregates (3–5 mm diameter) into still rainwater and leaving them for two hours. If the water turns cloudy the soil may respond to gypsum application. See also 'Sodicity'

Hardsetting: Hardsetting refers to a soil in which the surface horizon sets hard when dry. Hardsetting soils are high in fine sand and/or silt and/or an easily dispersed swelling clay such as illite. They are also low in organic matter. Cultivation can make hardsetting worse, especially if the soil is too dry, because it encourages the breakdown of organic matter and mechanically pulverises the soil. See ‘Texture’, ‘Moisture content’ and ‘Compaction’.

Hydraulic conductivity: Hydraulic conductivity is a measure of the movement of water through the soil profile. It determines where the water goes after infiltration, and how quickly. The hydraulic conductivity depends largely on the soil texture and structure; it reflects the size, arrangement and number of pores.

Illite: Illites are clay minerals. Another name for them is clay micas. They are the dominant clay minerals in most of the red brown earths, solonised brown soils, calcareous red earths, and terra rossa soils of southern Australia. In general, they are very stable clay minerals. Illites vary in their ability to swell, and are generally more prone to dispersion than kaolins and smectites. Hardsetting soils often have a high proportion of illite in their clay fraction.

Infiltration: Infiltration refers to the movement of water from outside the soil, through the soil surface, and into the soil profile. Many clay soils have a very high infiltration rate when dry because they have large cracks. This helps with water storage, because the water can soak deep into the profile where storage takes place. The cracks close up as the soil wets, so that moisture is stored out of range of evaporation, but still within the plant root zone. In non-cracking soils, old root paths and larger pores such as ant or worm holes are very important for infiltration.

Ion: Ions are electrically charged particles made up of atoms or molecules. Cations are positively charged ions. Anions are negatively charged ions.

Irrigation: Flood and furrow irrigation are the most common methods of irrigation. In both cases, free water is supplied to the surface of dry soil. Water enters dry soil more quickly than wet soil. Many clay soils have a very high infiltration rate when dry because they have large cracks. However, after this initial infiltration, clay soils take in water very slowly because the hydraulic conductivity of the wet, swollen surface layer is very low. As long as there is free water above the ground surface, water continues to enter the profile, no matter how slowly.

Kaolin: Kaolin is the most weathered of the clay minerals, and has virtually no swelling potential. This type of clay is commonly called china clay, and is used in ceramics and pottery because of its inert nature. Soils dominated by kaolin clay occur mainly in areas of high temperature and rainfall. These soils are generally acidic due to the weathering process. This is because hydrogen and aluminium cations take up the exchange sites after the other cations are leached away. Kaolin clay soils are frequently strongly structured, with good infiltration and drainage. See also ‘pH’ and ‘Cation exchange capacity’.

Landforming: Landforming is an earthmoving process whereby the natural topography is changed to suit a particular purpose, such as surface irrigation. Landforming has two main effects on soils:

- an immediate effect on soil structure
- a longer term effect of removing topsoil in some areas and filling in others. This may create management problems and cause yield losses.

Choosing soils for landforming development

When you are choosing an area to develop, consider the topography and how much landforming will be required. Then carefully examine the soils, paying particular attention to the depth and structure of the topsoil, and the structure of the subsoil.

Poor topsoil structure is easily observed when the soil dries out. The most common forms are crusting, hardsetting and cloddiness. Subsoil structural degradation is harder to identify, but can show up in bent or stunted roots. Damaged soil may have coarse, platey clods, or, in the worst cases, may appear as a featureless mass.

When you are choosing country for landforming:

- avoid soils where the topsoil is shallow (less than 10 cm) or highly variable over the area
- avoid areas where the topsoil and/or subsoil structure is poor, especially if extensive cutting is required.

Effect on soil structure

Any kind of work carried out on soils affects soil structure. The effect is not necessarily harmful—ploughing is often beneficial. The most important factor that determines the benefit or harm done by working the soil is the moisture content. Clay soils are often worked when too wet, leading to smearing and compaction. Loams, on the other hand, are often pulverised when worked too dry, creating dust that blows away in the slightest wind.

