Sodic Subsoils in central west NSW

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Identification and management

CWFS
Central West Farming Systems

GRDC
Grains Research & Development Corporation

Acknowledgements

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References and further information

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Grains Research and Development Corporation www.grdc.com.au

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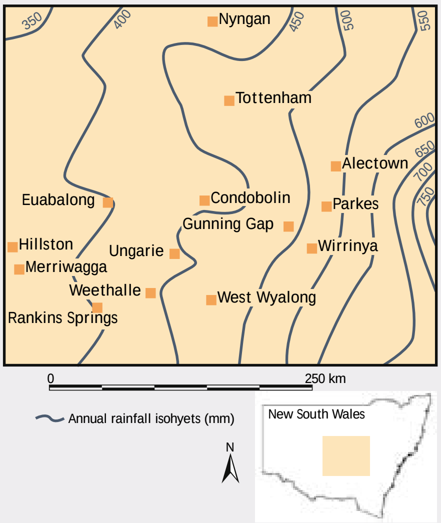

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Subsoils and Crops

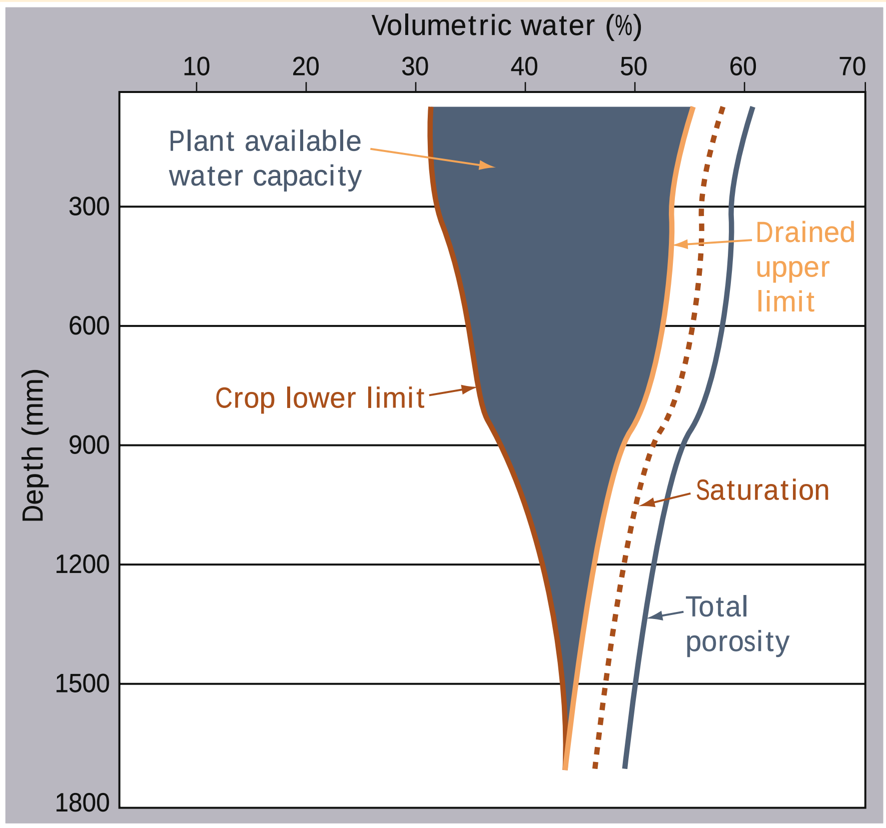
Subsoils and Crop Yield

Central West Farming Systems (CWFS) has focused recent research on subsoils as part of the Grains Research and Development Corporation (GRDC) National Subsoil Constraints Initiative.

Improvement (amelioration) of the top or surface soil has been occurring for many years and yet crop yield, in some cases, has remained lower than expected given rainfall. These lower than expected crop yields are likely to be an indicator of a subsoil problem.

The potential for crops to produce grain depends on having a supply of soil moisture and healthy roots to take up the water.

