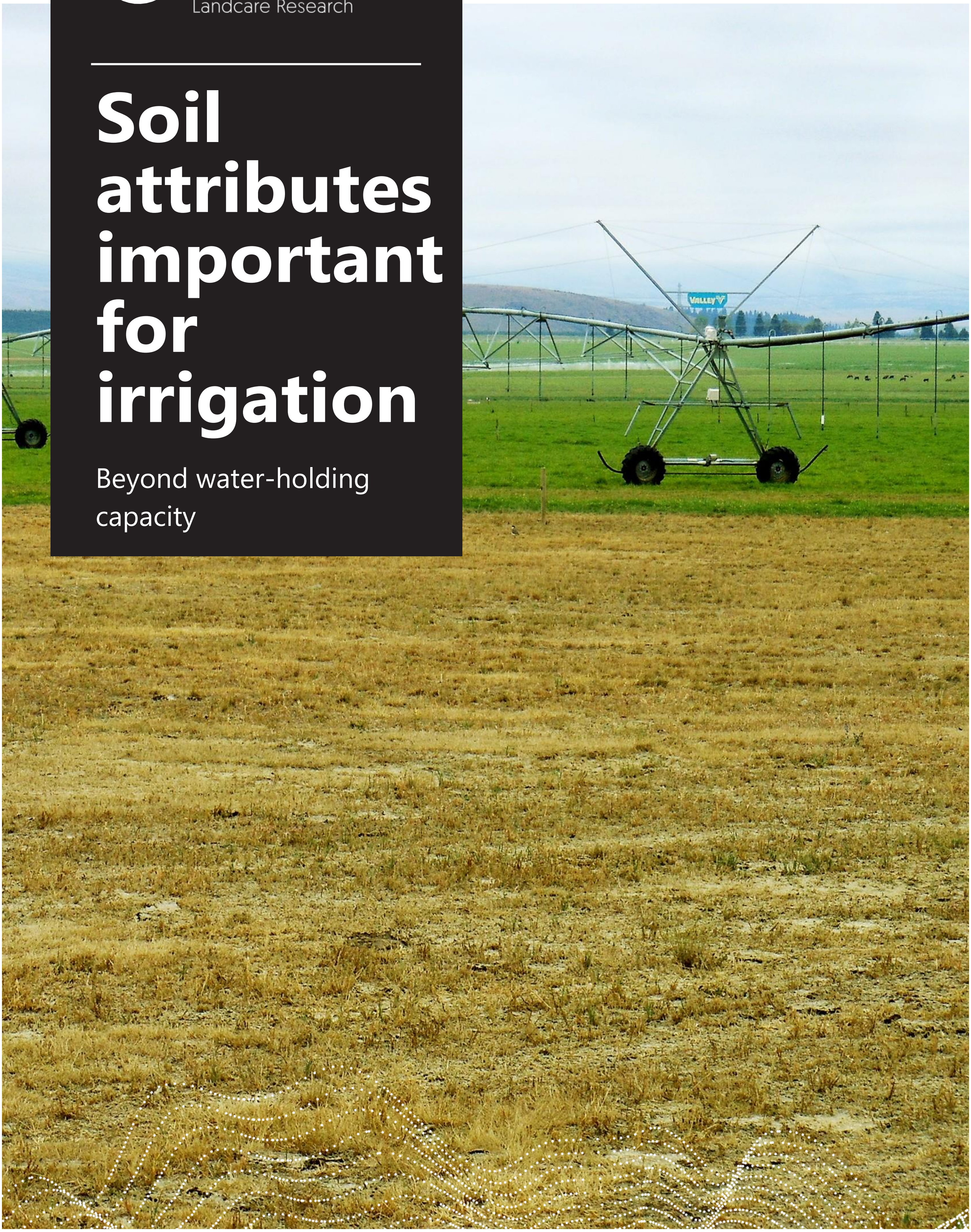
A Sustainable Farming Fund Project

Manaaki Whenua
Landcare Research

Soil attributes important for irrigation

Beyond water-holding capacity



Introduction

Understanding the behaviour of the soil water attributes underneath your irrigator is of great importance to efficient management of the water, soil and environment. Knowing the soil's water storage capability allows you to apply sufficient water for crop production while avoiding excess drainage and loss of nutrients to the environment. There has been a large increase in awareness and knowledge of soil water-holding capacity within the agricultural community, with farmers now monitoring soil water content underneath their irrigators. However, in addition to understanding and monitoring soil water content, there are many soil attributes that are important to consider for good irrigation management, such as infiltration rate, subsoil permeability and drainage class. If these attributes are not managed effectively, they will have an impact on soil health, plant growth and overall productivity.