There are enough problems to manage when landforming without the long-term cost and degradation caused by damaging the soil structure. To avoid damaging the soil structure, take 10 minutes to assess the soil moisture content. It is easy to assess soil moisture content by hand using the method described under ‘Moisture content’.

Cutting and filling

The effects of cutting and filling depend very much on the soil type. In general, though, there are two important changes in soil with depth:

- a change in soil structure
- a change in nutrient availability.

These two factors are the main causes of patchiness in crops growing in landformed soils. In most soils, the structure is poorer with depth, and the topsoil contains most of the nutrients. So it is best to keep cutting and filling to a minimum, because the deeper the cut, the worse the problem.

Patchiness can be overcome in some soils by gypsum application and the use of heavier rates of fertiliser. Adding organic matter also helps. However, the most successful long-term strategy is often topsoiling. Topsoiling is expensive in the short term, but, compared with not topsoiling, the yield responses usually make it more attractive in the long term.

Lime:

Lime is crushed and sieved limestone (calcium carbonate), and is most commonly used on strongly acid soils to make them more alkaline. The carbonate in lime neutralises the acidity in soils and so raises the pH. However, lime may also be useful on some acid sodic soils, because of its calcium content. Good quality lime contains 37% to 40% calcium.

There are several liming materials available, but agricultural lime is usually the most cost effective for correcting acidity. To be most effective the lime needs to be crushed very finely and incorporated into the soil. The finer the particles the faster they react with the soil. See also 'Gypsum' and 'pH'.

Magnesium:

Magnesium is an important part of chlorophyll, the green colouring material of plants. It is also vital for photosynthesis, the process that converts the sun's energy into food for the plant. Magnesite or Epsom salts can overcome magnesium deficiency. However, an excess of exchangeable magnesium in a sodic soil can worsen the dispersion caused by exchangeable sodium. See also 'Sodicity'.

Micro-organisms:

Micro-organisms (or microbes) include bacteria, actinomycetes, fungi, algae and protozoa. There are hundreds of millions of micro-organisms in a spoonful of soil, most of them of benefit to plants and soil. They are important for soil structure, as they form organic bonds that hold soil particles together. They also release carbon dioxide and energy as well as mineral nutrients that plants can use. They do this because they derive their energy by breaking down plant and animal material. When they die they decompose and release more nutrients for plant use.

The type of organic matter present influences the microbial activity in the soil. Material high in lignins and tannins (from hardleafed plants such as eucalypts) takes much longer to break down than less fibrous plants such as most vegetables. When plants with high levels of protein decompose, some micro-organisms change the protein to ammonium. Other microbes then change the ammonium to nitrate, the form of nitrogen plants can most readily use.

Microbes tend to favour higher temperatures, though some cannot survive the very high temperatures caused by fire. They are also more active in moist soil than dry soil because they take their nutrients in solution (in water). Microbial activity is influenced by pH; it slows down in very acid or very alkaline soil. Finally, most microbes need oxygen, though some are anaerobic and thrive in waterlogged conditions.

Moisture content:

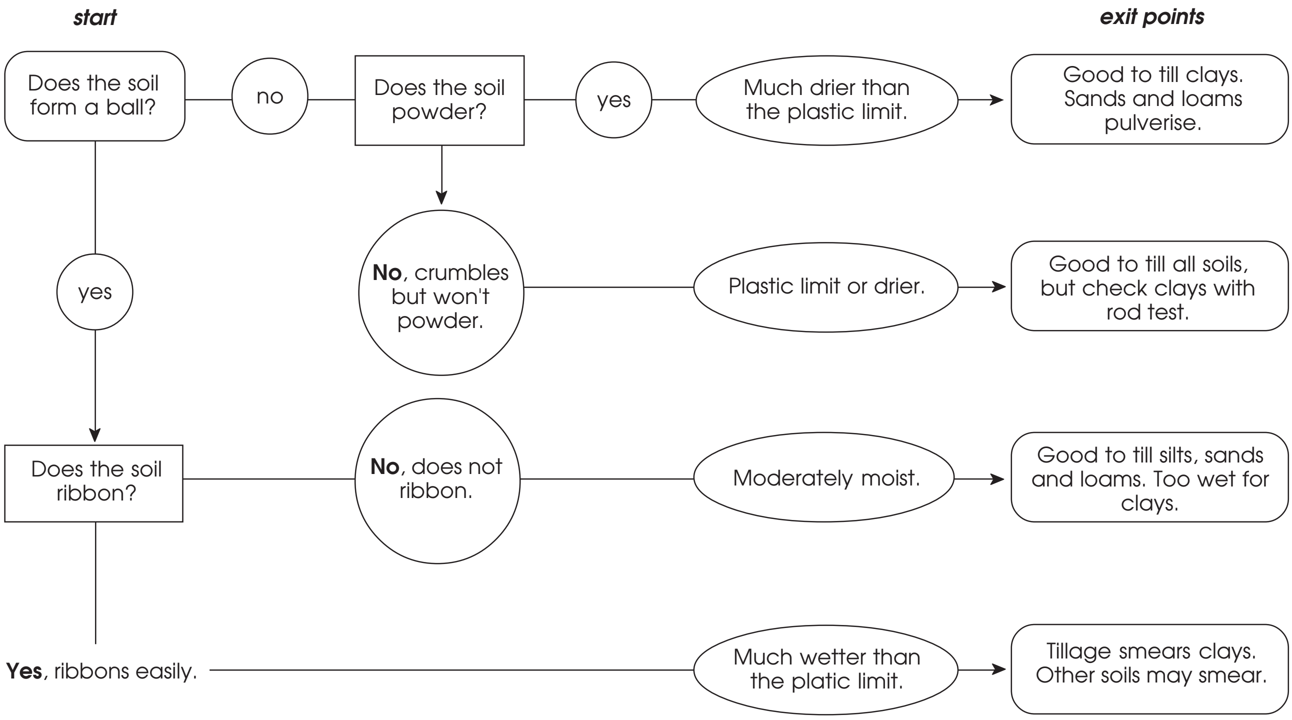
Moisture content affects soil strength, aeration, temperature, consistency and infiltration. It is an important soil property to observe, especially when you are planning tillage operations.

A simple and effective way to test soil moisture content for tillage is to mould some soil in your hand. See if it will form a ball, then try to form a ribbon, and finally try to roll it into a thin (3 mm diameter) rod. You need not always follow the test all the way through; the test has several exit points where it is obvious that there is no need to continue. (See next page.)

Will the soil form a ball?

Take a handful of soil—it could be one lump or some loose soil—and try to squeeze it into a ball with your hand. A dry soil will not form a

Moisture content chart



ball, but will break into smaller fragments or powder; in this case the soil is drier than the plastic limit. A very compact lump will not break, of course. You can safely till a clay soil at this moisture content: it will shatter and will not smear. A silty or loamy soil is too dry to till: it will pulverise, damaging the soil structure.

Will the soil ribbon?

If the soil forms a ball, place the ball between your thumb and forefinger and squeeze, sliding your thumb across the soil. If a ribbon forms, the soil is much wetter than the plastic limit. Tillage will smear a clay soil at this moisture content, damaging the soil structure.

Will the soil form a rod?

This test applies to clay soils. Not all soils form a rod. A soil needs a fair amount of clay to make it plastic enough for you to remould it into a rod. The rod test is a useful way to further test the moisture content of a clay soil that crumbles but does not powder. (See the flow chart.)

If the soil forms a ball, roll it on a flat surface to form a rod 3 mm thick. If it is just possible to form a rod, then the soil is at the plastic limit. If the soil crumbles before you can form it into a 3-mm rod, then the soil is drier than the plastic limit. If you can form a rod easily, the soil is wetter than the plastic limit and tillage will smear the soil.