Conditions in the subsoil may prevent water from being stored. These conditions can also prevent roots growing into the subsoil or from extracting soil water, so the plant available water capacity (PAWC; i.e. the soil water available for the plant to use) is reduced (*see figure below*).



The amount of water (% of soil volume) available to plants at depth within a soil. The grey shaded area represents the plant-available water capacity of the soil and will vary for different soil types.

Cultivation and Hard Pans

Many Australian cropping soils are difficult for plant roots to penetrate. Research has shown that uncultivated soils can be hard and cause roots to grow more slowly than in cultivated soil.

Subsoil constraints such as a plough pan can cause root distortion.

Photo: Warwick Holding, Pontara Grain, Yerong Creek

However, with cultivation, compacted layers of soil known as hard pans can form below the ploughed layer, impeding root growth and the movement of soil organisms.

Beneath the cultivation zone and any hard pan, most subsoils are very dense. When roots encounter soil with high density, root growth is restricted – sometimes roots become distorted.

Plant Root Growth

Wheat Root Penetration

Root depth can be restricted in all soils if the soil profile does not fully wet. CSIRO has reported that roots do not penetrate into red loam soil if it has less than 50% plant available water capacity, as it is too hard.

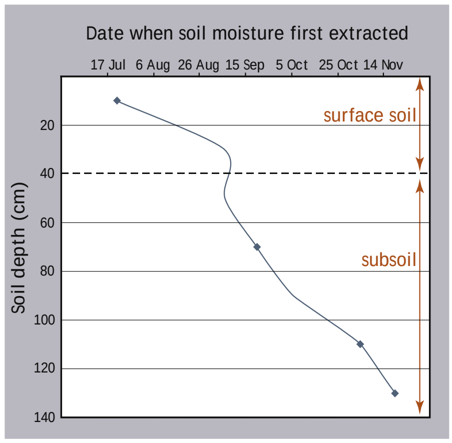
Wheat rooting depth is influenced by the depth of soil wetting, soil type and the season length of crop (sowing to anthesis).

The average root penetration rate (RPR) has been calculated for wheat:

- 1.01 cm/day in soil with a sodic subsoil
- 0.79 cm/day in soil with a hard subsoil
- 1.13 cm/day in a soil with no subsoil constraint.

Plants vary in their root structure, growth and ability to utilise soil water. This results in variation in growth (and yield) of different crop or pasture species.

Trials conducted at Condobolin investigated root activity, measured as water extraction, of a wheat crop over the growing season (*see graph below*).



Soil moisture extraction or the drying front of wheat at Condobolin.

The depth at which the subsoil begins is estimated to be 40 cm, indicated by the dotted line.

The line represents the drying front or the extraction of water by roots (presumably growing into this area of soil).

The drying front moved vertically from 50 cm (6 Sep) indicating rapid root growth in a short period of time. The roots grew from 50 to 130 cm in 69 days, equivalent to a root penetration rate (RPR) of 1.16 cm/day. This rate is similar to the CSIRO RPR where there is no subsoil constraint.

This wheat crop continued to extract water into November, during grain fill and ripening. Even though the wheat plant is beginning to senesce, it can still use water during this period if it is available.

Incomplete wetting of the soil profile often determines root depth; roots don't grow into dry soil.

This is of particular importance in central west NSW where in many seasons the soil profile does not wet to potential rooting depth. This is often the case following a dry spring and summer or after a perennial pasture such as lucerne.

Although the subsoils of this region have fewer *constraints* (*see table page 4*) than other Australian cropping zones, the fact that in many years the subsoils do not wet-up becomes a restriction in itself.

Remnant Roots

The presence of cracks and large pores, within which new roots grow, is perhaps more important than uniform *soil strength* (*see table page 4*).

Often, roots from previous crop or pasture plants have occupied these spaces, which become niche environments that actively growing roots can exploit.

Research in south west NSW has shown that at least half the roots of direct drilled crops were in direct contact with dead roots of previous crops.

