Summary of Major Soil Features[1]

South Australian soils are largely formed from ancient, highly weathered materials. Therefore they are often inherently infertile and fragile and it is important they are carefully managed. The importance of appropriate soil management is emphasised by the fact that soil is effectively irreplaceable, given its very slow rate of natural formation.

Soil features of greatest importance for South Australian conditions, land use and land management as described by Hall, Maschmedt and Billing (2009)[1] are:

1. Soil Constituents
2. Soil Fertility
3. Toxic elements
4. Soil Structure
5. Drainage
6. Salinity
7. Soil Carbonates
8. Soil Depth
9. Waterholding Capacity
10. Erosion

[1] Summarised from: Hall, J.A.S, Maschmedt, D.J and Billing N.B. (Bruce) (2009) *The Soils of Southern South Australia*. The South Australian Land and Soil Book Series, Volume 1; Geological Survey of South Australia, Bulletin 56, Volume 1. Department of Water, Land and Biodiversity Conservation, Government of South Australia.

Soil Constituents

- The major constituents of soil are mineral matter, organic matter (living and non-living), and water or air filled pore spaces.
- The mineral fraction is derived from chemical weathering and physical breakdown of rocks; the organic fraction comprises all non-mineral carbon-based matter, including all living soil organisms; and pore spaces provide for inclusion and movement of air, water and dissolved nutrients.
- The mineral fraction is categorised according to particle size:

Particle	Size
Coarse material (gravel, stone, stone and boulder size coarse fragments and hard segregations):	> 2.0 mm
Sand:	2.0 – 0.02 mm
Silt:	0.02 – 0.002 mm
Clay:	< 0.002 mm

- Sand and silt particles are predominantly composed of quartz, feldspar, mica or calcium carbonate. In South Australia, quartz is the most dominant of these but calcium carbonate particles are also very common.
- Sand and silt size particles have low surface areas and correspondingly low chemical reactivity.
- Clay size particles often have very large surface area and correspondingly high chemical reactivity.
- Much of the soil organic fraction consists of decaying and decayed plant and animal residues which are mainly broken down by microorganisms.
- Most of the many forms of organic matter have a large capacity to store and release nutrients because of their large surface areas and correspondingly high chemical reactivity.
- Pore spaces within soil matrices provide spaces for water (soil solution) and air (soil atmosphere). Ion exchange between the soil solution and charged sites on clay particles and organic matter, provides nutrients to the soil solution for uptake by plant roots and microorganisms. Ion and gas exchange between living organisms, the soil solution and the soil atmosphere allows for life in soil.
- Soil texture is determined by the proportions of sand, silt and clay size particles in a mineral soil layer.
- Texture grades range from coarse sand to heavy clay and are grouped into four primary texture classes:

Texture	Class
Sandy (including light sandy loam)	0-12% clay
Loamy:	10-25% clay
Clay Loamy:	20-35% clay
Clayey:	> 35% clay

- Soil organic matter is derived from proliferation, growth, death and decomposition of plants and soils organisms.
- Organic matter is modified and broken down by soil organisms and to some extent, inorganic chemical and physical processes in soil.
- Most soil biological activity occurs in the surface soil.
- In South Australia, climatic conditions do not generally favour proliferation and growth of soil organisms therefore organic-enriched surface layers are generally thin, and organic matter content generally relatively low (usually <2% organic carbon in top 10 cm).

