Soil Health

FOR FARMING IN TASMANIA

Bill Cotching

Cover photographs: Versatile Ferrosols used for intensive cropping in northwest Tasmania and soil investigation by Robert Addison and Bill Cotching.

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"One is born, one dies; the land grows" (Ethiopian proverb)

The minerals in our bodies come from soil and return there when we die. This demands that we respect soil, which requires us to understand its nature, its functions and its differences. Soils are complex natural systems that are a product of their local environment and no two places on earth have identical soils.

Professor Harry Gibbs inspired me to follow a career in soil science as he showed me the very practical nature of soils as well as the scientific understanding of the pedosphere and its relationship to a deeper understanding of landscapes. I credit him with teaching me to undertake careful observation and recording in the field as the basis of soil science that can be built on with further scientific investigation. The fruits of this careful observation can then be transferred in simple terms to those who manage the land on a day to day basis. We need to be wary about education being a process of trading awareness of the natural world for knowledge of lesser worth.

This book describes soil properties important for farming in Tasmania. It is intended as a guide to identifying readily observable soil attributes that impact on farm management. There is an emphasis on what you can see and feel with some guidance on what can be done about managing in a practical on-the-paddock way. This book is not intended to be a guide to soil chemistry, fertilisers or crop agronomy.

I have benefited from being able to practice soil science on farms in New Zealand and Australia where I have gained knowledge about the productive use of soils from farmers. There are many colleagues that have taught me much about soils and their behaviour. I wish to acknowledge Bob Allbrook, Colin Bastick, Doris Blaesing, Bill Chilvers, Des Cowie, Richard Doyle, Chris Grose, Marcus Hardie, Darren Kidd, Mike Laffan, Simon Lynch, Professor John McCraw, Neil McKenzie, Garry Orbell, Greg Pinkard, Wim Rijkse, Leanne Sherriff and Leigh Sparrow.

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1. Introduction

"Healthy soils make healthy people" (Hans Jenny)

Farmers have tilled the soil since settled agriculture originated some 10,000 to 13,000 years ago. Simple tools were developed to place and cover seeds in the soil, eradicate weeds and harvest grains. A written record of a type of plough is found in Mesopotamia dated at about 3000 BC. Today's farmers use more sophisticated tools to manage the soil for crop and pasture production. These agricultural implements have the potential to both enhance soil conditions for increased crop productivity and to degrade soil properties if inappropriately used. Farmers and scientists are aware of these potentials and they value new knowledge on how the soil behaves under particular conditions and the means to optimise productivity. This awareness has driven the need for information on soil properties.

Soil properties vary depending on where and how the soil has been formed. Landscapes and soil properties change with time both naturally and due to man's actions. Some change is slow and gradual while in other cases change is episodic and dramatic. Agricultural activity can result in changes in soil properties and it can also speed up the rates of change. Some soil properties are unlikely to change through agricultural operations and can for most practical purposes be considered to be inherent (e.g. soil texture and mineralogy, presence of specific horizons), whereas other soil properties are dynamic (e.g. organic carbon, available phosphorus). These dynamic soil properties are easily affected by human decisions and actions. Different characteristics are needed for different land uses. For example, soils that are good for growing potatoes are not necessarily good for dairy pasture. Soil is also dynamic, always evolving in response to its environment. Thus changes in land use often impart changes in some basic soil characteristics.

Soil properties also change due to spatial variations in the five soil forming factors of parent material, climate, topography, biological activity and time. Soils in different locations may be the same due to the same five soil forming factors operating in the same manner. A soil survey provides a map and description of how different soil types are spatially distributed in a region according to the five soil forming factors. Many soil surveys have been conducted in Tasmania at a range of scales and most of these are available either by request from the Department of Primary Industries and Water or directly from their website. Land managers can use the information in soil surveys to aid decision making on land use choices in order to reduce risks associated with production. They require information on inherent soil properties as these properties impose limitations on the type of enterprise that can be undertaken successfully. Soil surveys often contain interpretations that concentrate on the limitations for particular broad-scale land uses such as cropping, forestry, horticulture or pastoral use. However, the financial return from intensive agriculture can justify far greater inputs to overcome inherent soil limitations in order to achieve profitable and sustainable crop yields. Land managers developing intensive agricultural enterprises require interpreted soil information that gives them information on the level of inputs required to overcome inherent soil limitations. This allows the land manager to decide whether to proceed on the basis that the economic returns justify a certain level of inputs. An example of such an investment is the installation of underground drainage in the Cressy district which has allowed for sustainable potato production by reducing the risk of wet soils at harvest time.

Soil health

Soil health can be defined as the capacity of a soil to sustain biological productivity, maintain environmental health, and promote plant, animal, and human health. Investigation of soil health is an important key to sustainable land management because it allows for: evaluation of soil management practices in terms of effects on the soil; determination of any trends in soil changes; focusing conservation efforts by both farmers and others influencing land management decision making; and guiding farmer decisions on best practices.

Poor soils can be in good health just as good soils can be in a degraded state. There is no single soil property that can be used to define the health of a soil. Soil health is based upon a variety of soil properties. Agricultural use of land can have impacts that enhance or degrade soil health. Conclusions obtained from research into soil health may depend on the attributes investigated and these can be classed as chemical, physical and biological characteristics. There are now a small number of key attributes that indicate the health of a soil for particular farming types in Tasmania including soil carbon, pH and topsoil structure score. Farmers are generally keen to keep their soils in good condition because they believe that soil health has a direct impact on crop performance.

Soil health is not an end in itself. The ultimate purpose of assessing soil health is not to ensure high aggregate stability, biological activity, or some other soil property. The purpose is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms, including people. Soil characteristics are used as indicators of soil health, but in the end, soil health can only be identified by how it performs all of its functions. Soil health can be related to the emerging concept of ecosystem services. Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. They include: inputs to production; regeneration of ecosystems; stabilisation of soils, climates and weather; assimilation of wastes; amenity; and options for the future. Probably the highest priority that soil health must perform for farmers is to be able to produce optimum yields. A change in soil health can greatly affect crop growth and economic return to farmers and so it is important that relevant productivity information is linked to a range of soil properties that characterise soil health.

Concerns over the health or condition of the general environment have increased in the wider community over the past 30 years. Managers need information on dynamic soil properties to test whether current systems of land use and management are sustainable or whether change is required. Increased community awareness of environmental values is bringing new constraints on agricultural enterprises. The community, as well as farmers, is increasingly concerned that agriculture is sustainable and that the dynamic soil properties are not being degraded by current management practices. Landholder and community concerns now include the effects of agriculture on off-site environmental attributes such as water quality. Intensive agriculture has the potential to have dramatic off-site affects due to the consequences of high risk activities such as cultivating ground at a time of year when intense rainfall is likely to cause soil erosion, or applying fertilisers when surface runoff is likely. Providing information on off-site impacts of current soil management practices allows for the explanation of processes, the prediction of future impacts, and where changes to practices are likely to lessen these off-site impacts. Several State of Rivers reports in Tasmania have identified degraded water quality, measured by increased levels of nutrients and turbidity, as occurring in catchments with large proportions of intensive landuse such as cropping or dairying. Information on off-site impacts is likely to become an increasing part of industry reporting requirements as Environmental Management Systems and State of Environment reporting by Governments become more pervasive.

Diagnosing soil health

Soil testing is no one-stop catch-all to determine soil health. There are a vast array of soil tests available today measuring everything from phosphorus available for plant growth to ratios of fungi to bacteria. This ability to monitor so many aspects of soil health with such accuracy can be enormously useful. However, because of this availability, some farmers and agronomists have come to see soil health as little more than the ordering of tests. If we want soil testing to do more good than harm, it has to be used carefully, like many soil amendments.