Mulch:

Mulch is a layer of material (usually organic) that sits on top of the soil. Some heavy clay soils are actually self-mulching in that they form a layer of loose granules on their surfaces that acts as a moisture and temperature mulch. Mulch has several functions:

- It reduces evaporation, thereby conserving soil moisture. Less water is lost, reducing the watering required by up to 70%. In low lying, protected areas, mulching may make soils extremely wet.

- It modifies soil temperature. The effects of mulch on soil temperature are complex, but in general terms it reduces the extremes of hot and cold. The effects of mulch are affected by the amount of moisture in the soil. Organic mulches tend to cool the soil.
- It reduces weed growth. A thick mulch helps to control weeds by smothering them.
- It adds organic matter. A mulch of organic matter, such as straw, leaves and bark, will eventually break down and improve the humus content of the soil.
- It protects and improves the soil structure. Mulch protects the surface from such structural damage as crusting or hardsetting after heavy rain or watering.

Mycorrhizae:

Mycorrhizae are soil fungi that act as extensions to plant roots, helping roots take in more nutrients. They start life as inactive spores, which germinate and send out fine strands called hyphae. The hyphae move into plant roots and enter cell walls. They act as rootlets and greatly increase the amount of nutrients available to some plants, particularly phosphorus and zinc.

They also improve soil structure by binding soil particles into aggregates. However, there are only a few plant species that are known to use them. These are mainly cereals such as wheat, oats and barley.

Some plants cannot get enough nutrients, particularly phosphorus and zinc, from their roots alone, and rely on mycorrhizae to infect the roots and grow into the soil. The fungi in turn take their metabolites from the plant roots. While growing, mycorrhizae produce spores. If these spores germinate and cannot find any plant roots they will gradually die out. Fallowing causes them to die out, as do excessive tillage and soil fumigation. Some plants, such as canola, do not need mycorrhizae, so the spores tend to die out when these crops are grown.

Growing crops as often as the soil moisture allows helps to keep mycorrhizae populations active. Maintain high populations by growing crops that host the fungi, reducing tillage and avoiding long fallows. Plants growing with mycorrhizae are generally healthy and more able to resist disease, and are particularly resistant to root rots. Scientists believe that mycorrhizae may check disease fungi.

Nitrogen:

Nitrogen is a key element in plant growth. Plants take nitrogen from the soil during the growing season, and this nitrogen is harvested mainly as protein. Nitrogen has to be replaced after a crop is grown. Soils high in organic matter are generally higher in nitrogen too. Nitrogen needs to be converted into inorganic form, mostly nitrate, to be available to plants.

You can replace nitrogen by: using a fallow, which allows microbes to mineralise the nitrogen in the soil; growing a legume, which fixes nitrogen from the air into a form available for plant growth; or adding fertiliser. However, nitrate leaches from the soil easily, so take care with fertiliser application timing and rates. When nitrate leaches, excess hydrogen ions are left in the soil. The more hydrogen ions in the soil, the more acid it becomes. Also, nitrate may leach into the ground water, contaminating it.

Organic matter:

Soil organic matter consists of any living or dead plant and animal material. Organic matter is important for both the chemical and the physical properties of the soil. Organic matter makes bonds between soil particles, creating and maintaining soil structure. It also contains nutrients that are essential for plant growth. However, plants cannot take up nutrients in their organic forms. The soil provides the environment and the microbes to change the nutrients into plant-available inorganic forms.

The rate of decomposition of organic matter depends on the environment within the soil. The warmer and wetter the climate, the faster the rate of organic matter addition and breakdown. Organic matter eventually decomposes to humus, a dark crumbly material that cannot be broken down any further and is the basis of a soil's natural fertility because it allows the recycling of nutrients. Humus has a colloid structure. The colloids have negative charges that attract and hold cations in the same way clay minerals do. Humus colloids have a much greater cation exchange capacity than clays, making them very important for soil fertility.

