Soil science
&
the soils of Greater Melbourne

Robert van de Graaff

A little bit of tourism and theory and
some practical applications to LCA

Soils are riveting topics to a wide audience! You won't be bored!

What is soil?

- Mineral silicate material such as sand, silt and clay, plus organic matter (mainly in the topsoil)
- Oxides and hydroxides of metals such as iron, manganese, various compounds, salts, nutrients (Phosphate, nitrogen, potassium, trace elements, etc.)
- Voids between the mineral particles containing air and water
- Living organisms: microbes, fungi, roots of living plants, burrowing insects, worms, etc.

Try to imagine sands, silts and clays
Try to imagine water movement here

FIGURE 8.3
Soil crumbs are probably held together in this way. O = organic matter, C = clay mineral particles. *After* W W Emerson *J. Soil Sci.* 10: 235, 1959

- Sand: all mineral particles with a diameter between 2 mm and 0.02 mm
- Silt: all mineral particles with a diameter between 0.02 mm and 0.002 mm
- Clay: all particles with a diameter < 0.002 mm [*these tend to have different mineralogy and crystal structure to sand and silt*]

There are lots and lots of different soils. We shall give them names

Warrandyte – yellow mottled duplex soil on mudstone and sandstone

Melton – red brown earth on recent basalts

More soils ....

Williamstown – black cracking clay (black earth) on recent basalts

Glenmaggie – yellow mottled sodic duplex soil on Tertiary sedimentary rocks

More soils, and there are still many more…

Deer Park – grey cracking clay on recent basalts

Miss Universe – podzol (spodosol) on Pleistocene sands

A "giant " and damaged "Miss Universe" Podzol in Gippsland

Note the accumulation of iron oxides and organic matter below the former subsurface layer. This is a sand mining site.

Iron on the move within soils

Buckshot development at boundary of topsoil and subsoil meaning seasonal perched waterlogging (LCA interpretation!)

Iron accumulation in the more permeable strata of weathered rock over millions of years

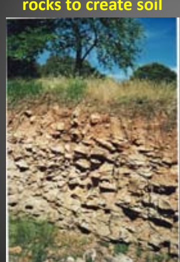
The movable life of soils

Podzol profile got buried under fresh wind blown sand

Termites are turning the soil upside down and leaving lots of underground channels

Where do soils come from and where do they go? #1

Break up and weathering of rocks to create soil

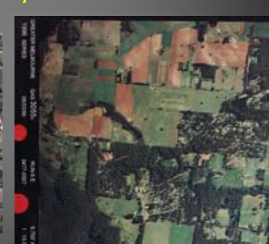


River sediments dropped as alluvium on land elsewhere

Where do soils come from and where do they go? #2

Land slips and erosion near Silvan Dam, Monbulk, slowly moving soil down hill to rivers

Erosion of ancient red soil on Kinglake Plateau, washing soils to rivers, exposing younger yellow brown soil

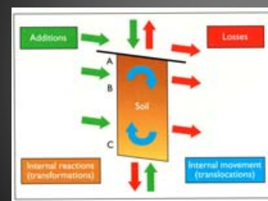


Soil formation

- Water
- Wind
- Gravity
- Chemical processes
- Biological processes
- Solar radiation & heat

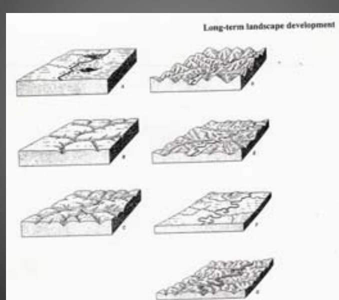
…acting on the rocks and soils at the Earth's surface over very long periods of time

What's happening to the silicate minerals making up rocks and soils?



- The minerals in the rock (as well as those in soils) are being attacked by passing rain water, dissolved weak organic acids, etc.
- The minerals are altered and broken up to form new, more stable new minerals, for example clay, iron oxides [Fe_2O_3, $FeO(OH)$], lime [calcium carbonate, $CaCO_3$], sodium carbonate [Na_2CO_3] etc., etc.

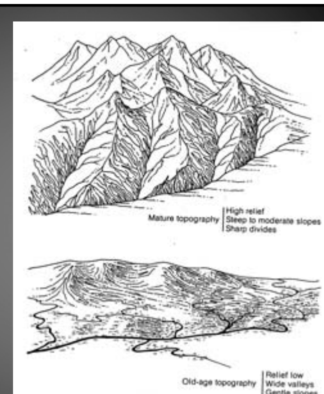
Cycles of landscape stability and deep weathering followed by instability causing erosion and soil removal



Shallow and deep soils

Steep slopes promote soil loss and soils may be lost at the same rate as they are formed by weathering of the parent rock; soils are young and are not able to develop differentiated profiles

Gentle slopes minimise erosion but weathering of the parent rock continues; soils tend to be deeper and more differentiated down the soil profile; they become older

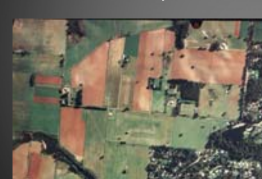


Geomorphic surfaces around Melbourne

Kinglake Surface – Pliocene age – highly weathered soils
Nillumbik Surface - Tertiary, younger than Pliocene, variable aged but very old on plateau surfaces
Quaternary basalts – Quaternary age, soils vary in age from 4 M years to tens of 1000nds
Coastal Plains – Pleistocene age, young soils