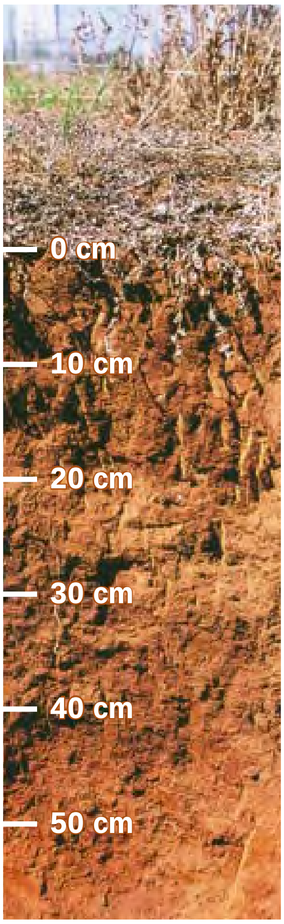
The use of existing cracks, pores and old root channels makes root growth 'easier', enabling the root to extend more quickly into the subsoil, extracting more water and nutrients.

Remnant roots in direct drilled situations may hold the key to improving the way crop root systems make use of subsoils.

New wheat root growing through old root channel.

Photo: Michelle Watt, CSIRO Division of Plant Industry, Canberra

Soil layers	
Definition	**Red soil at Condobolin, typical of the region**
Topsoil or surface soil layer	
The surface zone (from the surface to 20-30 cm, usually the A horizons). Includes the area of accumulation of organic material. Topsoil can be modified by management practices such as cultivation and the addition of fertiliser, lime and gypsum.	Soil has a loam texture and is well structured. Pasture roots have proliferated.
Subsoil layer	
The underlying soil layers (B and C horizons). They are difficult to modify. In the red soils around central west NSW the subsoil is below 20-30 cm.	Clay content is higher and the soil is more compact than the topsoil. There are fewer roots growing through the soil.



Subsoil Constraints

Salinity is a major soil constraint. Surface soil salinity has greatly restricted plant growth at this site at Ootha.
Photo: Luke Beange, NSW DPI Dubbo

A subsoil constraint is:

- any physical or chemical characteristic of the subsoil that limits the ability of crops or pastures to access water and nutrients;
- either a natural occurrence or the result of farming practices;
- a natural occurrence throughout large sections of the Australian grain belt;
- known to occur on its own or with other constraints;
- known to vary greatly in severity within the space of even a few metres; and
- known to have a highly seasonally dependent impact on crops and pastures.

A reliable indicator of the presence of a subsoil constraint is water remaining in the soil profile at harvest that a crop did not use, especially following a dry finish.

Examples of subsoil constraints

Subsoil constraint	Description	Impact on plant growth	Comment
Acidity	Soil with pH less than 7.	Plant growth is affected when soil pH_{Ca} is less than 5.	Prevalent in many soils in Western Australia and some lighter soils in south-east Australia.
Alkalinity	Soil with pH greater than 7.	Plant growth is affected when soil pH_{Ca} is greater than 9.	Prevalent in areas of Victoria and South Australia and heavy clay soils in northern New South Wales and Queensland.
Nutrient deficiencies	As soil pH changes some nutrients become less available to plants.	Nutrient deficiency indicated by a range of plant symptoms.	Nutrient deficiencies and toxicities are more prevalent in soils with very high or low pH.
Nutrient toxicities	As soil pH changes excess levels of some nutrients are released into the soil at toxic levels.	Nutrient toxicity indicated by a range of plant symptoms.	
Salinity	Salinity is due to excess salt, often sodium chloride, within the soil.	Many plants do not grow in saline soils.	Salt scalds can often be identified by white crystals appearing on the soil surface.
Sodicity	Sodic soils have excess sodium attached to the clay particles in the soil.	Restricts root growth.	Soils disperse and resemble a plasticine-like mess when wet and a baked brick when dry.
Soil strength	Soil strength is often related to the bulk density of a soil.	Restricts root growth, particularly as soil dries.	A soil with high soil strength often cannot have a push probe (or similar) pushed into it, especially when it is dry.
Waterlogging	The presence of excess water in the soil that has replaced some or all of the air.	Plant roots cannot get air from the soil, greatly restricting plant growth.	Long-term waterlogging can cause plant death.