Infiltration rate

Knowing the rate that water infiltrates at the soil surface is essential for avoiding ponding and runoff under irrigation. If water is applied at a rate greater than it can infiltrate, it will pond on the soil surface. If the soil surface is uneven, this ponding can result in uneven wetting of the soil and uneven pasture growth. Water applied too quickly on a slope will cause runoff, which may in turn cause surface erosion.

The rate at which water infiltrates soil is not constant (Figure 1a). Initially infiltration is faster as water fills the empty soil pores near the surface, but then the infiltration rate slows as the infiltrating water must displace existing water in the soil pores.

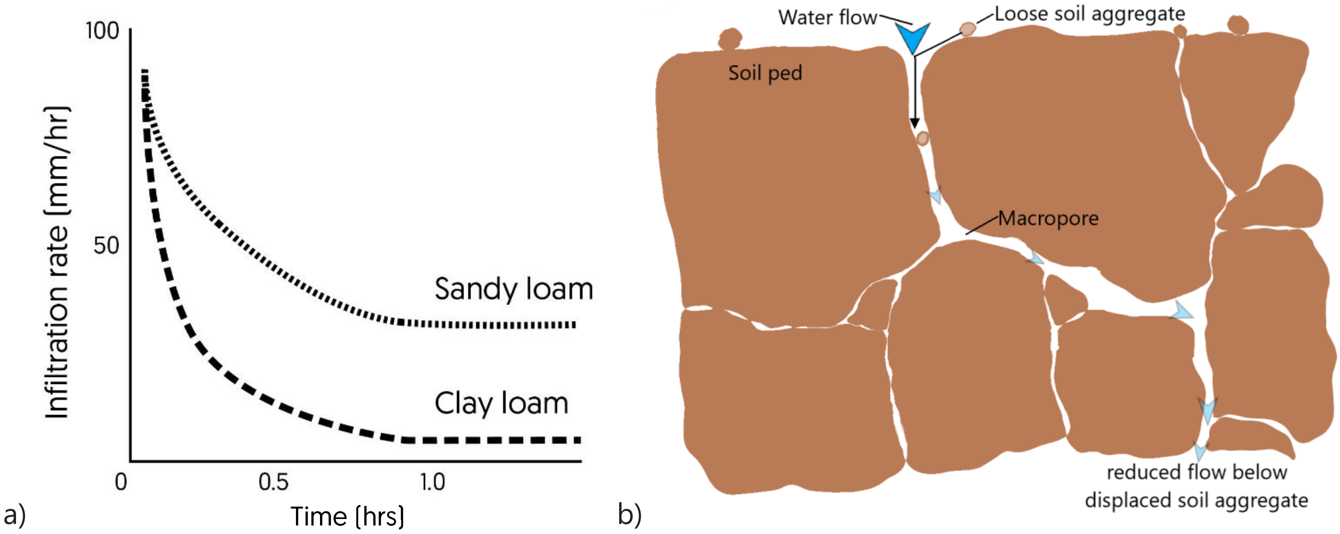


Figure 1. a) Infiltration rate against time for two different soil textures; b) soil pores may become restricted by dislodged soil aggregates (adapted from McLaren & Cameron 1996).