The Kinglake Plateau - Old land surface N of Melbourne on Silurian mudstones

Erosion is slowly removing the old soil. Pale areas have younger yellow brown soils with moderately poor conditions for on-site systems



Fossil iron-rich red soil formed in tropical wet climate. Perfect drainage for on-site systems

Remnant of old Nillumbik plateau in Eastern suburb of Melbourne (Nunawading) on Silurian mudstones

Minimally affected by erosion but weathering has continued and deepened

Soil profile is 2 m deep to weathered mudstone

Tunstall Park, Nunawading, in geomorphological context

- Park is on plateau surface
- Koonung Creek runs to the north; top end of Blackburn Creek is to the south west
- Donvale & Doncaster are on the slopes to tributaries of Yarra River

Youthful dissected slopes nearby on Silurian mudstones within Nillumbik surface

Soils < 1.2 m deep)

Well drained site
Does LCA assessor recognise this?

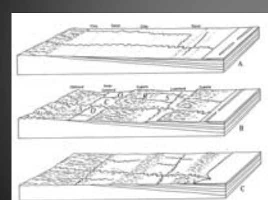
Poorly drained site
Does LCA assessor draw conclusions?

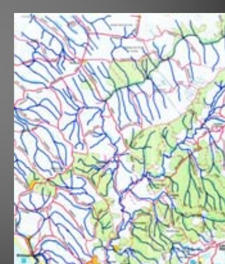
Coastal Plain between Princetown and Simpson, Corangamite Shire

A local LCA assessor should understand local area

Land slowly uplifted, shore recedes seawards

Today location of roads and creeks – and soils! - are determined by this history





What has this foot slope soil to say about its history?

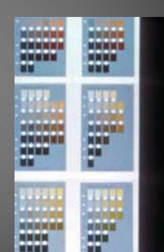
What has the LCA assessor said about this profile to demonstrate his/her understanding?

- It was washed down hill and came to rest, a little bit each year
- The stone line betrays a stage of more violent episode of erosion uphill and deposition down slope in its history
- Subsequent stability allowed the soil to form differentiated strata
- Organic matter accumulation in topsoil
- Clay (yellow) accumulation in subsoil
- Bleaching in the subsurface indicates seasonal perched waterlogging and anaerobic conditions

The iron (Fe) released forms different oxides and hydroxides which coat and colour the soil particles

Colours of individual iron oxides

Munsell Soil Colour Chart
(soil colours also include colour of organic matter)



Soil colour reflects soil drainage

Should be described in LCA reports

Fragment of soil from a marsh; grey, bluish and light yellow indicate an anaerobic soil (Fe^{2+})

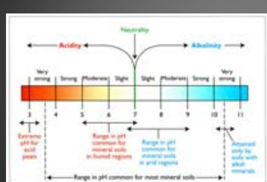
Uniform reddish brown indicates a soil that is generally aerobic which lets the iron be oxidised to Fe_2O_3 (Fe^{3+})

Soil colour reflects mineral soil material and organic matter – Does the LCA assessor understand this?

- "Youthful" alluvial soil from the levee of the Yarra River at Wesburn
- Profile is quite uniform lacking vertical differentiation (LCA!)
- Organic matter, good aeration and oxidation and natural mineral soil render everything dark grey brown (LCA!)

Soil pH – measuring acidity to alkalinity

pH is important to plants on dispersal area and to mobility of phosphate – part of LCA report



- Spontaneous dissociation of some water: $H_2O \leftrightarrows H^+ + OH^-$
- pH = negative logarithm of the hydrogen ion $[H^+]$ concentration in moles/Litre
- In water the dissociation constant is: $[H^+] \times [OH^-] = 10^{-14}$
- In neutral water:
- $[H^+] = [OH^-] = 10^{-7}$ or pH = 7
- pH < 7 means acid
- pH > 7 means alkaline

Example: pH 5 water has 10 times more H^+ ions per liter than pH 6 water

CSIRO-developed field kit for pH

Available from Inoculo Labs, Moorabbin

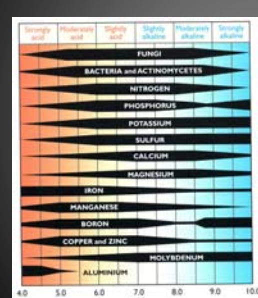
Dye that changes colour with pH dribbled on soil and dusted with inert white powder

White powder (barium sulphate) absorbs the dye and acts as neutral back ground

CSIRO kit from INOCULO

- **Post Office Box 720**
- **Moorabbin Vic 3189**
- **Ph: 061-3-9553-2766**
- **or: 061-3-9555-5939**
- **Mobile: 0438-393-048**
- **Fax: 061-3-9553-27**

Soil pH affects availability to plants of many nutrients and trace nutrients and should be part of LCA



- Mechanism: pH affects the stability and solubility of compounds that incorporate nutrients

Example 1:

- *Below pH 6* phosphorus becomes increasingly insoluble as hydroxy-apatite $AlH_2PO_4(OH)_{2s}$ and at pH *above 8* as variscite $Ca_5(PO_4)_3OH_s$

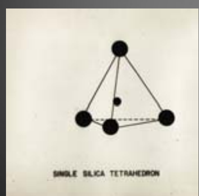
Example 2:

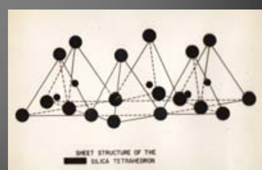
- Below pH 5 manganese can become so soluble as to create toxicity to many plants; however above pH 8 manganese can be deficient