Soil Fertility

- Seventeen elements are essential for the development of all or most higher plants. A plant cannot complete its life cycle in the absence of any of these elements, and no other element can substitute for their functions.
- Essential plant nutrients are divided into macronutrients and micronutrients (or trace elements) according to the relative plant requirements:

Macronutrients		Micronutrients	
Carbon	C	Copper	Cu
Hydrogen	H	Zinc	Zn
Oxygen	O	Manganese	Mn
Nitrogen	N	Iron	Fe
Phosphorus	P	Boron	B
Potassium	K	Molybdenum	Mb
Sulfur	S	Chlorine	Cl
Calcium	Ca	Nickel	Ni
Magnesium	Mg		

- Some plants require other elements such as cobalt, silicon, sodium and vanadium.
- Oxygen, carbon and hydrogen make up the vast majority of plant material so are required in the largest amounts, and are supplied by air and water.
- Primary soil-supplied macronutrients are nitrogen, phosphorus and potassium and are often deficient in soils. Potassium deficiency is uncommon in dryland cropping areas of South Australia.
- Secondary soil-supplied macronutrients are sulfur, calcium and magnesium and are less commonly deficient in soils. Calcium and magnesium are rarely deficient in South Australia soils except in high-demand horticultural systems.
- Micronutrients copper, zinc, manganese, iron, boron and molybdenum are deficient in some South Australian soils and conditions.
- Clay amount and type in a soil layer is a major determinant of soil fertility. The surface area and reactivity of clay-size particles range from relatively low to very high, varying with clay mineral type. Chemical reactivity is gauged by cation exchange capacity (CEC) and physical reactivity by the soil's potential to swell upon wetting.

Soil Mineral Reactivity

Soil Mineral Particles (prominent elements)	Chemical Reactivity (CEC in cmol(+)/kg)	Potential for Swelling
Crystalline Aluminosilicate Clays		
Vermiculite (O, Si, Al, Mg)	80-150	moderate
Smectites (O, Si, Al)	60-150	high
Illite (O, Si, Al, K)	10-40	low
Chlorite (O, Si, Al, K, Mg, Fe)	2-40	none
Kaolinite (O, Al, Si)	1-20	negligible
Amorphous Aluminosilicate Clays		
Allophane (O, Al, Si)	25-150	none
Sesquioxide Clays		
Metal oxides (O, Fe, Al)	0-4	none
Siliceous or Carbonate Silt and Sand		
Silt (O, Si or O, C, Ca, Mg)	0-2	none
Sand (O, Si or O, C, Ca, Mg)	negligible	none

- Soils with clayey and clay loamy textures often have high inherent fertility and nutrient retention capacity while sandy soils have limited capacity to retain nutrients.
- Organic matter provides nutrients as it decomposes (especially nitrogen, sulfur and phosphorus) and releases and exchanges adsorbed nutrients (especially calcium, potassium, magnesium and micronutrients).

- Soil organisms have profound effects on plant nutrient uptake through their effect on nutrient accumulation, depletion, immobilisation and mineralisation, especially in the rhizosphere.
- Upon decomposition by soil organisms, some soil organic matter and plant residues are converted to mineral nutrient forms but much is assimilated by living organisms, adding to soil biomass.
- Soil pH is an indicator of soil fertility.
- Organic matter decomposition and subsequent release of nutrients into soil solution is slowed at high and low pH levels because of decreased microbial activity.
- The more acidic a soil, the less capacity it has to retain nutrients. The more alkaline the soil, the greater the restrictions on plant availability of certain nutrients.
- In strongly acidic soils (pH_{CaCl_2} < 4.5) aluminium, manganese, hydrogen, iron (rarely) and heavy metal toxicities; and calcium, magnesium, molybdenum, iron, nitrogen phosphorus and sulfur deficiencies, can occur.
- Soil pH and presence of fine carbonate affects the availability of micronutrients. Most have maximum availability in slightly acidic soils except for molybdenum which prefers alkaline conditions.
- Manganese, zinc and iron have reduced availability in calcareous conditions.
- Soil structure can affect fertility. The better the soil structure, the better access plant roots have to the whole soil matrix and the nutrients contained within. Root growth and exploration are restricted in poorly structured soils.
- Plant growth and function are reduced in cold and wet soil conditions, and some nutrients might be in short supply because of slow organic matter breakdown, leaching, loss in gaseous form, or more ready conversion to less available forms where conditions are calcareous or where ironstone is present.