Increasing soil organic matter levels may require a change in management practices. Even a short (1–2 year) pasture in the rotation, particularly grass pasture, can be highly effective. Minimising soil disturbance (tillage) will slow the rate of breakdown of organic materials. Reducing fallowing periods helps to maintain organic matter levels. The concentration of organic matter at the surface is most important for soil structural stability.

pH:

The term pH stands for a measurement of the number of hydrogen cations in a solution. The 'H' stands for hydrogen, and the 'p' indicates a negative logarithmic scale. This means that a solution with a pH of 7 has 10 times more H^+ cations than a solution of pH 8. The pH scale goes from 1 to 14, with 7 being neutral. A solution with a pH greater than 7 is alkaline, while a solution with a pH less than 7 is acid. The pH level is very important in the soil solution, because plant growth and yield are reduced in highly acid or highly alkaline soils. One reason is that some plant nutrients become unavailable at certain pH levels.

The standard method of measuring soil pH is with a suspension of 1 part air-dried soil (by weight) to 5 parts liquid (by volume). The recommended liquid is 0.01 M $CaCl_2$ (calcium chloride). Results in this case are reported as pH ($CaCl_2$). Distilled water is sometimes used in place of calcium chloride, in which case results are reported as pH (water). Soil tested in $CaCl_2$ solution registers about 0.5 to 0.8 units lower than the same soil tested in water. See also 'Available nutrients' and 'Acidity'.

Phosphorus:

Phosphorus is a nutrient that is vital for seedlings and young plants. Many Australian soils are naturally low in phosphorus in forms that agricultural plants can use. Some exceptions are the grey clays and black earths of northern New South Wales and the red brown earths and sands of south-western New South Wales. Native pastures are adapted to these low levels, but introduced crops and pastures are not.

Fertiliser phosphorus does not move far from where it is applied, because it reacts rapidly with the soil. It binds with iron and aluminium in the soil and becomes unavailable to plants, especially in acid soils. For this reason, plants take up only 5% to 20% of applied phosphorus in the short term, but may use up to 50% in the long term.

Below are some options to improve the uptake of phosphorus from fertilisers.

- Get a soil test done. The plants may not be responding because the phosphorus levels are already high enough. If the test shows the soil is low in phosphorus, place the fertiliser close to the seed when sowing. This is very effective, as you need to apply only half the fertiliser compared with broadcasting. Also, broadcasting increases the risk of fertiliser being washed into waterways.
- Test the pH of your soil and, if it is acid, lime it. This will increase the availability of phosphorus.
- Monitor available phosphorus levels regularly, as plants can take up only a small proportion of what you apply.

Phosphorus is a relatively immobile element and thus very little leaches through the soil, with the possible exception of sandy soils. It is mainly lost from the soil by erosion of soil particles containing phosphorus. For this reason, controlling soil erosion is the main method of minimising the loss of soil phosphorus to waterways in cultivated areas.

Plastic limit: This is the moisture content at which clay behaves like plasticine, because the clay plates slip smoothly across one another with very little force. The plastic limit applies only to clay soils and varies with the amount of clay in the soil, but it can easily be determined by hand. (See moisture content.) At the higher plastic limit the soil is very weak and is easily remoulded by external pressure, for example, by machinery, stock and even the weight of a human. The smearing and compaction that can occur if the soil is worked wetter than the plastic limit can do much damage to the soil structure and affect crops for years.

At the lower plastic limit the soil is firm and shatters on cultivation.

Potassium: Potassium is important for plant growth and disease resistance. Some potassium, held on clay minerals and organic matter, is easily available to plant roots. Potassium occurring naturally in some soil minerals is released only slowly for plant use. Potassium is low or deficient in some sandy soils, and deficiency can occur on soils used for intensive grazing, intensive cropping and haymaking. The most common potassium fertilisers are potassium chloride (muriate of potash) and sulfate of potash. Care needs to be taken with potassium chloride, as chloride levels can build up, causing salinity problems.