Crystalline structure of a mineral sheet making up part of a clay mineral

The centre of the tetrahedron is an Silicon atom, Si^{4+} surrounded by Oxygen atoms, O^{2-}

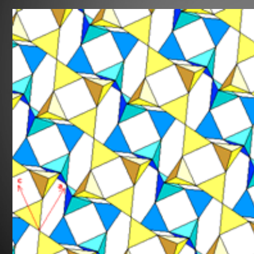
Tetrahedrons can be linked in a sheet, sharing the oxygen atoms at the corners





Feldspars, the most common building block of rock minerals

Steven Dutch, Natural & Applied Sciences, Univ. Wisconsin, Green Bay Campus

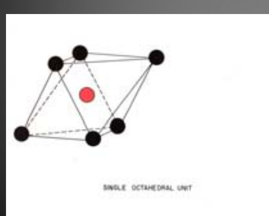


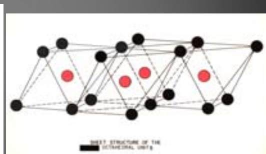
- Aluminium, Al^{3+}, replaces some of the silicon, Si^{4+}, in the tetrahedra resulting in electric charge imbalance, compensated for by extra positive ions, K^+, Na^+, Ca^{2+}, Ba^{2+}
- The general formula for the feldspars is $XAl(Al,Si)Si_2O_8$, where X is potassium, K^+, sodium, Na^+, calcium, Ca^{2+}, or barium, Ba^{2+}.

Crystalline structure of a mineral sheet making up part of a clay mineral

The centre of the octahedron is an aluminium atom, Al^{3+} surrounded by OH^- ions

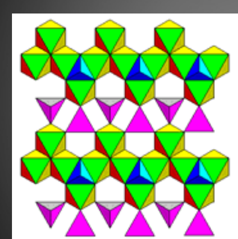
The octahedrons can also be linked to form a sheet, sharing oxygens at corners





Dark minerals, e.g. olivine, biotite, muscovite have octahedral units

Steven Dutch, Natural & Applied Sciences, Univ. Wisconsin, Green Bay

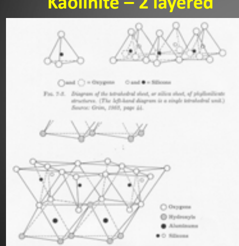


- The structure of olivine in a polyhedral format. Every vertex represents an oxygen atom. Iron or magnesium atoms are at the centres of the octahedra, silicon at the centres of the tetrahedra. Blue tetrahedra sit over openings between the octahedra and correspond to the purple tetrahedra in the next layer down.
- **Advantages:** three-dimensional structure and atomic coordinations are much clearer. Two layers are shown and part of a third so that the layering sequence becomes apparent.
- **Disadvantage:** the close-packing of the oxygen atoms is harder to see.

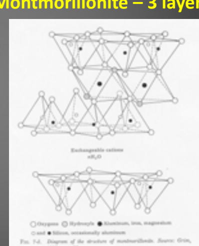
Two common clay minerals

Structure explains many properties:
slick behaviour, high surface area, etc.

Kaolinite – 2 layered

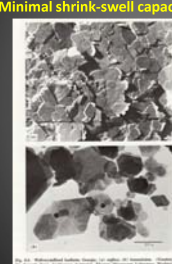


Montmorillonite – 3 layered



Clay minerals photographed in electron microscope – (note scale bars)

Well-crystallised kaolinite
Minimal shrink-swell capacity



Montmorillonite
Strong shrink-swell capacity!!

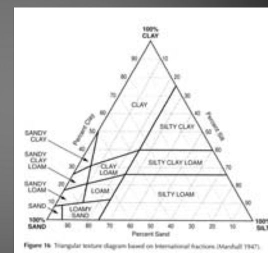
Clay minerals have huge specific surface areas for adsorbing water & chemical compounds

Cation-exchange capacities and specific surface areas of clay minerals - *Upper limit of estimated values (Encyclopedia Brittanica)

mineral	cation-exchange capacity at pH 7 (milliequivalents per 100 grams)	specific surface area (square metre per gram)
kaolinite	**3–15**	**5–40**
halloysite (hydrated)	40–50	1,100*
illite	10–40	10–100
chlorite	10–40	10–55
vermiculite	100–150	760*
smectite	**80–120**	**40–800**
palygorskite-sepiolite	3–20	40–180
Allophane	30–135	2,200*

Soil texture – the proportion of sand, silt and clay

- The sum of sand, silt and clay = 100% of the mass of the mineral soil
- The triangular diagram can be used to demarcate various soil texture groupings
- A lab analysis enables one to place the result in the diagram and determine its texture



Manual soil texture estimation

- Soil is moistened with water until it can be moulded
- The feel (smoothness, stickiness, plasticity), and the length of ribbon that can be made can be interpreted as texture classes

Manual soil texture estimation

- For example:
- Loamy sand: slight coherence; sand grains of medium size; can be sheared between thumb and forefinger to give minimal ribbon of about 5 mm
- Silty loam: coherent bolus; very smooth to often silky when manipulated; will form ribbon of about 25 mm

Soil structure – the way that solids and cavities are organised & affect effluent flow and aeration

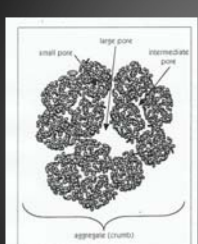


Figure 6.3 A well aggregated soil has a range of pore sizes. This medium size soil crumb is made up of many smaller ones. Very large pores occur between the medium size aggregates.