Diagnosing soil health starts with a paddock's history even in this age of advanced technology. In many cases more useful information on soil health in a paddock can be gained by talking to the farmer than looking at a soil test result sheet. Many soil health problems arise from one-off events such as when a crop had to be harvested in the wet, or cattle were kept on a new paddock of pasture for too long. A physical examination is the next step in soil health diagnosis. A lot can be seen, felt and even smelt that will indicate a soil's health. Check out the shape and depth of plant roots as they are a good indicator of soil health. Good advisers and agronomists use a spade when giving paddock advice. The third step in diagnosing soil health is to get appropriate soil tests conducted. Unfortunately getting a full range of soil tests can be more confusing rather than clarifying in diagnosing soil health. Many soil tests are being reported with an indicated normal range that should be expected. However, normal depends very much on soil type and desired levels for the plants to be grown. If you order enough tests, you're bound to turn up a few 'abnormal' results simply because statistically some soils fall outside the normal range. This can be particularly so for trace elements which should be considered only when there is a recognised plant or animal health symptom.

Applying some wonder compound or mix sold to you by a convincing salesman, is not going to result in a recognizable improvement in soil health and subsequent plant growth. I consider these to be tinkering at the edges of soil health when there can be more fundamental issues controlling production such as drainage or compaction. Make sure advice on soil health relates to visual symptoms in the paddock and that any soil test is interpreted in relation to the paddock's management history and local soil types. A soil test result may not be the way to identify what the most limiting factor is to plant growth or to allow for identification of remedial action to amend a degraded soil.

Soil sampling procedure

Identifying changes in soil properties requires sound soil sampling techniques with repeated sampling over many years as many soil properties change only slowly with time. The following points should be considered when testing a soil:

1. Changing labs can change results. The results you get from year to year will be more consistent and comparable if you use the same lab each time.
2. Ask whether the lab you are using is accredited for all of the tests you are paying for. The lab should have National Association of Testing Authorities Australia (NATA) and/or Australasian Soil and Plant Analysis Council Inc. (ASPAC) accreditation for all the tests.
3. Make sure you sample at the same time every year, preferably when you can be sure that the soil moisture will be the same, as differences in soil moisture can affect the results. The preferred time is usually spring or late winter.

4. It is important to avoid small atypical areas in the paddock, eg changes in soil type, breaks in slope, fence lines, waterlogged patches and obvious stock camps.
5. Sampling along the same transect each time minimises variability. Transects can be marked on the fence line to allow for repeatability of sampling. Sampling the same paddock from year to year allows for comparison over time.
6. The cores should be spread out evenly along the transect. Avoid taking samples from where there are dung or urine patches or from where plant growth appears unusually good or poor.
7. Sample to the same depth every time the paddock is sampled (75 mm is standard for pasture and 150 mm for cropping in Tasmania). It is difficult to compare results from samples that have been taken from different depths.
8. The soil samples should be taken using a tube sampler, rather than a spade.
9. Collect at least 30 individual cores per paddock for nutrient analysis (Figure 1). These should be mixed to form the sample for the paddock. As paddock size increases, so should the number of cores.
10. The cores should be collected into a clean bucket (with no trace of fertilisers in it), mixed well and put into a clean plastic bag.
11. Make sure all samples are labelled clearly (some labs will supply labels).
12. Keep samples cool (in an esky) before sending to the lab ASAP. Samples allowed to sweat in the bag can affect results.

Figure 1. Collect multiple samples from the one paddock as a composite bulk sample for testing.

2. Crop rotations & paddock management

"The earth is not thirsty for the blood of the warriors but for the sweat of man's labour"
(Brazilian proverb)

Tasmanian farmers use a range of paddock rotations that can include a wide range of crops and the cell grazing of livestock around the farm. Many farmers are concerned about the long term effects of more intense cropping and high stocking rates on their soils. The basis for a particular rotation should be the quality of the land and its ability to sustain intense agricultural practices. Some paddocks will be rotated with one crop every 5 years, while others may be cropped 4 years out of 5. The cost of irrigation infrastructure has meant that some farmers are adopting cropping and grazing rotations that are beyond their soils capability and the long term consequences on soil health and crop yield are yet to be experienced. Relatively few areas in Tasmania are continuously cropped. Rotations have been used since agriculture began to 'rest' the soil or allow for natural regeneration and today there is good understanding that crop and livestock rotation give benefits of increased pasture growth, maintenance of soil organic matter and soil structure, healthy soil biology and crop disease suppression.

The combination of good soil management and crop rotation can maintain soils in a healthy condition. Practices such as green manure or cover cropping and stubble retention help to maintain healthy soils. A nutrient budget should be prepared for all farming enterprises with green manure or cover crops considered as 'catch crops' that take up nutrients not used by the previous crop, thus avoiding leaching past the root zone. Any particular crop should be seen as part the whole rotation so that if erosion occurs under one crop in the rotation, then the whole rotation should be reviewed or the way a paddock is laid out should be designed to cater for all the crops to minimise erosion risk. What ever the crop, the high erosion risk areas in a paddock need to be protected permanently with drainage lines and steeper slopes under perennial vegetation. Sites in paddocks under permenant pasture that suffer from erosion should be fenced off from livestock and planted to trees.

It is important to plan paddock cultivation ahead, keeping in mind what the future requirements are for the next crop's seedbed, what has happened on the paddock to date, and the time of year which will influence soil wetness and temperature or plant growth rates. The management undertaken will be reflected in the future health of the soil as the past paddock history is one of the ways to diagnose soil health (Chapter 1). For example, a paddock coming out of cereal and going into potatoes need not be cultivated in the autumn to bury the stubble. Let the cereal regrowth provide a ground cover over the winter months when rainfall is heaviest.

Green manure crops

Green manure crops provide essential protection from erosive autumn and winter rains as well as improving soil structure, preventing plant nutrients from leaching and returning organic matter to the soil. The particular green manure crop to grow will be determined by the time of year, the next crop in your rotation, the length of time until the next cash crop needs to be sown and the benefits desired. The time of year will influence which crop it is best for you to grow. In February or March, you've got all the options available including short-term ryegrass, legumes or brassicas. An early start will ensure maximum benefits but you may have to irrigate to get the crop to strike. If sowing in April or May, cold growing conditions will limit you to short-term ryegrass or cereals. Ground cover in late

autumn is essential to reduce erosion and oats will do the best job. Your crop rotation will determine how long you have for a short-term green manure crop. If you have less than 8 weeks between cash crops then leave a rough surface on the soil and try to leave as much trash as possible. The best option for short periods is to grow oats, either Coolibah or Esk varieties.

Understanding the various benefits of commonly grown green manure crops is critical in deciding which crop to grow. Determining what your soils require is also important such as soil structure improvement, building organic matter levels, biofumigation to prevent a nematode problem developing, or providing quick ground cover. Green manure crops are the only way to maintain organic matter in a continuous cropping rotation. Farmers are better to try and maintain organic matter rather than to build it up after years of decline. Ryegrass is best for soil structure and building organic matter as it has a viorous fibrous root system; oats for quick ground cover and erosion control, lupins for soil fertility and brassicas for biofumigation. Decide which you need by looking at the paddock history and your soil conditions. Minimal ground preparation is required for sowing a green manure. Spreading seed with a spinner and deep ripping or discing will achieve adequate germination conditions. Only rip if loosening is required and when soil moisture is appropriate. Prior to soil preparation at the end of the green manure crop cycle, spray off well in advance (4 - 6 weeks) and incorporate when dry by top working with discs or a rotary hoe. Oats can be a problem in spring because of difficulties incorporating a large volume of wet tops. If incorporating wet material, reduce bulk by mulching and turn under with a mouldboard plough. Remember that soils will stay wetter with a high trash content and avoid feeding off green manure crops to stock when soils are wet in order to prevent compaction.