Toxic elements

- Toxic concentrations of elements can accumulate in soil layers via leaching from overlying layers or from the release into solution of normally insoluble elements at extremes of pH.
- Soil boron and sodium primarily originate from salt-bearing sea winds. They have accumulated in amounts toxic to plants in many soils and substrates in the low to moderate rainfall areas of South Australia, particularly where a clay loamy or clayey layer is present that restricts drainage and leaching.
- The depth at which these accumulations occur (i.e. within or below plant root growth zone) is important in their effect on plants.
- Aluminium and manganese can be released into soil solution and adversely affect plant growth in high rainfall districts with deeply weathered and strongly acidic soil profiles.

Soil Structure

- Soil structure is the way individual particles of sand, silt and clay are physically arranged in relation to each other and pore spaces within soil layers.
- Soil particles can remain as discrete entities, form a continuous mass or form distinct aggregates.
- The main determinants of soil structure are clay content and type, relative proportion of exchangeable cations on clay exchange surfaces, and the amount and type of organic matter.
- As clay content increases, aggregation in soil layers often becomes more pronounced.
- Favourable soil structure allows unrestricted root growth throughout a soil layer and provides adequate pore spaces for the movement of air and water.
- Favourable structure is provided by loose sands, low-strength and massive loams, as well as loams to clays with loosely packed small-size aggregates.
- Soil layers with large concentrations of calcium on clay exchange surfaces and surface soils with high organic matter content, are typically well structured.
- High amounts of organic matter lower soil bulk density and promote micro-aggregation, enhancing soil porosity and drainage.
- Humus is very important as a soil aggregate binding and stabilising agent. It can bond to clays and enable the joining of soil particles to larger soil aggregates.
- Calcareous soils are often friable because of their high calcium content and relatively high organic matter contents. Higher than usual amounts of organic matter are due to reduced microbial activity under calcareous conditions.
- Poor soil structure restricts root growth because of high soil strength and bulk density.
- Few pore spaces are available for water and air movement in poorly structured soils and the resultant restricted drainage increases the severity and likelihood of waterlogging and erosion.

- An excessive sodium concentration on clay exchange surfaces promotes poor structure, especially where textures are clayey or clay loamy.
- Sodic subsoils are usually coarsely structured and dispersive, and common in low to moderate rainfall districts.
- In South Australia, poor soil structure is associated with hardsetting and massive loams and clay loams; coarsely structured, high-strength clays and clay loams; clays with tightly packed and small-size aggregates; massive and dense clays; and tightly packed, compacted sands.

Drainage

- Many SA soils have restricted drainage caused by low permeability and poorly structured subsoils, particularly in texture-contrast soils.
- Water can perch on low permeability subsoils in texture-contrast soils, forming a zone of seasonal saturation with the soil profile.
- Low permeability subsoils are predominantly clayey or clay loamy.
- Roots of most plants do not grow well in low-oxygen conditions caused by saturation. Most roots will not grow into and through a saturated subsurface zone.
- Excess water associated with perched watertables can lead to excessive deep drainage and lateral seepage of water in the landscape, exacerbating land salinisation via a rise in groundwater levels, and aggravating waterlogging in lower lying areas.