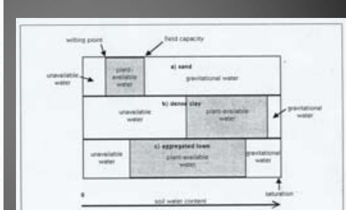
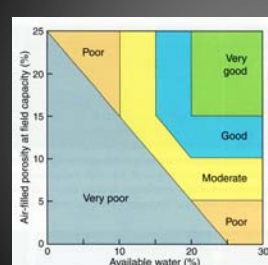


Figure 6.2 Water storage for three soils. (Shaded area represents water stored in soil that is available for plant use.)

How to quantify soil structure in terms of plant growth to promote water & nutrient uptake?



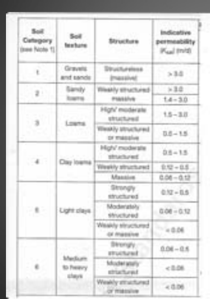
- Air-filled porosity = total pore volume – volume of water. (Lab measurement)
- Field capacity FC is the amount of water remaining in the soil after a thorough wetting and sufficient time to allow all free drainage to occur. (Lab measurement or estimate from Table of texture & structure)

Soil macro structure – a very poor guide to soil permeability – soil on right is much more permeable

Cracking clay developed on basalt

- When wet, this soil swells enormously with all cracks closing
- Soil becomes practically impermeable
- If subsoil is exposed to rain water or other low salt water, clay will disperse causing turbid runoff

AS/NZS 1547:2012



Soil Category (see Note 1)	Soil texture	Structure	Indicative permeability (K_{sat}) (m/d)
1	Gravels and sands	Structureless (massive)	> 3.0
2	Sandy loams	Weakly structured	> 3.0
		massive	1.4 – 3.0
3	Loams	High/ moderate structured	1.5 – 3.0
		Weakly structured or massive	0.5 – 1.5
4	Clay loams	High/ moderate structured	0.5 – 1.5
		Weakly structured	0.12 – 0.5
		Massive	0.06 – 0.12
5	Light clays	Strongly structured	0.12 – 0.5
		Moderately structured	0.06 – 0.12
		Weakly structured or massive	< 0.06
6	Medium to heavy clays	Strongly structured	0.06 – 0.5
		Moderately structured	< 0.06
		Weakly structured or massive	< 0.06

- There is no proven experimental basis for this Table
- It ignores the impact of soil sodicity and soil structure stability on permeability
- Using it is irresponsible

Sodic clay soils breaking up in water

Dispersing & eroding sodic clay soils, note turbid water

Effect of calcium salts on soil structure stability within 6 hours

Small clump of soil dumped in low salinity water

Small clump of soil dumped in gypsum solution

School effluent field on sodic soil after EPA Works Approval obtained without soil chemical testing

LCA consultant discovering soil permeability in sodic soil using distilled water is virtually zero, yet recommending loading rate of 10 mm/day, 33 times Ksat value

Lab Ksat in distilled water	1 x 10^{-9} m/sec	ksat in mm/day	0.086
In situ Ksat Test #1	3.5X10^{-9} m/sec	ksat in mm/day	0.302
Ksat Test #2	No result given		
Disposal field size specified per LCA, not withstanding almost impermeable soil	450 m^2		
Loading/day	750 L		
Disposal field size per calculation in m2	750/0.3024	2480.16	m^2
Disposal field size per calculation in hectares		0.248	ha

Reliable soil interpretations

- Soils – Their Properties and Management
- Peter E.V. Charman and Brian W. Murphy (Eds.)
- Oxford University Press

Soil permeability (Ksat) ranges for various soil textures and grade of structure in relation to (soil sodicity) ESP and (soil salinity) EC. Charman & Murphy, 2000

Soils with low ESP and low EC

Texture	Soil Category (AS/NZ 1547)	Structure Grade*	ESP	EC(1:5) (dS/m)	Low Ksat (mm/hr)	(mm/hr)
Clayey Sands	1	1,2,3,4,5	-	-	2.5	60
Loamy Sands	1	1,2,3,4,5	-	-	60	700
Sands	1	1, 2, 3, 4, 5	-	-	120 >	700
Sandy Loams	2A	4,5	-	-	60	700
Sandy Loams	2B	1, 2, 3	-	-	5	60
Loams	3A	4,5	-	-	60	300
Loams	3B	1,2,3	-	-	5	60
Clay Loams	4A	4,5	< 6	-	20	300
Clay Loams	4B	3	< 6	-	5	20
Clay Loams	4C	1,2	< 6	-	2.5	5
Light Clays	5A	5	< 6	-	5	40
Light Clays	5B	4	< 6	-	2.5	5
Light Clays	5C	1,2,3	< 6	-	0.5	2.5
Medium & Heavy Clays	6A	5	< 6	-	2.5	40
Medium & Heavy Clays	6B	4	< 6	-	0.5	2.5
Medium & Heavy Clays	6C	1,2,3	< 6	-	0.5	2.5

Soil permeability (Ksat) ranges for various soil textures and grade of structure in relation to (soil sodicity) ESP and (soil salinity) EC. Charman and Murphy, 2000