When water is sitting on top of the soil, the soil surface is effectively saturated and is vulnerable to compaction. Overland flow and ponding may also cause the transport of fine sediments (loose soil aggregates), which settle in the ponded area and can partially block soil pores. This further slows the rate of infiltration and prolongs the period that soil is at risk of structural damage (Figure 1b).

The infiltration capacity is strongly dependent on the structural condition of the topsoil, which can be easily and quickly assessed in the paddock using Figure 2. Guidelines are also available to show how to do a full visual soil assessment (Shepherd 2000).

Dark topsoil, good aeration, good infiltration	Medium structure, moderate to low infiltration	Pale grey, poor structure, low infiltration

Figure 2. Identifying infiltration from topsoil structure and colour (source: Shepherd 2000).

Infiltration rates can also be impaired by a denser and less porous subsoil layer preventing drainage through the profile (Figure 3). In addition to slow infiltration, overly rapid infiltration can also be a limitation for irrigation. Sandy topsoils overlying sandy subsoils or gravels will have rapid permeability and infiltration. Water applied to these soils generally moves quickly through the soil profile, although some perching of water may occur in sandy loam layers above gravels (Beecroft et al. 1986). Rapid infiltration reduces problems associated with ponding and saturated soils, but soils with rapid infiltration typically have a low available water capacity, limiting their suitability for some management and irrigation systems. If not managed carefully, such soils may have greater potential for the loss of soluble nutrients.

Medium soil structure **Good** infiltration **Low** ponding risk

Coarse, dense soil structure **Slow** infiltration **High** ponding risk

Figure 3. Identifying permeability and infiltration from subsoil structure and colour

Subsoil permeability

Permeability is the rate at which water is able to flow within the soil profile (whereas infiltration is entering the soil surface). It is dependent on the nature of the pore system in the soil.

For many soils, the permeability rate of subsoil is different from that of the topsoil. So while your soil surface may have a fast infiltration rate, if the subsoil permeability is slow, water will be 'perched' above the slow subsoil horizon (or layer), elevating the risk of ponding and compaction (Figure 4).

This perching of water means the soil is at or near saturated conditions. The soil is now in its most vulnerable structural state, and heavy machinery or stock can easily cause compaction or pugging damage. Slowly permeable soils also have impaired aeration, leading to low root respiration and slow plant growth.

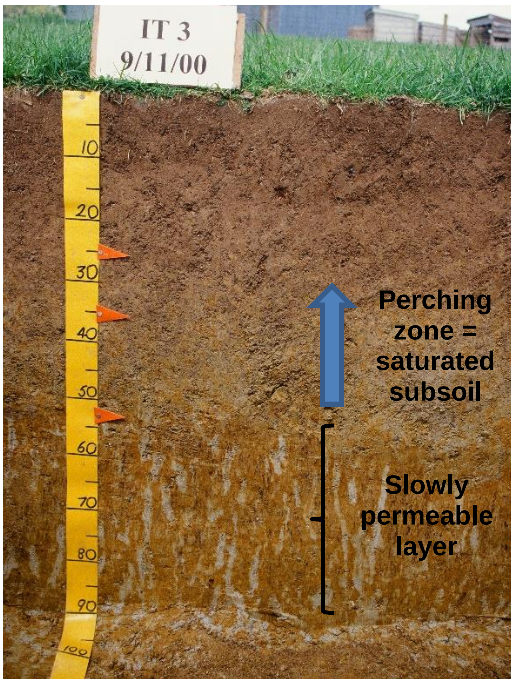


Figure 4. Effect of subsoil permeability

Knowing the soil's permeability is important when considering such things as artificial drainage spacings, and irrigation system design and management. Soil permeability is often described in terms of different classes, such as rapid or slow, and can be either directly measured or estimated from soil characteristics such as structure, porosity, compaction, texture and colour (Griffiths 1975).