Paddock preparation in a cropping rotation
Seed bed preparation requires considering factors such as: seed size to be planted, type of drill, immediate paddock history, harvester requirements such as clods over a potato harvester web, soil wetness, soil structure appearance, time available and the weather. The following two practical guidelines for soil preparation to prepare a paddock for another *crop, vary according to what the previous crop was in the rotation.*
Following a green manure crop
- Spray off green manure crop in August/September.
- A dense crop should be mulched when desiccated following herbicide application to aid incorporation.
- Mouldboard plough to a depth of 100 – 200 mm.
- Leave green manure to break down in the soil for at least 2 weeks.
- Further preparation depends on moisture condition, degree of incorporation of green manure and soil cloddiness. One pass with an S-tine cultivator will break up the ploughed surface. When using a Roterra after ploughing, increase the forward speed and decrease the rotary speed so as to not overwork the soil. Remember, overworking in spring when soils are wet can produce a compact and cloddy seedbed.
- One day before planting, incorporate fertiliser using a roterra or similar with a crumble roller.

Following peas, poppies or cereals
- Mulch and incorporate the crop stubble by using implements such as discs, rotary hoe, Kuhn or Roterra during autumn.
- Sites with known soil compaction problems should be agroploughed during autumn. Wait until after the first rain so that soils are moist but subsoils are still relatively dry to achieve the maximum effect. Remember, make sure rip tines are close enough to

break up the maximum cross-sectional area of soil. Alternatively attach wings to the base of each tine.

- Leave the cultivated surface rough during 6 - 8 weeks of winter fallow. A rough surface will encourage infiltration and minimise runoff and erosion.
- Spray off weed seedlings during July.
- Final seedbed preparation with a Roterra, or similar implement, with a crumbler roller. A second pass using a Roterra or Lely with increased forward speed and decreased rotary speed may be necessary if the paddock is particularly cloddy.
- If cultivating in the spring from a bare fallow, use of the mouldboard plough is better than the agroplough. Using plastic boards on the mouldboard results in minimal damage to the soil in moist conditions. Using an agroplough or other deep cultivation in spring results in smearing of plastic soil because it is too wet at depth. Remember, soils are wet in spring, particularly at depth, and so if there is minimal stubble or plant residue to bury, then ploughing should be restricted to 100 mm depth.

Wet soil management under intensive grazing
Soil management problems under intensive grazing e.g. dairying, most often occur when soils are wet in winter and spring. All soils are wet at some time during the year. Potential problems which occur under wet soil conditions are:

- Trampling; Pasture damage by treading can result in 30 - 60% reduction in pasture growth.
- Poor pasture utilisation; Wet conditions increase the risk of pasture being trampled into the mud. This reduces the amount of feed a cow can eat off the paddock. Added with this cows will not eat heavily soiled pasture.
- Buying in extra feed or applying extra fertiliser; If pasture utilisation decreases, supplements may need to be purchased to cover the shortfall. This can be expensive as the farmer is paying for the pasture trampled into the ground as well as the bought-in supplement.
- Soil structure damage caused by pugging and machinery (Figure 2); Pressure from stock and/or machinery can lead to severe damage to soil structure. An example would be pugging or wheel ruts through the paddock. The carryover effects on pasture production can last several seasons. Options such as working up the paddock and sowing down a new pasture can be expensive.

Figure 2. Pugged pastures have long lasting effects on productivity.

- Environmental mastitis; The risk of environmental mastitis within the herd increases if the herd is wintered on muddy paddocks. The risk is especially high at drying off and calving. If the cow is culled based on mastitis the cost is high.
- Machinery access; Wet paddocks can reduce the access of farm machinery onto the paddock. This reduces the options for farm management. An example would be a farmer that cannot feed out silage during the winter months because their silage wagon would get bogged.
- Stress; Managing stock and machinery in muddy conditions can place stress on the farm management team.

Some low cost solutions to minimise these problems include:
- Low-lying wet paddocks should be grazed early to minimize the chance of having to graze them on a long round in winter. Similarly, known dry paddocks should be targeted for later grazing.
- On-off grazing; Research has shown that cows can eat their daily ration within 3 hours. Therefore, one management option is to remove the cows onto a holding pad, lane way (Figure 3) or sacrifice paddock for the remainder of the day.

Figure 3. Standing cows on a laneway after paddock grazing minimizes soil damage.

- Sacrifice paddocks reduce the damage on the rest of the farm by localizing the problem on one part of the farm. Paddocks targeted for pasture renovation may be ideal for this role. One option is to cultivate the paddock in later spring, sow down turnips for the summer, and then into new pasture in the autumn.
- Backfencing not only prevents cattle moving over grazed areas and damaging them, but also increases pasture growth rate. Back fencing is an important strategy when long rotations are in place.
- Ignore them; Don't ignore the problem as this will prove disastrous, but rather ignore the cows. Once you have made your decision have faith in it. Do not go visiting the cows and giving them an excuse to walk up and down the fence.
- Adopt more than one strategy; In any given situation it may be better to use a combination of these strategies rather then depend on one alone. Remember the most important strategy when it comes to managing wet soils is to remain flexible.

Longer term alternatives for managing stock over this winter/spring period are:
- Agistment; Wintering stock off the property can reduce the problems of wet soils as well as building up pasture cover for calving. By having stock off the farm it can also reduce the stress on the farmer.
- A feedpad is similar to a sacrifice paddock as it allows you to remove cows from the paddocks. The advantage is that no paddocks need to be taken out of the round to be "sacrificed". This eliminates the cost of re-grassing as well as increasing the available feed on the farm. A solid base allows for regular cleaning. Allow 2m^2 per cow for standing.
- Open ditches are essential as a first step in any drainage system. This is because they are the means by which water is removed from paddocks whether the ditch is collecting water from a pipe drainage system, acting directly as a land drain to lower the watertable, or intercepting surface or groundwater flow. Deep ditches need to be fenced and regularly sprayed to control growth.
- Underground pipe drains can be installed to intercept ground water flow or to lower the watertable over a wider area. They can also tap into seeps and springs and are very effective on permeable soils. Check to make sure there is sufficient fall on the paddock for your soils to drain to pipes before burying your money underground.
- Mole drains are only recommended for clay rich soils. Heavy clay soils or soils with heavy clay sub-soils readily become waterlogged after rain or irrigation due to water building up (perching) on the surface or on top of the clay subsoil. Because water moves so slowly through these soils, successful drainage requires very closely spaced drainage systems, in the order of two to seven metre spacings. In most situations this would be too costly using underground pipes and would be impractical with open ditch systems. If improved drainage is wanted with these soil types, then a choice must be made between drainage using surface drainage systems (hump and hollow systems) or sub-surface systems using mole drainage or gravel moling. Successful mole drainage depends on the water being able to rapidly enter the mole drain, flow unimpeded down the channel and exit the system either via an open ditch or into a deeply set pipe system.
- Hump and hollow drainage systems may be appropriate on low lying areas where the soils have little internal drainage (see Chapter 9).