Soils with moderate ESP and low to moderate EC

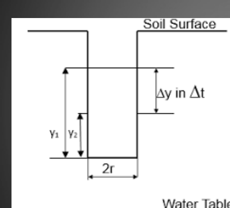
Texture	Soil Category (AS/NZ 1547)	Structure Grade*	ESP	EC(1:5) (dS/m)	Low Ksat (mm/hr)	High Ksat (mm/hr)
Clay Loams	4A	4,5	> 6	< 0.7	0.1	2.5
Clay Loams	4A	4,5	> 6	> 0.7	5	10
Clay Loams	4B	3	> 6	< 0.7	0.1	2.5
Clay Loams	4B	3	> 6	> 0.7	5	10
Clay Loams	4C	1,2	> 6	< 0.7	0.1	2.5
Clay Loams	4C	1,2	> 6	> 0.7	5	10
Light Clays	5A	5	> 6	< 0.7	< 0.1	2.5
Light Clays	5A	5	> 6	> 0.7	5	10
Light Clays	5B	4	> 6	< 0.7	< 0.1	2.5
Light Clays	5B	4	> 6	> 0.7	5	10
Light Clays	5C	1,2,3	> 6	< 0.7	< 0.1	2.5
Light Clays	5C	1,2,3	> 6	> 0.7	5	10
Medium & Heavy Clays	6A	5	> 6	< 0.7	< 0.1	2.5
Medium & Heavy Clays	6A	5	> 6	> 0.7	5	10
Medium & Heavy Clays	6B	4	> 6	< 0.7	< 0.1	2.5
Medium & Heavy Clays	6B	4	> 6	> 0.7	5	10
Medium & Heavy Clays	6C	1,2,3	> 6	< 0.7	< 0.1	2.5
Medium & Heavy Clays	6C	1,2,3	> 6	> 0.7	5	10

Soil permeability (Ksat) ranges for various soil textures and grade of structure in relation to (soil sodicity) ESP and (soil salinity) EC. Charman and Murphy, 2000

Soils with high ESP and moderate to high EC

Texture	Soil Category (AS/NZ 1547)	Structure Grade*	ESP	EC(1:5) (dS/m)	Low Ksat (mm/hr)	High Ksat (mm/hr)
Clay Loams	4A	4,5	> 15	< 1.9	0.1	1
Clay Loams	4A	4,5	> 15	> 1.9	5	10
Clay Loams	4B	3	> 15	< 1.9	0.1	1
Clay Loams	4B	3	> 15	> 1.9	5	10
Clay Loams	4C	1,2	> 15	< 1.9	0.1	1
Clay Loams	4C	1,2	> 15	> 1.9	5	10
Light Clays	5A	5	> 15	< 1.9	< 0.1	1
Light Clays	5A	5	> 15	> 1.9	5	10
Light Clays	5B	4	> 15	< 1.9	< 0.1	1
Light Clays	5B	4	> 15	> 1.9	5	10
Light Clays	5C	1,2,3	> 15	< 1.9	< 0.1	1
Light Clays	5C	1,2,3	> 15	> 1.9	5	10
Medium & Heavy Clays	6A	5	> 15	< 1.9	< 0.1	1
Medium & Heavy Clays	6A	5	> 15	> 1.9	5	10
Medium & Heavy Clays	6B	4	> 15	< 1.9	< 0.1	1
Medium & Heavy Clays	6B	4	> 15	> 1.9	5	10
Medium & Heavy Clays	6C	1,2,3	> 15	< 1.9	< 0.1	1
Medium & Heavy Clays	6C	1,2,3	> 15	> 1.9	5	10

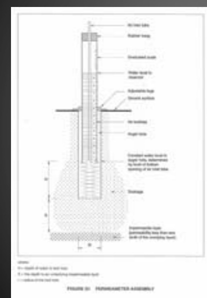
Percolation or falling head or inverse auger hole method



Measuring Ksat *in situ*

- Falling head percolation test or auger hole method (Porchet equation)
- $K_{sat} = 1.15\, r\, [\log (h_{t1} + r/2) - \log (h_{tn} + r/2)] / (t_n - t_1)$
- where:
- r = radius of the hole;
- h_{t1} = initial depth of water standing in the
- hole, at time t_1;
- h_{tn} = depth of water standing in the hole
- at the next reading, at time t_n;
- Note: a percolation rate is not identical to permeability. It just states how fast the water table in the hole drops, which depends on the size & shape of the hole as well as the soil, whereas we want to know the soil property Ksat itself

Measuring hydraulic conductivity Ksat in situ



$$K_{sat} = \frac{4.4Q\left[0.5\sinh^{-1}\left(\frac{H}{2r}\right) - \sqrt{\left(\frac{r}{H}\right)^2 + 0.25} + \frac{r}{H}\right]}{2\pi H^2} \quad \text{Eq. G1}$$

where:

K_{sat} = saturated hydraulic conductivity of the soil in cm/min

4.4 = correction factor for a systematic under-estimate of soil permeability in the mathematical derivation of the equation

Q = rate of loss of water from the reservoir in cm^3/min

H = depth of water in the test hole in cm

r = radius of the test hole in cm

Constant head soil permeability tests done by clever consultant in 4 minutes and results provided in mathematical format: 1.7E+00 m/day for EHO's benefit (who immediately knows this is 1.7 m/day)
Note that "steady state" has not been reached

Test hole geometry

	Test 1	Test 2
Hole depth (m)	0.5	
Depth (m) of water in hole	0.4	
Hole diameter (mm)	66	
Depth (m) to imperm. layer	0.4	