Sodic Soil

Sodic soils have excessive sodium attached to the clay in the soil which turns the soil into a plasticine-like mess when wet and a baked brick when dry.

The dispersive nature of a sodic soil causes soil pores to become blocked. Sodic soils are characterised by:

- restricted water infiltration;
- restricted soil water movement and internal drainage;
- reduced soil aeration;
- reduced porosity;
- high bulk density; and
- reduced capacity to store water.

Crop germination, establishment and growth can be dramatically reduced. Root growth, water use efficiency, and the resulting crop yield or pasture production is often very poor.

Surface soil sodicity

In the surface soil layer, the effects of sodicity can be overcome by application of chemical ameliorants (e.g. gypsum) or addition of organic matter (e.g. manure) combined with reduced/zero-tillage practices to promote soil fauna (e.g. earthworms, termites) that create macropores (large holes in the soil).

Subsoil sodicity

Sodic subsoils can restrict plant root growth and water uptake.

In addition, sodicity alters the nutrient balance in the crop, restricting uptake of some nutrients but allowing others, such as aluminium, to be taken up in excess of the crop requirements. This leads to nutrient imbalance and can result in nutrient toxicity and further restriction of soil water uptake.

Many sodic subsoils are effectively impermeable. Crops grown in them are often subject to waterlogging in the surface soil layer and a lack of oxygen. Crops can also be subjected to moisture stress due to the low soil water availability within the subsoil layer itself.

Sodicity increases with depth in many central west NSW soils. The management of sodicity becomes more of a challenge with increasing depth.

Sodic Soil

In Australia, the term *sodic* has been applied to soils with an exchangeable sodium percentage (ESP) greater than 6%. That means the amount of sodium, as a percentage of the sum of the cations or the cation exchange capacity, is greater than 6%.

Recent research has questioned this definition of sodicity for a ***subsoil.*** It is suggested that an ESP greater than 15-20% should be used to define a ***sodic subsoil***.

Photo: Megan Rogers, NSW DPI Forbes

Subsoil Constraints in Central West NSW

Member Survey

CWFS surveyed members about their knowledge of subsoils. Of the respondents (71) over half (58%) considered subsoil constraints to be a problem.

The problems listed were:

- compaction (52%)
- sodicity (27%)
- acidity (11%)
- unspecified (16%)

Half of those surveyed managed their problem areas differently to the rest of the farm.

Most thought that subsoil constraints do limit plant rooting depth, decrease plant available water, decrease crop production and decrease profitability. Most were unsure about management of subsoil constraints. 92% of those surveyed were interested in learning more.

Central west NSW has soils with fewer subsoil problems than many other grain growing areas of Australia.

Incomplete wetting of the soil profile often determines root depth as roots cannot grow in dry soil. This is relevant in central west NSW where it is common for the soil not to wet to a significant depth, particularly if a deep rooted plant, such as lucerne, has been grown in previous years.

Although the subsoils in the region have fewer constraints than other areas, the incomplete wetting of the subsoils will result in a lack of plant roots in this zone.

Soils in the Condobolin District

Data for red soils was sourced from research trials in the Condobolin district and collated.

The majority of the soils were moderately acidic at the surface (56% had pH_{Ca} less than 5 at 0-10 cm) tending to alkaline with depth.

Soil pH_{Ca}, ESP and EC all increased with depth, whilst Ca:Mg decreased with depth.

Half the subsoils were sodic and had low Ca:Mg, which could result in dispersion.