- Crumb or nutty structure indicates moderate to rapid permeability. These soils usually have a yellowish-brown colour due to the presence of oxygen.
- Soils with a blocky or prismatic structure are likely to have slower permeability. This reduced permeability is often indicated by paler yellowish colours accompanied by mottles (rust-like blotches of colour).
- Grey colours in the soil indicate prolonged waterlogged conditions and may be indicative of a high water table or severely impaired drainage from a pan. The presence of a pan indicates very slow permeability. Generally, soils described with slow or very slow permeability require careful management under irrigation.

Effects of permeability in shoulder seasons

Slowly permeable soils need to be managed carefully during the shoulder seasons of autumn and spring to avoid elevating the risk of ponding and compaction (Figure 5). Although the soil surface may appear drier, the subsoil will take a long time to drain, particularly if affected by a high water table over winter.

Once a slowly permeable soil becomes saturated, it is often wet for the rest of the winter and must be managed carefully throughout this time by avoiding heavy stocking and machinery. In autumn, irrigation on slowly permeable soils should be avoided or minimised. This allows the soil to reach a greater moisture deficit and provides a greater time at the start of winter before the subsoil becomes saturated and vulnerable to compaction and pugging.

At the beginning of spring, slowly permeable subsoil will remain saturated much longer than the topsoil. The start of irrigation should be delayed as much as possible while the subsoil is wet to allow the subsoil to continue to drain and dry out. When no longer saturated, the soil will be less vulnerable to damage from cultivation or grazing, and it will warm up faster, boosting pasture growth. Minimising irrigation in spring will also reduce the effect of late storms by allowing the soil to absorb more water and reduce runoff.