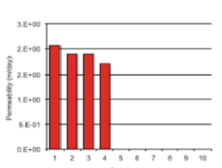
TEST 1

Depth interval (m) tested 0.1 to 0.5

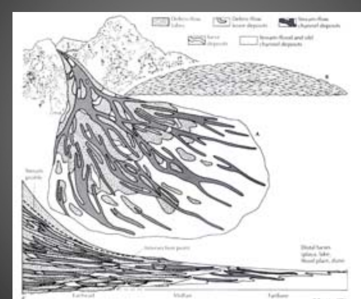
Test duration (mins)

Reading No.	Water infiltrated (L)	Time to infiltrate (min)	Infiltrat. rate (L/min)	Perme-ability (m/day)
1	1.2	2.5	4.8E-01	2.1E+00
2	1.1	2.5	4.4E-01	1.9E+00
3	1.1	2.5	4.4E-01	1.9E+00
4	1	2.5	4.0E-01	1.7E+00

Soil type tested



LCA provides a single design and loading rate for onsite systems in proposed subdivision on alluvial fan



Measuring Ksat *in situ*

Siphon to remove excess water from test hole and create constant head during test

Bulk density of soil

BD = Mass of soil / volume of solids and voids (g/cm^3)
High BD → low porosity & low permeability, poor for plant growth and treatment
High means BD > 1.6-1.8 g/cm^3

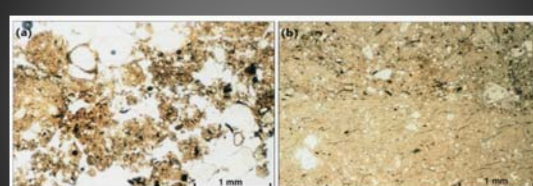


Figure 1.15: Thin sections of a soil viewed with a microscope (a) with a low bulk density (~ 1.0 Mg/m^3) and abundant pore space (the white areas between solid soil are filled with air), and (b) a similar soil in a compacted condition and with a large bulk density (~ 1.5 Mg/m^3). Note the absence of pore space and, as a result, a very small volume for storing and transmitting water and air.

Bulk density interpretation for plant growth and water movement

Table 1. General relationship of soil bulk density to root growth based on soil texture.

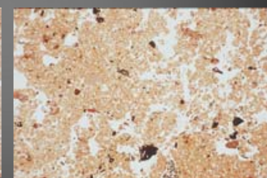
Soil Texture	Ideal bulk densities for plant growth (g/cm³)	Bulk densities that restrict root growth (g/cm³)
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

Incorporating compost lowers bulk density and increases air porosity and water holding capacity

Can the soil of the dispersal area be improved?

Clay soil with low humus

Same clay soil after compost addition at 20 tonnes/ha

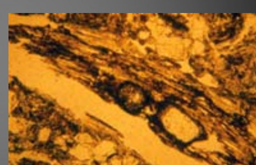


Biological effects on soil structure

What can be done to promote biological activity?

Termite channel with termite saliva reinforced walls

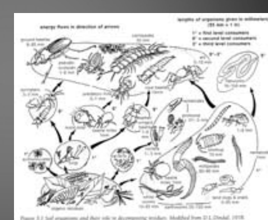
Decomposing plant root leaving a channel, bacteria shown in cell



More biological effects on soil structure

Mycelium forming strands enveloping tiny soil particles

Soil organisms contributing to soil structure formation



Organic matter

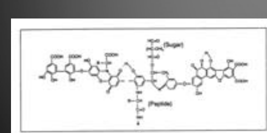
The life of the soil from the death of living things

- Formed from a host of naturally occurring organic chemicals
- Decomposing to form a very wide range of new organic materials including humic acids and fulvic acids
- The higher the degree of decomposition, the more that the remaining compounds are harder to break down
- The average age of soil humus can be from several 100 to 10,000 years
- Most soils have OM contents between 1 – 8%

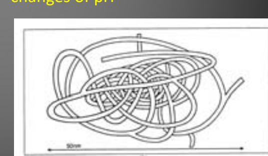
Cellulose	Vegetation, microbes, cell wall
Chitin	Insects
Gums	Exudates damaged tissues
Hemi celluloses	Vegetation, microbes, cell wall
Lignins	Plants, especially wood
Lipids	Animals, microbes, vegetation
Proteins & peptides	Animals, microbes, vegetation
Starch	Microbes, plants
Microbial saccharides	Microbes
Etc., etc.	

Soil organic matter molecules are huge and complex

Soil OM has long intricate chains of carbon "rings" with attached functional groups than can hang on to nutrients but are hard for soil organisms to digest; therefore soil humus lasts…this is a model of a humic acid molecule



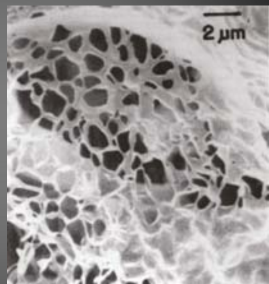
Soil OM performs many vital functions: stabilises soil structure, increases water holding, provides huge cation exchange capacity for storing nutrients like Ca, Mg, K and buffers the soil from rapid changes of pH



A macro-"molecule" of fulvic acid

(James Dragun, 1998. The soil chemistry of hazardous materials)

- The picture has been magnified approximately 23,000 times
- *[the scale = 2 thousandths of a mm]*
- Note the very large surface area available for adsorbing exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, H^{+}, Al^{3+}, etc.)