Salinity: Salinity refers to the concentration of all salts in the soil solution. Although the most common salt in most Australian soils is sodium chloride (common table salt), any readily soluble salt (including fertilisers) may contribute to soil salinity. Salts are present as ions when dissolved in the pore water. If the soil solution is saline, plants may have difficulty taking up both water and nutrients. Some plants are also sensitive to specific ions, such as sodium and chloride. Salt tolerance varies between species. For example, barley is much more tolerant of salinity than wheat. Cucurbits such as squash and zucchini are more tolerant than legumes such as peas and beans.

Soil salinity is measured in soil tests as electrical conductivity. The more electrical current that is conducted in a soil solution, the higher the salt content of the solution.

Widespread clearing of deep-rooted native vegetation and its replacement with shallow rooted species under European-style management practices have allowed more water to enter the subsoil. In irrigation areas this process has been intensified. As the water moves through the soil and the material beneath, it dissolves stored salt, which is carried to the underlying ground water. This process increases the salt content of the ground water, and the extra volume of water raises the ground water level (watertable) closer to the surface.

A saline clay soil may appear well structured because the salts flocculate the clay, forming fine aggregates. See also soil solution, electrical conductivity, dispersion.

Sand: Sand refers to particles between 0.02 and 2 mm in diameter. Fine sand is between 0.02 and 0.2 mm and coarse sand is between 0.2 and 2 mm in diameter. Sand comprises mainly quartz particles that will not break down further. Since sand has no electrical charge it does not hold water or nutrients, and does not contribute to soil fertility. However, the large pores between the relatively large particles are important for the movement of air, water and plant roots.

Self-mulching: Some heavy clay soils form a layer of loose granules at the surface when they dry. Soils with this behaviour are called ‘self-mulching’. Although water is lost from this and the adjacent layer by evaporation, the self-mulched layer acts as a moisture and temperature mulch. The remaining moisture in the profile is then conserved better than in clay soils that do not self-mulch.

Shrinking and swelling: In some clay minerals, such as smectites, water can enter between the clay particles, causing swelling. As these clays dry, the water evaporates from between the clay particles and the soils shrink, in some cases leaving quite large cracks. Most soils shrink and swell on drying and wetting to some extent, but this is most marked in soils containing smectite clays. Those soils that do shrink and swell have the capacity to repair any structural damage (for example, compaction and smearing) over the space of a few wetting and drying cycles. See ‘Self mulching’.

Silt: Silt is the particle size fraction in soils that lies between sand and clay (that is, between 0.002 and 0.02 mm in diameter). Silty soils are prone to hardsetting and crusting. See also ‘Texture’ and ‘Hardsetting’.

Smearing: Smearing is the realignment of clay particles from a random to a parallel orientation, producing a hard, shiny surface on drying. Smearing results from horizontal shear forces, produced by, for example, a spinning tractor wheel or a tine moving through the soil. Smearing occurs when a soil is wetter than the plastic limit.

Smectite: Smectites are the clay minerals that shrink and swell on drying and wetting. They are an important component of black earths and other cracking clays. A soil that is dominated by smectites is a relatively young soil—as it weathers with time, the smectites will break down into the other, less reactive clay minerals.

Sodicity:

Sodicity refers to the amount of exchangeable sodium cations (Na^+) in the soil, expressed as the exchangeable sodium percentage (ESP). Soils with an ESP greater than 6 are regarded as sodic. Sodicity is usually determined by the type of minerals present in the soil's parent material. Sodic soils swell strongly and may also disperse on wetting ('spewy' soils). Sodic soils are generally poorly structured.

Sodium ions have only one positive charge. This means the bonds between the clay particles are relatively weak, so there is a strong likelihood of dispersion.

Calcium maintains strong bonds between the clay particles because it has a double charge.

Magnesium also has a double charge, but it is more highly hydrated than calcium (that is, it attracts and holds a larger number of water molecules), so it is more likely to disperse than calcium.

Crusting is often a result of sodicity. When a sodic clay topsoil is wet, the clay swells and may disperse into solution. As the soil dries, a surface crust or seal may form. Sodic subsoils swell strongly and can reduce infiltration and drainage, frequently resulting in waterlogging.