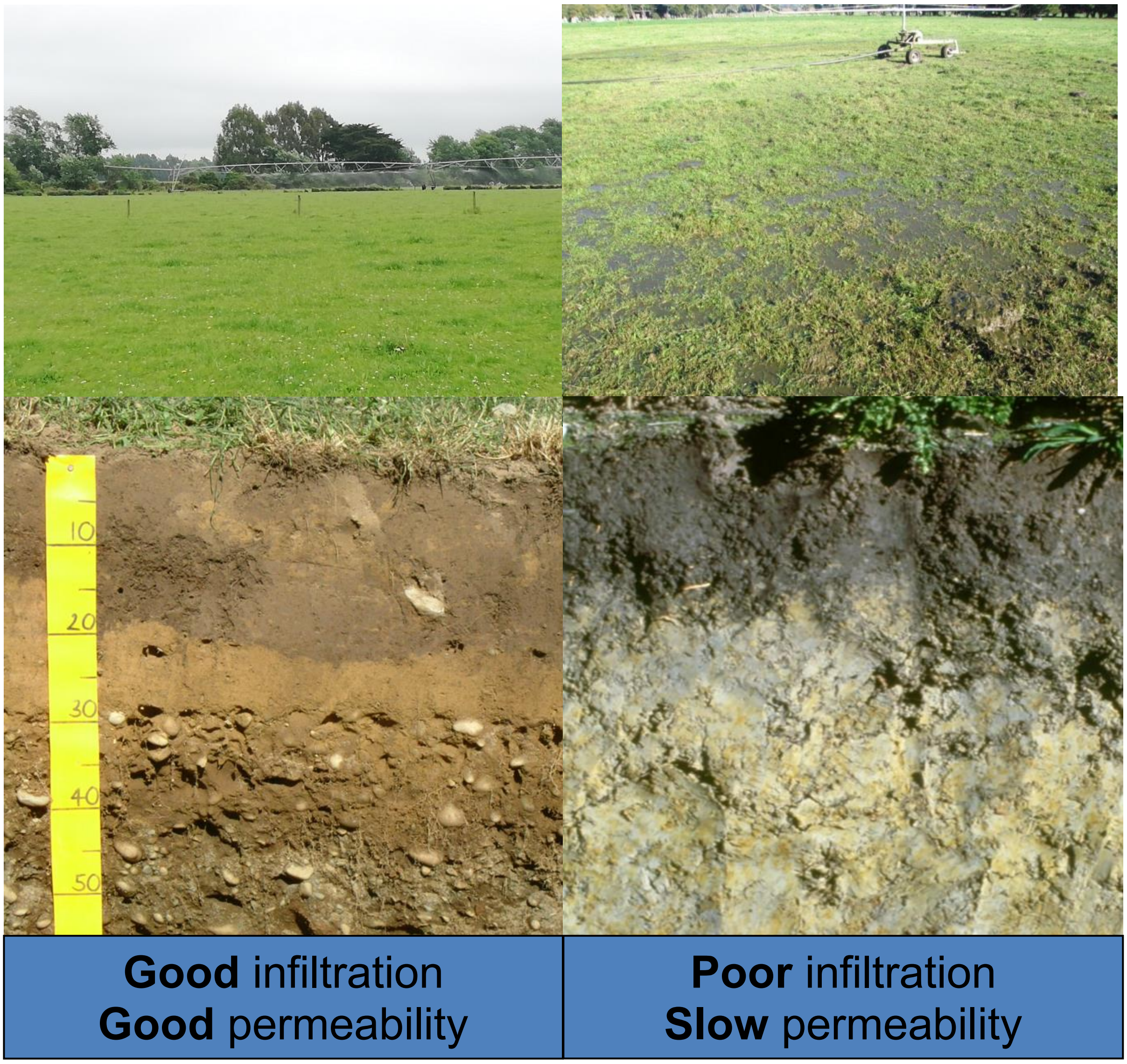


Figure 5. Soil structure and colour, and associated ponding risk.

Salinity

Salt causes soil aggregates to lose their structure and disperse, and the soil pore system to collapse or become blocked by fine particles. These soils then have poor drainage and a weak structure, making them vulnerable to compaction and erosion. In addition to the effects of soil structure on plant growth, salinity can further reduce plant growth by reducing the amount of water that can be taken up by the plant and, in extreme cases, can remove water from plant cells (because of the increased osmotic potential of the soil solution).

It is therefore important to manage soils and soil water carefully in areas where salt deposition is an issue. In New Zealand, salinity is mostly a challenge in parts of the Central Otago basins, where salt deposits have accumulated through gradual weathering of the soil material and there has been insufficient rainfall to wash these salts through the soil. When irrigating these areas it is essential to ensure that irrigation water is clean. Water accumulating in low-lying areas may contain accumulated salts that have been leached from surrounding soils and should not be used for irrigation. Likewise, over-irrigating higher areas in the landscape can cause issues with salts being washed out into adjacent lower areas.

Salt accumulation may also occur in coastal areas due to the influx of saline water below the ground surface, or where past estuaries have become uplifted and are now part of the land surface.

Through careful management, salts can be flushed through the soil profile with clean water. The addition of calcium or magnesium to saline soils can help to alleviate the effects of salt on soil structure by causing flocculation (the formation of dispersed soil particles into soil aggregates or peds).

Drainage class

Adequate drainage of excess water is essential to ensure soil aeration is sufficient for root and microbial growth, and to allow the soil to support heavy machinery and stock. Fine-textured soils with poor structure generally have slow permeability and some degree of drainage limitation, while coarse-textured stony or sandy soils have rapid drainage but a low water-holding capacity. Drainage is also affected by the presence of subsoil pans and shallow water tables, with both resulting in water being held up or ponded within the soil profile (termed 'perching'). Slope, surface runoff and position in the landscape also influence drainage class, as it is a measure of the overall rate at which water is removed from the soil (Beecroft et al. 1986).