Soil organic matter dynamics: increases or declines

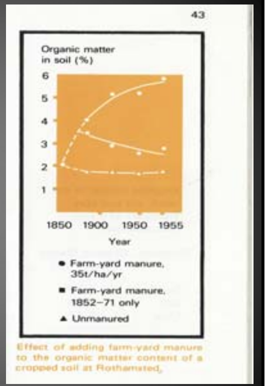
Famous experiment at Rothamsted, UK, Experiment, today 160 yrs ongoing

Each plot has always had exactly the same manuring treatment and same crop (wheat)

(a) Plots that remained unmanured gradually lost some of their original OM but then stabilised due to additions of OM from the crop residue

(b) Plots that have had 35 tonne/ha of manure have slowly increased the soil OM content but appear to be stabilising at a new, high level

Questions: What controls equilibrium OM content in the natural soil? How long will a dose of compost added to the garden last?



Soil organic matter dynamics: increases or declines - An Australian example from Kybybolite, SA

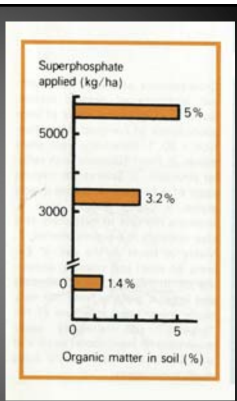
Kybybolite has a dry climate and low fertility soils, mainly sheep grazing country

Native soil OM = 1.4%. Experiment started in 1919 and ended 1958, 39 years duration.

Long term annual fertilisation with superphosphate increased fertility and stimulated pasture growth, causing soil OM to increase to levels shown in 1958 but also show slow levelling off.

Adding 3200 kg of superphosphate each year for 39 years caused the soil OM to more than double (3.2/1.4=2.3), but this does not go on forever…

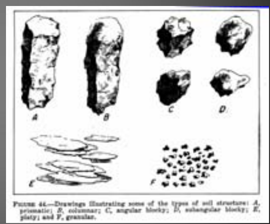
Question: What can one do to counter greenhouse carbon dioxide by sequestering carbon in the soil by agricultural methods?



Soil structure at macro level

Shrinkage and swelling initiates fracturing; fracture surfaces may be coated with organic matter and become permanent

Recognised soil structural forms



Soil structure at macro level

A very poor guide to soil permeability!

Heavy clay with prismatic compound structure, breaking into angular blocky

Sandy clay loam with platy structure, breaking to angular blocky

Soil structure at macro level

Columnar structure in the NT (entirely silicified and rock hard)

Tops of columns exposed looking like blue stone pavement

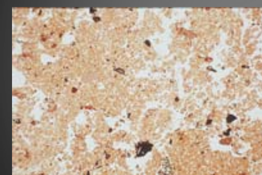
Soil structure at macro level

Paralellipipedum (only in heavy clay subsoils that shrink and swell a lot and polish the rubbing surfaces)

Coarse prismatic heavy clay breaking up in medium angular blocks

Soil structure at a micro level
Where it really matters!

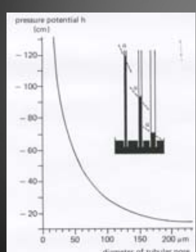
Micro-drying cracks



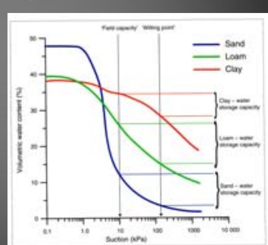
Termite channels stabilised with organic

How is water held in soils?

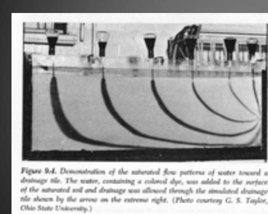
All soil pores act as capillaries
A pore with a diameter of 20µm exerts enough suction to pull water up 1.2 m



Sand contains mostly large pores so these can only be full at low suction; clay has predominantly smaller pores so clays have much of its pores full of water at a wide range of suction

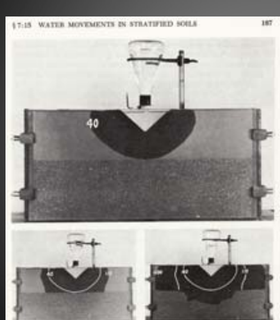


How does water flow through soil?
Saturated flow



- Saturated flow controlled by flow lines through a uniform medium
- Flow velocity is controlled by hydraulic gradient which is non-uniform here
- Hydraulic gradient equals difference in water table height divided by flow path length
  (explain)

How does water flow through soil?
Unsaturated flow



- Unsaturated flow controlled by size of capillaries (soil pores)
- Upper soil layer in picture is loam with fine pores having stronger capillary suction than lower layer of sand with bigger pores
- Only when loam layer is saturated and suction there drops to low level can water enter the sand below

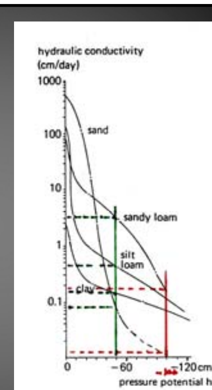
How fast can water flow through soil?