3. Soil structure and compaction

"Six feet of earth make us all equal" (Italian proverb)

Soil structure describes how mineral particles and organic matter are arranged to form aggregates, as well as how pore spaces are arranged within and between aggregates. Soil structure is the clods and aggregates that you can see rather than soil texture which you can feel. Soils with degraded structure can result in low yields and are difficult to manage due to a restricted range of soil wetness for tillage operations. If a soil has poor structure this can lead to problems with drainage due to the blocking of soil pores resulting in a decrease in the rate at which water can enter soil (infiltration rate) and the rate at which water can drain through the soil (hydraulic conductivity). Compaction can lead to reduced aeration when wet, particularly on heavier textured soils such as Ferrosols, resulting in restricted volumes of soil available for root growth. Soil compaction leading to increased soil strength can limit plant growth by restricting root elongation as well as limiting the range of tillage options for soil preparation. If the ability of plants to penetrate the soil is reduced when structure is poor, this reduces plant access to both soil nutrients and moisture which affects crop yields. Poorly structured soils are more likely to form a surface crust after heavy rainfall and are more easily eroded by wind or water.

How to assess soil structure

The first step in soil structure assessment is to consider whether the paddock history could have resulted in poor soil structure. Evidence could include a wet crop harvest, wheel ruts running across parts of the paddock, areas of poor plant growth, weed incursion, or greater susceptibility to erosion than neighbouring paddocks. The next step is to use a spade to dig a hole (Figure 4). If the soil is hard to dig, then this may indicate compaction and structure degradation. The structure status of a topsoil can be assessed visually using a pictorial scorecard (Figure 6) developed for local Tasmanian soils. The combination of pictures and descriptive text on the scorecard allows for repeatable visual assessment of soil structure condition over a range of soil wetness. The method is to use a spade to dig a hole approximately 300 mm square to the base of the topsoil. Take a 50 mm wide vertical slice of topsoil from the edge of the hole and place soil on a clean surface, such as a fertiliser bag.

Figure 4. Assess soil structure by digging your soil.

Use your hands to break the slice of soil apart, noting the force required and the resulting clods or aggregates. The scoring should be done quickly, rather than agonizing over subtle differences with three to four samples in each paddock. It is better to do several quick scores in a paddock than to labour over one score. It helps to carry with you soils with different scores for comparison (e.g. In an ice-cream container). Compare the soil in the paddock with soil from under the fence line which has not been compacted by stock or machinery. You can put some soils in 'storage' for comparison in a year or two to see if your soil structure has changed. A structure score of 6 or less is considered degraded as such scores have been correlated with decreased potato yield on Ferrosols in north west Tasmania and decreased poppy yield on Dermosols in the northern Midlands. If you can see a structure problem, it is costing you money in lost yield. Use of soil structure scoring can predict crop yield even before the crop is planted. I was able to demonstrate this with farmers by scoring several of their Ferrosol paddocks to be used for potato growing prior to planting (Table 1). The relationship used for prediction of potato yield is:

$$yield = 18.4 + 4.67 \times structure\ score$$

Table 1. Predicted and actual potato yields with associated soil structure scores on Ferrosols.

Structure score	Predicted potato yield (t/ha)	Actual potato yield (t/ha)
10	65	62-67
9	60	58-60
8	56	55-58
7	51	50-52
6	46	44
5	42	43-50
4	37	37-39

Good structure is characterised by many rounded, irregularly shaped aggregates of 2 – 10 mm diameter, with larger aggregates having rough surfaces and many holes for good aeration. Aggregates have rough surfaces which are often broken by crop stubble and other plant residues. Poor structure is characterised by large firm clods of 20 – 100 mm diameter, that are angular with smooth faces and no pores. The clods and overworked soil break into loose, fine powdery soil. Degraded soil is hard to dig, crusting is often visible following sealing by rain, particularly on sandy loam textured soils, and surface water ponding occurs. It is important to note that abundant actively growing fine plant roots need to be present in a soil to get a score of 10. This is because plant roots are intimately associated with forming and maintaining healthy soil structure.

A study on the effects of soil factors (microbiological, chemical and physical properties) and field information that may relate to carrot disease and quality in Tasmanian Ferrosols showed that the soil factors identified as having the greatest influence on carrot production were related to soil structure. This result is not surprising, as the appearance of carrots produced for the fresh market is highly critical. The main factors associated with reduced carrot packout or quality in Ferrosols in Tasmania were levels of root disease, misshapen carrots and total soil carbon. All these factors can be linked to soil structural conditions.

Soil compaction

Soil compaction is the process of increasing the density of soil by packing the particles closer together causing a reduction in the volume of air. The volume of water, at least initially, remains unchanged. Soil water acts as a lubricant increasing compaction when a load is imposed on the soil. If near saturation, however, the load is likely to exceed the soil strength and bearing capacity, resulting in excessive wheel slippage and rutting as well as soil mixing and smearing. Ideally, about 50% of the total soil volume should be pore space filled with equal volumes of air and water. By packing primary soil particles (sand, silt, clay) and soil aggregates closer together, the balance between solids, and air-filled and water-filled pore spaces is dramatically altered. Compaction usually eliminates the largest soil pores first. A large portion of the initial soil air is forced out of the upper plant root zone, and the channels of greatest continuity, and least resistance to air movement, water movement and root penetration, are destroyed.

Increased compaction of the soil results in less plant root proliferation in the soil (Figure 5), and lowers the rate of water and air movement through the soil. Because of the root restriction the amount of water available to the crop is often decreased. Slower internal drainage results in poorer subsurface drain performance, longer periods of time when the soil is too wet for tillage following rainfall or water application, increased denitrification and decreased crop production. Increased compaction also adds to the energy consumption by tractors for subsequent tillage. Most effects of compaction are detrimental. However, in some cases slight compaction near seeds can aid germination and improve plant growth in times of low soil moisture caused by low rainfall or low water-holding capacity soils. In this situation some kind of roller can be used to firm the seedbed after planting. This can be a press wheel trailing the implement and I have seen improved cereal strike with the use of a rubber tyred roller when direct drilling cereals on black Vertosols in the Sorell district.

Figure 5. Plant roots growing around compact clods.

**Figure 6. Soil structure scorecard
for clay loam textured topsoils in Tasmania.**

Score 1 – 2
Large compact clods (50 – 100 mm) with few fine aggregates. Clods are angular or plate-like with smooth sides and no pores.

Score 3 – 4
Mainly firm large clods (20 – 50 mm) that are angular with smooth faces and no pores. Clods and overworked soil break into loose powdery soil.
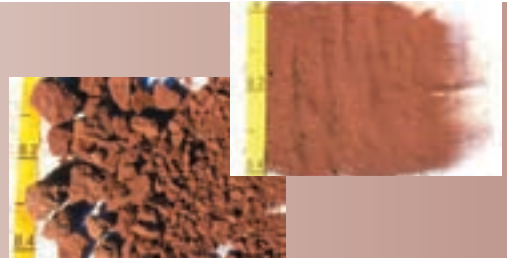
Score 5 – 6
Few medium and large firm, rounded aggregates (5 – 30 mm) with mostly finer aggregates (< 2 mm) and some powdery unaggregated soil.

Score 7 – 8
Friable soil with many rounded aggregates (5 – 20 mm). Many fine rounded aggregates (< 2 mm) but little powdery unaggregated soil.

Score 9 – 10
Porous loose soil with many rounded, irregular shaped aggregates (2 – 10 mm). Large aggregates have many holes for good aeration and drainage. Little or no powdery unaggregated soil.
Often has abundant very fine roots.