Using the ***subsoil sodicity definition,*** ESP greater than 18% (see page 5), the Condobolin soil data now showed:

- 3% are sodic at 20-40 cm
- 8% are sodic at 40-60 cm
- 14% are sodic at 60-80 cm
- 25% are sodic below 80 cm

Average subsurface soil chemical properties for red soils of central west NSW

Soil Depth	pH_{Ca}	eCEC	Ca	Mg	K	Na	Al	ESP	Ca:Mg	EC
10-20 cm	5.43	11.46	6.94	2.92	1.12	0.39	0.19	2.81	3.14	0.05
20-40 cm	5.92	14.30	8.14	4.36	0.87	0.85	0.20	4.79	2.36	0.06
40-60 cm	6.38	17.42	9.12	5.92	0.84	1.48	0.15	6.90	1.81	0.11
60-80 cm	7.24	25.06	13.08	8.04	1.06	2.86	0.76	8.72	1.77	0.27
80+ cm	7.58	28.74	14.23	9.24	1.15	4.11	0.46	11.56	1.63	0.37

pH_{Ca}—soil pH measured in calcium chloride solution; pH_{Ca} less than 5 affects plant growth.

eCEC—effective cation exchange capacity (cmol/kg); sum of the cations Ca, Mg, K, Na, Al.

Ca—calcium
Mg—magnesium
K—potassium
Na—sodium
Al—aluminium
(each in cmol/kg)

ESP—exchangeable sodium percentage; a measure of sodium as a percentage of the sum of the other cations, excluding Al; ESP>6 in surface soil affects plant growth.

Ca:Mg—the ratio of calcium cations to magnesium cations; if less than 2 soil is usually dispersive.

EC—electrical conductivity (dS/m); a measure of salinity; greater than 1 dS/m may affect plant growth; >0.1 dS/m may affect growth of salt-sensitive plant species.

Subsoil Water in Central West NSW

Seasonal conditions have a significant impact on the value of subsoil water. In cereals it is likely to range from 0 to 100 kg extra grain grown per hectare for each millimetre of water, depending on the season.

Plant species differ in their ability to use subsoil water. Soil moisture content was monitored at Condobolin in both cereal and field peas.

The results are presented in the graphs below. Soil moisture was measured to 170 cm at sowing time and at harvest.

The subsoil starts at approximately 40 cm and is indicated by the dotted line.

The difference between the two lines on each graph, plus rainfall, is the amount of water used by the crop between the two sampling dates.

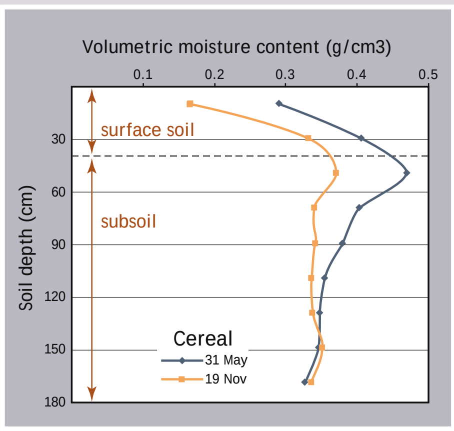
The cereal extracted or used water down to 140 cm (the point where the two lines meet), while the field peas used little water below 90 cm.

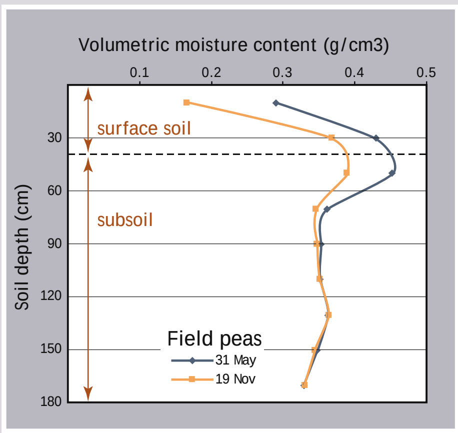
Monitoring at the CWFS Core Site found 30% less soil water to 3 metres depth in a farming system that contained a perennial pasture phase (generally lucerne) compared with a continuous cropping system with annual crops. Wheat extracted water to a depth of 90 cm and lucerne to a depth of 150 cm.

In another program conducted by CWFS soil in seven paddocks was monitored for three years to investigate the effect of sodic subsoils on plant growth.

The seasons were all dry and plant roots were found to be extracting soil water in all years.

The results showed a great effect of soil water on plant growth but little effect of sodic subsoils.