Sodicity is often treated by applying gypsum and/or lime. If the sodicity is high, and particularly if it affects both the topsoil and the subsoil, it may be preferable to leave the soil under pasture. Pasture helps to bind the soil particles together, and helps to protect a sodic soil from dispersing. When cropped, the soil loses this protection and may crust or erode badly. See also 'Dispersion' and 'Structure'.

Sodium:

Sodium is a cation with a single positive charge. For this reason, the bonds between clay minerals with a high proportion of exchangeable sodium cations are weak. A high level of exchangeable sodium (sodicity) causes the separation (dispersion) of individual clay particles in solution.

Although all ions in solution contribute to salinity, sodium is usually present in significant quantities in saline soils. Salinity refers to the concentration of ions in the soil solution. A high salinity makes clays clump together in the same way calcium does. This means that a soil that is saline, but not sodic, will have fine crumbly aggregates, while a soil that is only sodic is cloddy or crusted. If sodicity remains the same, but salinity increases, a soil's behaviour may move across the line from dispersion to flocculation. On the other hand, if the salinity remains the same and the sodicity increases, a previously flocculated soil may disperse. See also 'Cation exchange capacity' and 'Sodicity'.

Soil organisms:

Earthworms, termites, ants and other soil organisms are very important for soil structure, especially in soils that do not crack. Soil animals are also important for incorporating organic matter and breaking it down so that plants can use the nutrients.

Overcultivation and loss of organic matter will discourage soil organisms, leaving the soil hard and lifeless. See 'Micro-organisms'.

Soil profile:

Soil profile refers to the sequence of horizons (layers) down to, and including, the parent material. The A horizon is the topsoil and the B horizon is the subsoil. Observing the soil profile can help you to manage your soil by giving you a good idea of its advantages and limitations.

Soil solution:

The water that is in the soil pores, or that coats the pores as the soil dries out, is always a solution of cations and anions. Since plants take up nutrients in solution, the types and proportions of these ions determine the ease with which a plant can take up nutrients. Salinity, alkalinity and acidity are all a result of imbalances in the soil solution. See also ‘Salinity’, ‘Alkalinity’ and ‘Electrical conductivity’.

Strength:

For successful plant growth, the soil must not be too weak (the wind can blow plants over, lift seedlings from the ground, or cause erosion), or too strong (seedlings cannot emerge, roots will be unable to grow vertically through a hardpan, or may grow flattened in narrow cavities).

The moisture content is the most important modifier of soil strength, although texture, structure, organic matter and clay type are also important. Cultivation can damage structure and reduce organic matter levels, leading to higher soil strengths as the soil dries out.

Structure:

Soil structure refers to the arrangement of the sand, silt and clay particles and organic matter to form aggregates, as well as the arrangement of pores within and between aggregates. It has an important effect on the distribution of water and air in the soil, and is therefore important for the ease with which plant roots can exploit the soil for water and nutrients. A well structured soil has aggregates large enough to allow water, air and plant roots to move through the soil easily. Texture, moisture content, organic matter, clay type, cultivation and even the root systems of crops can affect soil structure.

Texture:

Texture is a measure of the proportion of sand, silt and clay and organic matter in a soil. Organic matter and the clay minerals provide the bonds that hold a soil together. In clay soils the clay minerals do most of the bonding. However, as the proportion of clay in a soil decreases, organic matter becomes increasingly more important. Loams (which have roughly equal proportions of sand, silt and clay) are generally good topsoils. However, if these soils lose organic matter, the particles can repack to form a very dense layer, and become hardsetting.

To assess texture:

- Take a small handful of soil and remove any gravel, stones, leaves or twigs. (Gravel should not be ignored, however, as any of the above can be modified by the prefix ‘gravelly’, for example, gravelly clay loam.)
- Break up aggregates if possible.
- Adding a small amount of water at a time, knead the soil in your hand to make a small ball. Make sure that the soil is wet right through and there are no lumps.
- Stop adding water as soon as the ball begins to stick to your hand. Knead for another 30 seconds.