What causes compaction?
- Tillage - Tillage-induced compaction is caused by primary tillage under less than optimum soil moisture conditions and by excessive secondary tillage. This form is most apparent in the soil's plough layer (Ap horizon). Secondary tillage destroys soil aggregation and structure allowing the surface soil to puddle, crust, and reach densities greater than would otherwise occur in an untilled state. With mouldboard ploughing under wet conditions, the base of the mouldboard can cause smearing and localised impermeable layers. The major compaction problem, however, is associated with the rear wheel of the tractor running in the open furrow, forming a compacted layer at even greater depths (ie. up to 30 cm or greater).
- Traffic - Traffic-induced compaction is caused primarily by wheel traffic associated with farm operations and is of greatest concern in the subsoil zones. Compaction below the plough layer is generally of more concern since it is not easily self-correcting (ie. by freezing-thawing or wetting-drying cycles) and is difficult if not impossible to totally reverse or correct. Traffic in the form of livestock can also cause compaction but the depth of such compaction is normally much shallower than that caused by machinery.

It has been estimated that, given conventional tillage practices and other planting-harvesting farm operations, as much as 90% of the field area will be wheel tracked on an annual basis and that much of the field area receives 4 or 5 wheel passes. These acts, when combined with the considerable gross vehicle weights of larger farm vehicles (often 10 to 20 tonnes or more), demonstrate the magnitude of wheel loadings currently being imposed on our soils.

Remember
- Depth of compaction is determined by axle load (see Figure 7)
- Degree of compaction is determined by tyre pressure
- Nearly 70% of the compaction caused by wheel traffic occurs on the first pass. This is the basis for suggesting the same track be used for repeated passes (i.e. controlled traffic).

The impact of a machine on the soil depends on the load on the wheel and the ground pressure it exerts. The effect of a wheel load on the soil is represented schematically in Fig. 7. The wheel load generates a pressure pattern which extends into the soil beneath the wheel. The degree of compaction is very sensitive to tyre pressure. Reducing tyre pressure is an avenue relatively easy to follow compared with other ways of reducing compaction. Spreading the load over more axles, more tyres or ultimately tracks will minimise the depth of compaction.

Figure 7. Vertical pressure zones under different loads exerting similar ground pressures (GP = ground pressure) (D. Forristal, 2003).
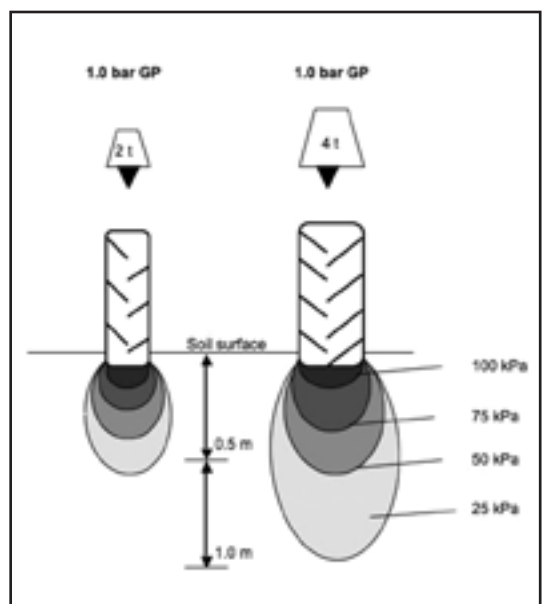
Deep Soil Compaction

Deep soil compaction is defined as excessive soil compaction below the normal annual tillage depth, usually 150 - 250 mm. Soil compaction below tillage depth is of greater concern than surface compaction because it is a difficult problem to solve. Heavy wheel loads are believed to be the cause of most deep soil compaction. The volume of soil compacted by a wheel pass varies with soil type, soil moisture, tyre size, pressure and total load. Pressures are transmitted deeper into wet soil than in dry soil by the same tyre size and wheel load. A comparison of pressures in the subsoil shows that wide tyres carrying a large load at the same pressure as narrow tyres will cause compaction to a greater depth than the smaller tyres with smaller loads. Large tyres with heavy loads can transmit excessive pressures 400 to 600 mm into the soil when soils are moist or wet.

Larger tyres hold a greater volume of air and, consequently, can operate at a lower inflation pressure and exert a lower ground pressure (Table 2). The type of tyre used will influence the ground pressure exerted. Cross ply tyres will exert greater sidewall pressure on the soil. Radial tractor tyres have flexible carcasses, which exert quite low sidewall forces and these tyres can operate at lower inflation pressures resulting in greater contact areas than stiffer tyres. Tyres designed for high inflation pressure, such as truck or harvester tyres, will exert greater ground pressure than similarly sized tractor tyres. Tyres have to carry the load without damaging their own construction and so the aim should be to have the lowest inflation pressure that still allows the tyre to carry the load within its manufacturer's stated limits. Incorrect tyre pressures mean tractors can waste 20 - 40% of engine power through tyre slip and rolling resistance.

Table 2: Tractor tyre sizes, internal air volumes and inflation pressure requirements (D. Forristal, 2003).

Tyre size	Internal volume (litres)	Required pressure (bar)	
		2.5 t load	4 t load
16.9 R 38	411	1.4 (20 psi)	-
18.4 R 38	574	1.0 (14.5 psi)	-
20.8 R 38	698	0.6 (9 psi)	1.6 (23 psi)
650/65 R 38	840	0.6 (9 psi)	1.2 (17 psi)
800/65 R 32	1150	0.4 (6 psi)	0.7 (10 psi)

How to diagnose a compaction problem

There is no rapid or simple means of measuring compaction damage in the field. Three methods to indicate field compaction are:

1. Shovel or probe. This method measures compaction by the resistance encountered as you push down through the soil. It is useful for detecting dense soil layers that may resist root penetration or growth.
2. Penetrometer. This instrument provides relative measures of soil strength and resistance to root penetration, but the measures are highly sensitive to soil moisture content. These readings still require adjustment and careful interpretation before they can have any great practical meaning.
3. Soil pit. Dig a small pit crossing the crop root zone, use a knife to examine the rooting pattern and test the resistance to penetration. Note denser zones of soil and see if they coincide with a reduction in root growth.

All three methods are relative tests, and should be compared to areas with similar soils and where compaction is known not to be a problem.

4. Higher bulk density – measured with constant volume rings. The significance of bulk density depends on the soil texture. Rough guidelines for the minimum bulk density at which a root restricting condition will occur for various soil textures are:

Texture	Bulk Density (g/cm^3)
Coarse, medium, and fine sand and loamy sands	1.80
Sandy loams	1.75
Loam, sandy clay loam	1.70
Clay loam	1.65
Sandy clay	1.60
Clay	1.40

Soil and crop symptoms of compaction

Types of Compaction	Soil Symptoms	Crop Symptoms
Traffic Induced	Ponding of surface water	Delayed or reduced seedling emergence
	Formation of soil crusts	
	Pan formation	Uneven crop stands
	Increased runoff	Nutrient (N) deficiencies
	Reduced soil water storage	Plant water stress
	Platey structure	Flattened, turned, or stubby plant roots
Tillage Induced		
	Increased implement draft and fuel costs	Shallow root system
	Increases resistance to root penetration	Drought stress
	Poor soil aeration	Nutrient deficiencies
	Poor soil drainage	Unhealthy roots - reduced yield - delayed crop maturity - plant water stress

How long will compaction last?