Soil moisture content at sowing (31 May) and before harvest (19 Nov) of cereal and field peas at Condobolin.

One method to measure soil moisture is to take a soil core (top), split it into desired depth increments and bring samples to the laboratory in well sealed plastic bags (middle). Samples are weighed, then dried in tins (bottom), then re-weighed. The soil water is the difference between the initial sample weight and the dry weight.

Photos: Daryl Reardon, CWFS

Managing Subsoil Constraints

Identifying the soil problem

When considering high-cost soil management options:

- Identify the exact subsoil problem(s). Do not assume, guess or use a neighbouring paddock test.
- Test each paddock individually or the problem area within a paddock. Soils and their test results can be variable over short distances.

Photo: Linda Brangwin, formerly CWFS

Crops are always constrained by the most limiting factor. When there is more than one subsoil constraint, addressing the most limiting constraint first is essential to achieving improvement in crop yield and pasture production.

For growers in central west NSW, the greatest constraint to crop yield and pasture growth is often the lack of subsoil moisture.

Subsoil improvement

Growers may be able to maximise yield potential by ameliorating the subsoil. However results have varied significantly, depending on the paddock and crop. The cost of solutions to subsoil constraints may also preclude their implementation.

Selecting and implementing an agronomic management system to accurately match production with the potential of the paddock is likely, in many cases, to be the initial course of action.

Agronomic management

Agronomic management can be used to reduce the impacts of subsoil constraints. Practices such as timely sowing and adequate nutrient supply can improve root growth, increasing the volume of topsoil exploited by crop roots. This reduces the reliance of crops and pastures on water and nutrients in the subsoil.

Selected agronomic practices can be used to manage sodic soils and improve crop yield and pasture production (see table page 9).

Management considerations

Before any management practice is undertaken to improve soil conditions the associated implications need to be considered. For example:

- yield penalty (short term);
- yield improvement (short and long term);
- implementation costs (ameliorant including freight, machinery, additional fuel, etc.);
- trafficability of the paddock after subsoil operations;
- risk of erosion;
- cost of enterprise change;
- benefit of enterprise change; and
- opportunity cost of alternative investment.

The management strategy used will depend on:

- the nature and extent of the constraints present; and
- the relative cost of the strategy compared to potential improvement in financial returns.

Managing Sodic Soils

Agronomic management of sodic soils

Tactic	Comment
Gypsum application	The addition of gypsum is the most effective way of improving a sodic surface soil. The most efficient method is to apply low rates annually. The main aim is to change the sodic properties of the soil by removing sodium from the clays, replacing it with calcium and providing the complementary salt concentration in the soil solution.
Lime application	The addition of lime has been found beneficial to some sodic surface soils. In many cases it has been used in conjunction with gypsum which works quickly while the lime works more slowly.
Long-term pasture phase	Organic matter is important in improving soil structure as it forms linkages between soil particles which are stable in water. Sodium removal is essential to improving sodic soil structure. Once sodium is removed e.g. by gypsum, organic matter from a long-term pasture phase allows the formation of stable linkages between soil particles.
Deep ripping	Can aid infiltration and root growth in the short term. In some cases deep ripping can cause aggregates to slump back to a worse state than before ripping. Use gypsum with deep ripping to reduce the risk of this disastrous effect.
Primer crops	Primer crops modify the soils by providing biopores (pathways) for the roots of following crops. Lucerne may be grown as a primer crop in central west NSW. In other regions chicory and sulla have been used successfully. Growing a primer crop may dry the soil profile, reducing plant available water and subsequent crop yield.
Raised beds	Raised beds have greater infiltration, lower bulk density, lower shear strength and lower penetration resistance compared to conventional treatments. Grain yield may be reduced significantly by temporary waterlogging from perched water tables overlaying poorly structured (sodic) clay subsoils with low porosity, even in lower rainfall zones (350 - 550 mm annual rainfall). Raised beds may be a way to increase the root zone and limit the impact of this waterlogging. Some paddocks are not suited to raised beds because of inappropriate soil type or slope. On a heavier clay soil around Forbes, much success has been achieved through the use of raised beds to improve soil structure, increase the root area and decrease waterlogging.
Tolerant crops	Crop or pasture species choice can be used to optimise production. Pasture species have been tested in the Bland area of south west NSW, on hard-setting, heavy clay soils which are mostly sodic. The best annual legumes were Clare sub clover, balansa clover, rose clover, gland clover, burr medic and waterlogging tolerant yanninicum sub clovers such as Riverina. *Dear et al. (2005)*