If irrigation is undertaken on or around areas with poorly or imperfectly drained soils, then artificial drainage may be needed on farm, and an irrigation scheme drainage system may be required in extensive low-lying areas. The required depth and spacing of drains will be determined by the depth to the water table (when at its shallowest) and the permeability of the soil. Soil permeability will determine the rate that water can move laterally though the soil to the drain, as well as vertically down the soil profile. Careful management of water application can help combat drainage problems through the control of both irrigation frequency and application rate, particularly in the shoulder seasons, when these soils can easily become waterlogged.

Well drained	Imperfectly drained	Poorly drained
<2% mottles within 90 cm of surface	<50% grey colours within 15 cm of the topsoil	>50% grey colours within 15 cm of the topsoil

Figure 6. Drainage classes used to classify New Zealand soils

Drainage class can be identified by looking at the visual characteristics of the soil (Milne et al. 1995, p. 148; Griffiths 1975, p. 28). A key feature to observe is the colour pattern in the soil underneath the topsoil (the subsoil). Soils are grouped into one of five drainage classes based on the presence and relative abundance of rust-like 'mottles' and grey colours in the subsoil. Well-drained soils typically have a uniform yellow-brown colour in the subsoil with less than 2% mottles. Increasing size and proportion of mottles and grey colours, and at shallower depths, indicates increasingly poorer soil drainage (Figure 6). Well-drained but young Recent soils may also have pale grey subsoil colours due to having had little weathering, so care needs to be taken not to confuse these with poorly drained soils.

Grazing time relative to irrigation

In order to avoid soil structural damage, timing your grazing or heavy machinery work around your irrigation is important. Compaction and pugging cause collapse of the macropores, as well as a reduction in the overall proportion of pores to mineral (solid) material in the soil. A pore of 1 mm radius will have a flow rate 10,000 times faster than a pore of 0.1 mm radius (McLaren & Cameron 1996).

Severe compaction and pugging will have a 'snowball effect' if not carefully managed. The reduction in size of, and connection between, pores will reduce infiltration, permeability and drainage, which may result in prolonged ponding and saturated conditions, leaving the soil vulnerable to further damage. Compacted or pugged soils should be avoided when wet, and they should be spelled to aid natural soil recovery processes (aided by soil microbes, worms, and freeze/thaw mechanisms during heavy frosts). Reduced aeration will decrease the ability of roots to breathe and grow, and will delay soil warming in spring, which explains the reduced productivity seen on compacted soils.

Summary

Infiltration, permeability and drainage of soils are interlinked, with slowly permeable soils also having impeded drainage and often slow infiltration. Different horizons or layers in the soil may have different permeability, and the overall behaviour of the soil profile is determined by the least permeable horizon. Even if a topsoil is highly permeable and has good infiltration, if there is a low permeability horizon below it then the water has nowhere to go, making drainage of the whole soil profile slow.

Many of the soil characteristics that are important for efficient irrigation management can be recognised by examining the structure and colour of the soil. Bright, uniform colours and medium structure indicate that excess water will move through the soil profile and it does not remain under saturated conditions. Coarse, blocky structure and the presence of mottles indicate that the soil can become saturated for periods of time. If the subsoil is largely grey in colour, then the soil is likely to be under saturated conditions for prolonged periods, and artificial drainage may be required in order to use the soil for agricultural purposes.

Irrigation water should be applied at a rate at or below the infiltration rate of the soil. If ponding does occur, these soils should be avoided until they have had a chance to return to field capacity. Similarly, heavy machinery or stock should be kept off low-permeability soils when wet. If ponding regularly occurs when irrigating, consider reducing the application rate of your irrigator, if your system allows this. Even if ponding does not occur, grazing should be avoided on paddocks that are being or have just been irrigated. Water applied will take time to infiltrate down through the soil profile, and the soil at the surface will be above field capacity and vulnerable to structural damage immediately after irrigation.

Irrigate with clean water. Salts in the soil will impair soil structure, reduce drainage rates and lower productivity. If irrigating with well or pond water in areas near the coast or lagoons, or in low rainfall climates, test the water to ensure it is free from salts that may damage your soil or reduce productivity.

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