The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and the climate. As the depth of compaction increases, the more persistent the condition. The type and percentage of clay determine the shrink-swell potential. The greater the shrink-swell potential and number of wet/dry cycles, the lower is the duration of compaction at a particular depth. Near surface (0-5 cm) compaction can be relieved relatively easily and is likely to be short lived. Deeper problems are going to be longer-lived and harder to treat. Compaction to 20 cm may take many years, or even decades, under vigorous pasture to rehabilitate. Research on Tasmanian soils has shown that deep sandy soils are the most prone to subsoil compaction at 20-40 cm depth (Figure 8). This has been associated with the use of heavy pea and potato harvesters on sandy Tenosols in the northern Midlands when the soils are moist or wet. Near surface compaction occurs on other soils which results in the formation of clods and restricted root growth which is evident on Ferrosols in the northwest of Tasmania and on Dermosols (Cressy soils) in the northern Midlands.

Ways to reduce and prevent compaction
Since compaction problems are likely to persist for a prolonged period of time, the best defence is avoiding the problem altogether.
- Schedule farm operations to avoid working paddocks when wet (Figure 9), such as spreading fertiliser. The soil should break easily and crumble at the deepest depth as it is being tilled. Dry soil will compact less than moist soil.
- Reduce secondary tillage passes as each additional tillage pass destroys aggregates and increases bulk density. Ideally adopt minimum or zero tillage systems.
- Control traffic patterns using tramlines as under conventional tillage systems as much as 90% of the land area can be tracked at least once.
- Remove excess weight on machinery and use only enough ballast to reduce slippage.
- Reduce surface pressure by reducing tyre pressure or by using lighter axle loads. Subsoil compaction increases dramatically with axle loads of greater than 5 tonnes.
- Traction versus compaction. A long narrow footprint is preferable to a short wide track (ie. duals). This can be accomplished by: Using larger diameter tyres; Replacing bias tyres with radials; Using tandem axles; Using 4-wheel drive or tracked vehicles.
- Avoid loaded trucks on paddocks and overloaded crop wagons.
- Improve drainage as this reduces the risk of being forced to work wet fields.
- Increase organic matter in soil by using cover crops, deep-rooted forages, and incorporating crop residues into the soil.
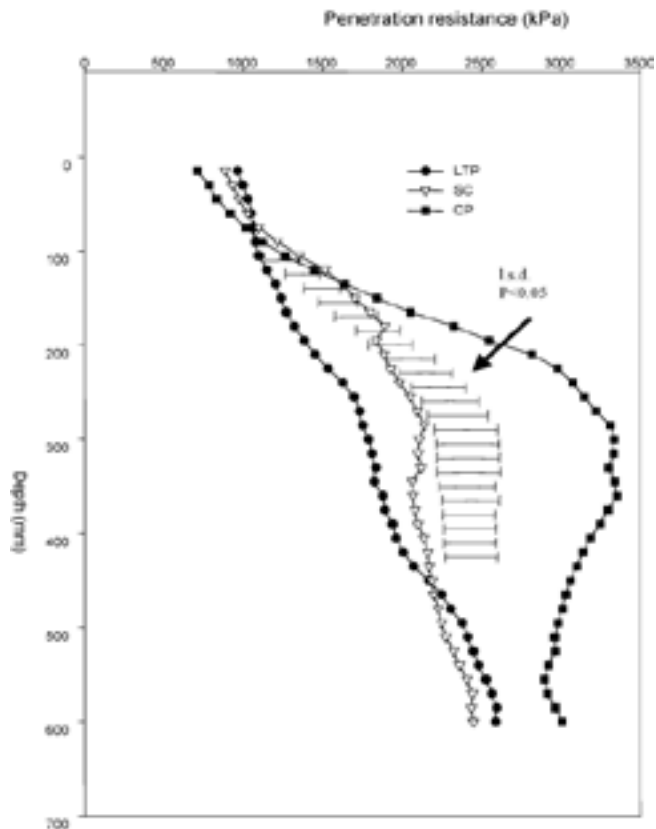
Figure 8. Subsoil compaction measured with a penetrometer on a deep sandy soil.

Getting rid of soil compaction
- Varying the annual tillage depth will deal with tillage induced compaction layers occurring just below the normal working depth of the primary tillage implement. The tillage depth is decreased in a wet year and is increased in a year when soil is dry enough to shatter a compacted layer.
- Crop rotation and growing vigorous pasture. This is normally a long-term method of reducing compaction. A diverse rotation is essential to stabilize and build soil aggregates. Crops should include both deep rooted and fibrous rooted crops.
- Deep ripping. This should be attempted only when soil is moist to dry and crumbles at the depth you are ripping. Operating depth should be no more than a few centimetres below the zone of compaction because operating any deeper uses more energy and risks the potential of deeper compaction.

Figure 9. Severe compaction resulting from traffic on the soil when wet.

4. Cultivation
Co-authored with Bill Chilvers

"While the sun is still up, let people work that the earth may live" (Hawaiian proverb)

What makes a good cropping soil?
Apart from being sufficiently fertile, a cropping soil has to satisfy three physical requirements:
1. Be suitable for plant growth. It must contain sufficient pores for aeration, drainage and water holding. Must be friable to allow root extension and proliferation, i.e. Have low bulk density.
2. Have a high bearing capacity to carry tillage & harvest traffic - must have sufficiently high soil strength to avoid excess sinkage and wheel slip, i.e. Have high bulk density.
3. Resist erosion. It must be sufficiently structured, vegetated or protected by conservation earthworks (mulched rip lines, banks or drains).

Soil needs to be of low bulk density for plant growth on one hand, and of high bulk density for carrying traffic on the other. A difficult compromise. The ideal way to address this compromise is to use bed systems and tramlines. Tramlines involve using narrow tyres with high pressure to form a highly compacted wheeling without affecting crop growth. They are used for all spray and fertiliser applications between sowing and harvest. Bed systems can either be in place for the life of the crop, e.g. Onions or carrots, or permanent where all traffic is permanently restricted to the wheelings between beds with the use of a geographic positioning system (GPS).

Purpose of cultivation
Cultivation is very subjective to the operator in that every cultivation implement can be found working on every soil type, and its appropriateness reasonably argued. Good soil management lies in the way the implement is operated and the soil conditions at the time. There are no textbook answers or recipes to follow as you stand in the paddock deciding on how to prepare the seedbed.
Cultivation has five purposes:
* Seedbed preparation
* Weed control
* Incorporation of plant residues and fertilisers
* Alleviating compaction
* Soil and water conservation

Cultivation at friable moisture content
The effect of moisture content on soil damage is normally far greater than the effect of differences in tractor weight, tyre size or pressures. Small differences in soil moisture can cause profound damage to soil. When moisture is added to a completely dry soil, the soil's behaviour moves through four distinct stages in terms of how it reacts to external forces.
(1) The brittle stage – when the soil behaves as a brittle solid.
(2) The friable stage – when the soil behaves as a friable semi-solid.
(3) The plastic stage – when the soil behaves as a deformable plastic.
(4) The liquid stage – when the soil behaves as a flowing liquid.