Salinity

- Soil salinity is an excess of salts in the soil solution.
- Two main types of soil salinity occur: that induced by shallow saline watertables (watertable-induced salinity) and that not associated with saline watertables (dry saline land).
- The main salt of concern is sodium chloride but concentrations of other salts might be significant in some soils.
- High soil salt content denies roots access to soil moisture causing moisture stress in plants.
- Relatively low amounts of chlorine can injure living tissue and high to very high concentrations of sodium can adversely affect plant growth.
- Plant species and varieties differ in their tolerances of saline conditions but no plants grow where soil salinity is extreme.
- Sodium chloride is extremely soluble and can be very mobile in soils.
- Most sodium and nearly all chlorine will be leached where drainage and rainfall are sufficient.
- Conversely, capillary action transports salt to the soil surface where saline groundwater is relatively shallow. Salt precipitates at the surface as water evaporates.
- Much of South Australia's agricultural land is underlain by saline groundwater, sometimes at relatively shallow depth.
- Soil salinity is usually high where saline groundwater is within one to two metres of the soil surface.
- "Primary' watertable-induced salinity is associated with land deemed highly to extremely saline since before European settlement and includes saline coastal swamps and ancient inland salt pans.
- "Secondary" watertable-induced salinity is associated with removal and replacement of perennial native vegetation by annual plants that use less water. The excess water drains to the groundwater, causing watertables to rise and exacerbate the salinity associated with shallow groundwater in the landscape.
- Secondary salinity is divided into "dryland salinity", associated with dryland agricultural areas, and "irrigation salinity", where excess irrigation water drains to groundwater.
- Dry saline land describes soils that have naturally high salt contents not associated with present-day saline groundwater.
- Most of the salt is derived from marine sources, distributed across the landscape by wind and rainfall. Some salts come from salt-bearing soil parent material such as marine sediments and some might be residual from former high groundwater levels.
- Rainfall can be insufficient to leach salt from the soil profile in low to moderate rainfall districts so salt usually accumulates at the depth reached by the average seasonal wetting front.
- Salt will move in the soil by leaching in winter, and capillary action in late spring and summer as the soil dries.

Soil Carbonates

- Finely divided or soft carbonate, and hard carbonate segregations are present in many South Australian soils.
- The carbonate is primarily calcium carbonate with inclusion of some magnesium carbonate.
- Most soil carbonates originate from sea-floor sediments that were entrained by wind and deposited upon the land surface.
- Finely divided carbonate occurs in many soils. Soils formed in carbonate-rich sediments are predominantly calcareous throughout.
- Unless carbonate is completely leached from the profile, leaching produces a subsoil layer of maximum accumulation of carbonate.
- Hard carbonate usually consists of concretions or nodules, calcrete fragments, or rubbly or sheet calcrete; all of these forms are very common in southern South Australia.
- Hard carbonate is formed from the dissolution and recrystallisation of calcium carbonate when subjected to long periods of wetting and drying.
- Calcrete and limestone are both primarily forms of consolidated calcium carbonate but different in nature and origin.
- Calcrete forms in a terrestrial environment, usually developing as a hard, upper layer within unconsolidated wind-borne deposits. Limestone is a sediment laid down under water and has consistent hardness throughout.

Soil Depth

- Soil depth can mean any of the following:
    - depth to which soil forming processes penetrate
    - average depth of seasonal rainfall penetration
    - depth to which the roots of perennial native vegetation will grow
    - depth to which the roots of annual or perennial crop or pasture plants will grow
    - depth to a hard layer
    - depth of topsoil.
- For agricultural soils, soil depth is often defined as the depth to which the roots of specific cultivated plants will grow, unimpeded by physical or chemical barriers.
- Physical barriers include basement rock or other impediments such as sheet calcrete or ferricrete. Very hard, poorly structured and very low permeability clay layers can also form a physical impediment to root growth and water movement.
- Chemical barriers in low to moderate rainfall districts include high concentrations of boron, high to very high amounts of sodium, strong alkalinity, moderate or greater concentrations of salts, and/or very low fertility.
- In higher rainfall districts, most common chemical barriers to root growth are strong acidity, toxic levels of aluminium and manganese, and very low fertility.
- Effective soil depth can be considered a plant-specific concept to some extent as different plant species and varieties have varying tolerances to adverse chemical conditions.

Waterholding Capacity

- Water storage capacity of a soil is determined by soil texture, soil structure, volume of coarse fragments and hard segregations, as well as effective soil depth.
- A productive soil requires a sufficient store of water to maintain plant growth during dry periods.
- A soil with large stores of water maintains strong crop or pasture growth during dry periods and when rains cease at the end of the season.
- A soil with small stores of water rapidly senesces or “hays off” when rains cease.
- Landscape position can also influence water availability as water in the landscape tends to move to lower lying areas.
- Not all water stored within soil profiles is readily available for uptake by plant roots; some water is held too tightly within the soil matrix for plants to extract.