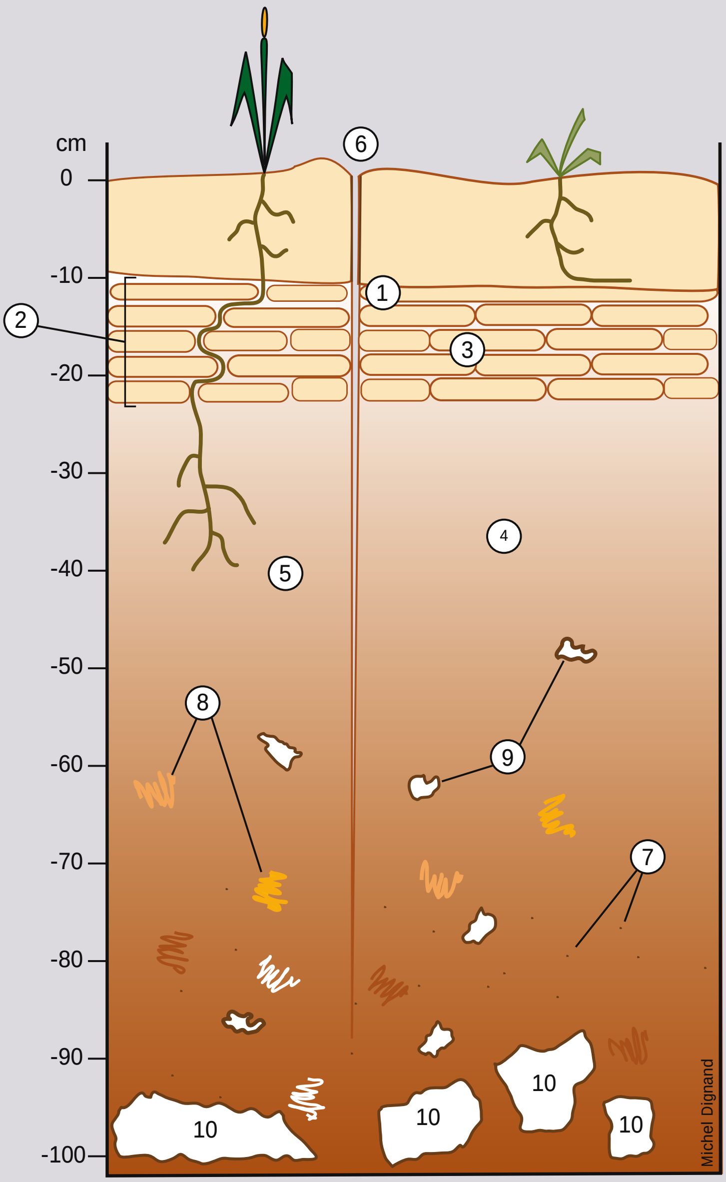
Use of Primer Crops

The soil profile immediately following lucerne was drier than observed for other rotations in trials at Temora, southern NSW.

However the residual lucerne root channels can improve water infiltration into the subsoil to delay the onset of waterlogging. These root channels also provide preferential pathways for the roots of following crops (*see page 3*) and the overall water use by crops can be increased.

Dear et al. (2005)

Soil Profile



1. Plough pan
2. Bleached zone (very pale layer)
3. Compaction
4. Texture change (clay increases in our soils)
5. Plant roots
6. Deep cracks
7. Buckshot
8. Mottling (mixes of colour caused by a range of factors e.g. waterlogging)
9. Lime concretions
10. Stones

Source: SoilPak Southern NSW

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