The moisture contents which mark the transition from solid to plastic, and plastic to liquid, have important consequences for soil behaviour and are termed the ***plastic limit*** and ***liquid limit***

respectively (Figure 10). A dry soil is difficult to compact, but as the moisture content increases soil becomes more easily compacted. The optimum moisture content for compaction tends to be at or just below the plastic limit. The plastic limit is often near field capacity in most well drained soils.
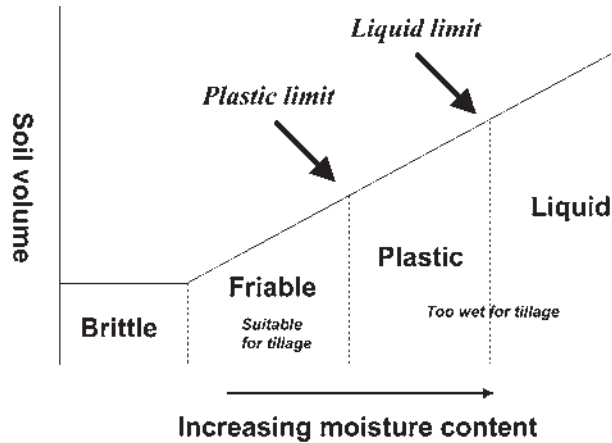
Figure 10. Soil behaviour according to moisture content.

The **plastic limit** is the moisture content at which soil just cannot be rolled into a thread or worm 3 mm in diameter and 75 mm long without cracking up. This marks the boundary between plastic deformation and brittle or friable fracturing. The plastic limit is useful in an agricultural context for determining if the soil in a paddock is friable and thus suitable for cultivation, ie. cultivate if the soil is drier than the plastic limit. The **liquid limit** is the moisture content between plastic deformation and flowing liquid failure, ie. the moisture content at which the soil will begin to flow under its own weight. Where the plastic limit is below field capacity (ie. at a lesser water content) soils are particularly difficult to manage. Soils where the plastic limit is above field capacity are considerably less difficult. This is because if the soil is plastic at a water content less than the field capacity, then the soil needs to be dried out to behave in a friable manner, ie. some evaporation and transpiration is needed to make it workable without causing plastic failure.

Is my soil too wet to work?
Get in the habit of having a close look at your soil prior to working. Working the soil when the soil is too wet causes compaction. Compacted topsoil results in clods. Compacted subsoil restricts drainage and rooting and is more difficult to alleviate than topsoil compaction.

A simple test is work some soil in your hands to an even consistency. Then try to form a thin sausage about 3-5 mm diameter by rolling the sample between your palms.
There are 3 possible results:

1. A 3 mm sausage is easily formed. This soil is too wet to work (Figure 11).
2. It cracks and breaks into short lengths. This soil is right to work (Figure 11).
3. If the soil crumbles and a sausage can't be formed – the soil is right to work but power requirements will be high.

Test the soil immediately below the plough layer. Often this will be moister and thus more likely to susceptible to deep compaction. Tillage should not be undertaken if the subsoil fails this test.

Figure 11a. When the soil is too wet for tillage a 3mm thick sausage roll will easily form.

Figure 11b. At the optimum moisture content the soil sample will crack and break into short lengths.

How an implement breaks the soil

When an implement engages with the soil, the soil is either loosened or compacted. Unfortunately it is not simply a case of deciding which we want, and selecting the appropriate implement. There are many soil and implement factors influencing the final outcome, the most important being soil moisture. If you were to extract a neat, undisturbed block of soil with your spade, and gradually stand on it, the block of soil would resist your weight up to a certain point, then suddenly break.

When a force is applied to the soil it can break in one of three ways:
Brittle failure occurs when soil crumbles along well defined natural planes of weakness and the soil is loosened. **Compressive failure** occurs when soil shears along an infinite number of planes in wet conditions or deep in the soil where uplift is confined and the soil is compacted. **Tensile failure** occurs when soil is placed under tension. Soil breaks along well-defined natural planes of weakness and the soil is loosened. Brittle or tensile failures are required for all types of loosening and clod breaking operations. Apart from their cutting action, discs create a mixture of brittle and tensile failures, as do forward inclined tines, and powered implements used carefully. If the soil is moist, any implement will cause compressive failure which degrades soil structure. Compressive failure occurs as a result of heavy loads applied to the soil or by tines working below critical depth (see later). Tensile failure is the most energy efficient way of loosening a soil and allows loosening at slightly higher soil moisture contents. The mouldboard plough or winged tines produce tensile failure.
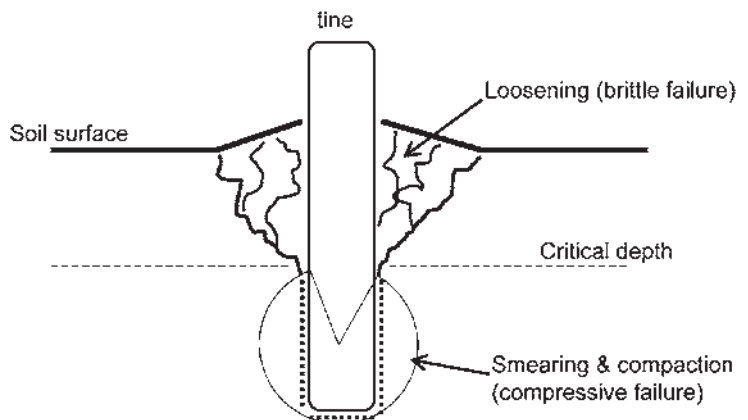
**Figure 12.
A tine operating below critical depth causing long term damage to the soil.**

Critical depth

The aim of chisel ploughing, ripping or subsoiling is to heave and shatter the soil, not to compact and smear below the surface. It's worth getting off the tractor and having a quick dig behind the implement to make sure you're not operating below critical depth. Critical depth is the depth above which brittle failure (desirable) occurs and below which compressive failure (undesirable) occurs. Soil near the tine below critical depth will be compacted (Figure 12).

In order to avoid soil compaction, it is desirable to have the critical depth as deep as possible. The critical depth is dependent on the soil conditions, the tine width and the rake angle. Under given soil conditions, the wider the tine, the smaller its rake angle and the looser the soil surface, the greater the critical depth. The wetter and more plastic a soil, the shallower is the critical depth. Also, avoid placing depth wheels near tines as these restrict upward movement of the soil and make compressive failure more likely. Using shallow tines to loosen the soil surface layers ahead of a deep tine reduces the upward flow resistance and so effectively increases the critical depth. The use of wings on a ripper also increases the critical depth. Above critical depth, soil breaks out or fails at about 45 degrees from the point of an implement. Tine spacing must be sufficiently close to avoid leaving undisturbed ridges of soil below the surface (Figure 14). Unless this is investigated with a spade, the operator can continue to do a poor job on the whole paddock.

Critical depth is constantly changing - its depth is controlled largely by moisture content and soil type. Its depth can be determined by digging a hole and investigating what the implement is doing to the soil. For deep ripping to be effective the operation needs to be above the point of critical depth so that the soil is shattering as the ripping tine moves through it. If the soil is being compacted and smeared by the tine, the operation is below critical depth. The tine needs to be lifted to achieve the main objective of deep ripping ie. shatter.

Cultivation implements
Tined implements
Deep rippers, chisel plough, cultivators, S-tine
Tines are varied in their effect on the soil, depending the angle, width, depth and springiness of the tine, and the condition of the soil. Nearly all seedbed preparations involve a tined implement, whether as a primary loosening tool or as secondary levelling and clod breaking tool.

Shallow tined cultivations - the S-tine
For all soil types, the S-tine is one of our most valuable and highly recommended tillage implements, particularly when combined with a front levelling board and rear crumble roller. It is gentle on soil structure, produces a good seedbed tilth and has a low draft requirement. It is recommended by poppy and onion company field staff to generally be the best implement to use for the final pass before sowing.