Depends (1) on soil hydraulic conductivity (i.e. permeability)

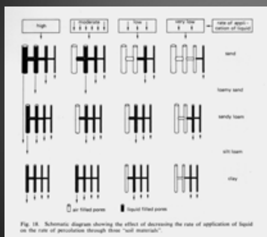
Depends therefore (2) on degree of saturation / un-saturation

If pressure potential (= capillary suction) is zero, the soil is saturated and every pore participates in letting water pass *(Note pressure potential negative!)*

As soil becomes more unsaturated, fewer and fewer pores contain water and more have air, so fewer pores are available for letting water to pass through the soil and they are narrower ⇨ conductivity decreases



Practical uses of capillary theory - Irrigation



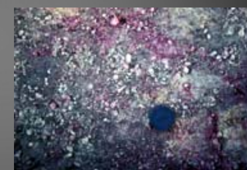
Schematic of pore sizes for different soil textures

1. Irrigating a sand with much water in a short time causes much water to be lost as the many large pores drain quickly; irrigating slowly forces only the small pores to let water through, keeping the water in the soil much longer
2. Irrigating a clay soil with much water could result in runoff, but irrigating at a moderate rate fills all the pores but these drain more slowly, keeping the water in the soil

How does percolation occur in a living soil? There are preferred pathways

Tracing flow with fluorescent purple dye – vertical flow

Horizontal flow



Grey water use for residential gardens as promoted by EPA

2.2 Greywater diversion in sewered and unsewered areas

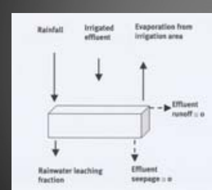
In urban areas the sewerage system is the preferred way to handle household wastewater, including greywater. If households in sewered areas are interested in utilising greywater on their own property they should install an approved system to collect and treat greywater, and store and irrigate the resulting effluent in accordance with Section 3.

Guiding Principles

1. No grey water must ever percolate down to groundwater table;
2. During any season when rainfall is enough for plant water needs, DO NOT IRRIGATE BUT STORE grey water in winter storage tank or discharge to sewer
3. Stored grey water is irrigated next season

Grey water use for residential gardens as promoted by EPA

Principle illustrated by diagram



Allowable leaching

Each drop of water that percolates down wards from a grey water irrigated garden must declare on oath that it was from Rain and not from the grey water

Is this realistic?

Grey water re-use in urban areas

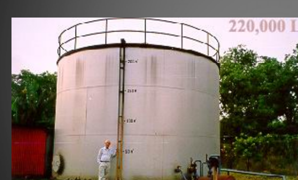
Calculation of size of grey water storage tanks for 'typical' areas in Victoria from EPA guideline [perhaps not in force today?]

EPA 168 "Guidelines for wastewater irrigation" also based on zero leaching of wastewater

Table 1: Indicative irrigation area and winter storage requirements for sites in Victoria

Location	Assume flow = 1000 litres/day		Assume flow = 500 litres/day	
	Area (m^2)	*Storage (m^3)*	*Area (m^2)*	*Storage (m^3)*
Marysville	1800	280	900	140
Welshpool/Yarram	1500	260	750	130
South-East Melbourne	1200	240	600	120
Wodonga	1000	240	500	120
Bendigo	810	220	400	110
Werribee	730	220	360	110
Horsham	360	180	180	90
Mildura	260	120	130	60

What do these winter storage tank sizes mean in real life?



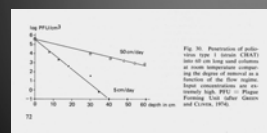
- This tank of 220 m^3 is what you need in your garden if you have a 3-bedroom house around the Bendigo area but would be 20m^3 short of what is required around the south eastern areas of Melbourne

EPA Conclusion in their own promotion document

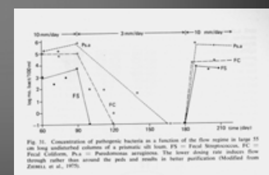
Table 1 indicates that reuse of all wastewater from a household is not feasible on typical urban lots in Victoria

Why the anxiety when the soil can be such a good purifier?

Removal rate of virus during percolation depends on loading rate. Irrigate a little a time and none make it through to ground water.



Removal rate of pathogenic bacteria. Same story: low loading rate → excellent removal



Water retention and soil texture

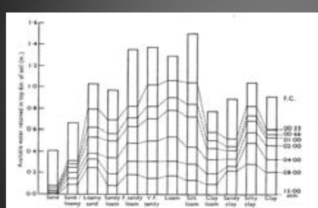


Fig.7. Water retention characteristics summarised for the different textural classes. (Salter and Williams, 1963)

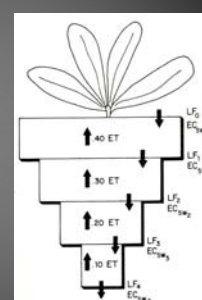
- The loams and silt loams have the best water holding capacities
- Most garden soils sold in Melbourne are very sandy

How is water taken up by plants?

Especially important under irrigation

- ET = evapo-transpiration = plant water use
- LF = leaching fraction
- EC = electrical conductivity of the water (i.e. its salinity)

Example: if applied water had a salinity of 1000 mg/L and 95% of the water was evapo-transpired, the water at the base of the root zone would contain 20,000 mg/L of salt. **Can the roots survive in that area?**



Develop a water and salt balance!

- Make sure the dispersal field is loaded to ensure some net leaching to remove added salts
- Treat the soil with gypsum (calcium sulphate) to assist the removal of excess sodium (Na)
- Always carry out a soil chemical analysis to use as a starting condition so that trends in soil chemistry over time can be determined

Technical handbooks for the LCA assessor