You will find it very difficult to mould a sandy soil, and quite easy to mould a clay soil. A gritty feel indicates sand. A silky feel indicates silt, and a plastic, sticky feel indicates clay.

Press the ball between your thumb and forefinger to form a ribbon. The longer the ribbon, the more clay is in the soil. The table on the following page allows you to class the texture of your soil based upon ‘feel’.

Texture table

Texture	Ball	Ribbon (cm)	Feel
Sand	will not form ball		single grains of sand stick to fingers
Loamy sand	ball only just holds together	0.5	gritty
Clayey sand	ball only just holds together	0.5–1,5	sticky, sand grains stick to fingers
Sandy loam	ball just holds together	1.5–2.5	very sandy to touch, visible sand grains
Fine sandy loam	ball holds together	1.5–2.5	fine sand can be felt
Loam	ball holds together	2.5	spongy, smooth, but not gritty or silky
Silty loam	ball holds together	2.5	very smooth and silky
Sandy clay loam	ball holds together	2.5–4.0	sandy, but plastic
Fine sandy clay loam	ball holds together	2.5–4.0	fine sandy, but plastic
Clay loam	ball holds together	4.0–5.0	smooth and plastic
Silty clay loam	ball holds together strongly	4.0–5.0	plastic, smooth and silky
Light clay	ball holds together strongly	5.0–7.5	smooth, plastic, slight resistance to ribboning
Medium clay	ball holds together strongly	7.5 or more	smooth, plastic, moderate resistance to ribboning
Heavy clay	ball holds together strongly	7.5 or more	smooth, plastic firm resistance to ribboning

Water:

Soil water is a very important component of the soil, because it affects aeration and soil strength. It also controls soil temperature, and affects evaporation rates.

Plants need water for growth and to obtain water through their roots. The roots are in soil (except for hydroponics), so the relationship between soil and water is very important for farmers.

Field capacity

Water enters the soil through pores within and between soil aggregates, through tunnels formed by organisms such as earthworms, and through shrinkage cracks. When the rain or irrigation stops, water drains out of the macropores but is held by surface tension in micropores. When the macropores are empty and the micropores are full—usually 24 to 48 hours after rain or irrigation—the soil is said to be at field capacity (this applies only to freely draining soils).

The amount of water the soil can hold at field capacity depends on the size of the pores. Sandy soils, for instance, hold very little water at field capacity because most of their pores are large. Clay and organic soils have a much higher field capacity water content because they contain many micropores.

Permanent wilting point

Healthy plants withdraw water from the soil according to the degree of plant cover, evaporation, and the increasing dryness of the soil. As the soil becomes drier, the remaining water is held more and more tenaciously by the soil and is harder for the plant to extract. When the plant can no longer obtain water from the soil, it may wilt and cease growing.

Temporary wilting occurs in hot, dry climates in the heat of the day because the plant cannot transmit water fast enough to replace that evaporated into the atmosphere. The wilting disappears when the temperature drops. If a plant does not recover when the temperature drops, the wilting is permanent and the soil is said to be at the permanent wilting point.

In sandy soils, the permanent wilting point is sharply defined. In clays and loams it is much less sharply defined, and plants in these soils will show increasing signs of wilting over several days.

Unavailable water

After a soil has reached the permanent wilting point it will continue to lose water until it becomes air dry. The water between the permanent wilting point and an air-dry state is generally unavailable to plants.

Available water

Plants are able to use only a part of the water held in a soil. Some water is held so tightly in the soil pores by surface tension that plant roots cannot extract it. By contrast, when a soil is saturated most plants suffer from lack of oxygen. Available water is the water in the soil between the field capacity and the permanent wilting point, and is thus available for plant use. Plant-available water capacity is the term used to describe how much available water can be stored in a particular soil. Soils of intermediate texture, the clay loams, tend to have the highest levels of available water. Sandy soils have little available water, while clay soils have high field capacity levels but also a high permanent wilting points. See also ‘Moisture content’.

Waterlogging: Waterlogging refers to a soil that is saturated with water—that is, all the pores are full of water and contain no air. See ‘Aeration’.

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