Soil water occupies pore spaces in the soil and pores can be categorised according to their diameter and corresponding plant-availability of water:

Soil Pore Size	Availability of water to plants
Macropores (> 30 micrometres):	Water will drain under force of gravity given no underlying impeding layers
Mesopores (0.3 – 30 micrometres):	Plant-available water
Micropores (< 0.3 micrometres):	Soil water is held too tightly for plant roots to extract

- Even in large pores, water in close contact with soil particles may be held too tightly by adhesive forces to be available for plant uptake.
- Soil layers with clayey textures have a much greater capacity to store water than those with sandy textures.
- A large percentage of water in a clayey soil is held too tightly for roots to absorb whereas most of the water stored in a sandy soil is available for uptake.
- Poorly structured clayey layers with coarse aggregates, or dense and massive structures, are unlikely to store as much water as well-structured clayey layers.
- Coarse fragments and / or hard segregations occupy space in soil profiles, consequently decreasing soil matrix volume and water storage capacity.
- Physical or chemical barriers that restrict soil depth also limit waterholding capacity as soil volume is restricted.
- Patchy wetting of soil profiles caused by water repellence limits effective soil waterholding capacity and plant-available moisture. Water infiltration is reduced and runoff increased.
- Water repellence in soils restricts wetting of the whole profiles.
- Water repellence mostly occurs in sandy soils (especially siliceous sands) but can also occur in some sandy loams.

Erosion

- Soils vary in inherent erodibility, which is primarily determined by surface texture, profile texture and soil structure.
- Almost any soil can erode when unprotected by surface cover, especially when disturbed (e.g.by cultivation).
- Climatic conditions greatly influence the amount, type and quality of vegetation, and the extent of soil protection that vegetation provides.
- Management of land has a large bearing on the quantity and quality of protective vegetation, and on the physical condition of the soil surface.
- On agricultural land, the risk of erosion depends on a range of factors including:
    - soil type
    - topography
    - surface soil physical condition
    - timing and nature of wind events
    - timing, amount, distribution and frequency of rainfall
    - growth and retention of crop and pasture biomass and residues
    - timing, type and frequency of tillage or other soil disturbance operations.
- Surface soils composed of loose, individual particles (i.e. single grain structure), especially those with sandy textures, are particularly vulnerable to wind erosion.
- Topographic position, as well as the presence of barriers to slow or deflect wind movement away from the soil surface, is important in exposure of soils to erosive winds,
- Low rainfall conditions increase the likelihood of poor vegetative cover and dry surface soils.
- Topsoils with loose individual particles (i.e. single grain structure), or small and loose aggregates, are particularly vulnerable to water erosion, especially where underlain by subsoil or substrate materials that restrict drainage.
- Hard and massive surface soils have limited capacity for rainfall infiltration and shed runoff, increasing the likelihood of erosion on adjacent soils.
- Overland flow begins when soil profiles can no longer accept rainfall. Slope steepness, length and curvature are important factors in determining the movement and convergence of overland flows and the likelihood of erosion.
- Water can detach and move soil particles by raindrop splash hitting the soil surface.
- Water flows can carry away soil via rill, sheet or gully erosion.
- Subsoils with poor structure, dispersive natures or high concentrations of toxic substances can be exposed by erosion and removal of topsoil.
- Exposed subsoils are often hostile to seed and plant establishment and can remain bare (or scalded) indefinitely.

Preferred way to cite this information sheet

Department for Environment and Water (2021). The Soils of Southern South Australia - Summary of Major Soil Features. https://data.environment.sa.gov.au/Land/Land-Resources/ (insert date web page accessed)

For more information

Department for Environment and Water

Email: DEWSoilsInfo@sa.gov.au

Website: www.environment.sa.gov.au

Prepared by Mary-Anne Young PIRSA, supported by Department for Environment and Water Sustainable Soils 2021.