Disc implements
Off-set discs, one-way plough
It is generally thought that discs are not good for the soil probably because discs were once the farmer's only tool beside the chisel plough, and thus took the blame for much of the soil degradation that has occurred in the past. Discs are not necessarily any worse than other implements at our disposal today, but like any implement, can cause great damage to the soil if used incorrectly or at the wrong soil moisture content. The cutting action of discs takes no account of the natural fracture lines of the soil. Cutting forms new aggregates

with shiny smooth faces. The smearing becomes severe as soil moisture increases, so that in wet conditions, discs are very damaging to your soil. Discs can also overwork sand and duplex soils if two or more passes are involved.

Discs for minimum tillage
Discs are best used together with tined implements in a top-working tillage system, which is appropriate for all soil types, particularly sands and duplex soils. Discs are an excellent tool for chopping and shallow incorporation of coarse organic matter, and reducing trash load for subsequent sowing. Shallow incorporation of surface stubbles or residues promotes biological activity and breakdown, reduces trash load for subsequent tined operations, and leaves sufficient cover for wind and water erosion control. Using discs offer a good compromise between leaving all the crop residue on the surface and deep burial. Left on the surface, organic matter has minimal contact with soil organisms and is too dry most of the time for biological activity. Deep burial disrupts soil structure and opens up the soil, exposing humus to breakdown, so that more organic matter can be lost than gained.

The mouldboard plough
Faced with the challenge of preparing a seedbed, farmers in Tasmania commonly opt to use the mouldboard plough in their tillage sequence. Correctly used, the mouldboard plough is an excellent implement for incorporating crop residues or green manure crops (Figure 13), and requires a minimal number of passes of secondary tillage to produce the seedbed. However, for some Tasmanian soils, the mouldboard plough is not appropriate. Soils prone to wind erosion are protected by coarse organic matter in the surface layer, which is buried by a mouldboard plough. Some soils are too shallow for mouldboard ploughing and these are permanently degraded because low fertility, structurally poor subsoil is mixed with the shallow topsoil. Inversion is the action of the mouldboard plough. Have a look at the paddock to be worked and decide if inversion is required, taking into consideration the requirements of the seed to be planted (small seeds require finer seedbeds), the moisture and structure of the soil, (very wet or dry, cloddy or fine), and surface cover (amount and type - pasture, green manure, stubble)

Figure 13. Cultivation to produce a seedbed suitable for fine seeds.

Plough performance
Finishing the paddock in record time is often the main yardstick of plough performance. In fact, the plough can produce a wide range of soil conditions, from an almost unbroken furrow to an open, broken finish with considerable loosening, by adjusting depth and speed of operation. Different mouldboard shapes are available to achieve similar soil conditions at different depths and speeds. Secondary problems arising after ploughing are largely associated with incomplete burial, cloddiness, levelness or openness of the surface and these can be minimised by making adjustments of depth and speed, or by changing mouldboard shape.

The skill in ploughing comes from setting up the implement and tractor and producing the desired finish. Read the plough manual as you will be surprised what you might learn. A good ploughman should aim for a level surface and a tight finish. Each pass should turn onto the last pass without noticeable difference and every board should turn its furrow identically. Lower speed means the board doesn't throw the furrow leaving a loose, unconsolidated finish. Soil structure is less disrupted, secondary pass wheelings are less severe, and a better seedbed is achieved with a tight, firm finish. For a well finished ploughed paddock, a single shallow (50 mm) powered implement or s-tine pass before sowing is all that is required. If a roller/packer is towed by the plough, the paddock can be sown directly. A rough, loose finish requires extra work to level and firm.

How deep should I plough?
Never plough deeper than the topsoil. Incorporating subsoil is more expensive than you think. Subsoil is very low in organic matter and therefore supplies few nutrients, has poor structure and is of little use for crop growth. Soil tests show that each centimetre of Ferrosol subsoil requires over $1000 worth of fertilisers and 8500 kg of organic matter per hectare before it approaches the value of topsoil. Popular makes of mouldboard ploughs are generally designed for deep, fertile European soils. This shape of board does a poorer job of burial and evenness of finish when attempting to plough shallower than 150 mm.

Sandy soils
Do not mouldboard plough sandy soils. Any soil low in organic matter is prone to erosion. Coarse organic material is a sandy soil's natural defence against erosion. Placing it at the bottom of the plough layer is asking for trouble. The erosion hazard is greatest for sand and sandy loam soils in dry windy conditions. Wind erosion is noticed first on mouldboard ploughed paddocks. When possible, these soils should be topworked with tined implements in a minimum tillage or direct drill system.

Duplex soils (sandy loam over clay)
Mouldboard ploughing is appropriate for deeper duplex soils only. The topsoil is the uppermost layer, and is usually darker and higher in organic matter than the pale spewy layer below. Never plough deeper than the topsoil. If the topsoil is less than 100 mm deep then the soil is not suitable for mouldboard ploughing. A depth of 100 - 150 mm is marginal. Many shallow duplex soils are prone to both wind erosion (on the banks) and waterlogging (in the hollows). Mouldboard ploughing early and leaving the fallow 'open', may help keep topsoil dry to allow early spring seedbed preparation, but this is at the expense of long term sustainability. Organic matter and structure decline under long fallows, increasing the risk of erosion and the degree of waterlogging. These soils are best managed under a program of surface drainage linking hollows with broad shallow ditches, subsurface drainage where appropriate (seek professional advice), and minimum tillage and stubble retention/incorporation using tines/discs and a trash handling drill.

Ferrosols, Cressy soils and loams
Mouldboard ploughing is highly appropriate for these soils. Intensive cropping requires incorporation of large amounts of organic matter, well-prepared seedbeds and good weed control. The mouldboard plough achieves these requirements while being relatively gentle on the soil's structure.

Black cracking clays
Mouldboard ploughing is less appropriate for these soils. These soils are self-mulching, creating a natural seedbed during shrink/swell cycles. This will only occur if stock are kept off the paddock particularly when the soil is moist or wet. By carefully using the self mulching capability, only minimal tillage is required. Shallow working with tines or discs at the optimum moisture content is best. If you do plough black cracking clays, a level finish is particularly important because the seed can be sown in the natural, self-mulched surface tilth produced over winter. A rough ploughing operation requires levelling prior to sowing. Levelling knocks the self mulched surface tilth into the hollows and exposes unweathered clay on the humps. This is a difficult seedbed to sow into. Black cracking clay paddocks are often ploughed rough with the aim of drying out the surface. If drainage is managed with drains then a rough finish is not required.

Powered implements
Roterra, rotary spikes, rotary hoe
Powered implements force the soil to fracture along new lines, forming new fragments. Gentler implements allow the soil to fracture along existing lines of weakness, forming natural aggregates. During the cropping phase soil structure tends to degrade. Good soil management is all about slowing the rate of degradation to a minimum. Powered implements used without care and skill degrade soil structure very rapidly by overworking or operating in soil too moist for tillage. Powered implements are immensely variable in their action on the soil. At best, they create a level, firm seedbed, chop and incorporate coarse organic matter and break clods all in a single pass. However, at worst, in a single pass powered implements can create more damage than any other implement, while appearing to do a fine job.

Overworking and working in moist soil conditions are the two chief problems associated with powered implements. Soils with a history of powered implement use tend to:
• Require more energy to form the seedbed each year
• Suffer 'clods and powder' seedbed syndrome
• Suffer poor drainage as natural pores and cracks are destroyed
• Crust more readily
• Have a high wind and water erosion risk. An overworked surface layer can act like a sponge, preventing excess water moving down through the profile.

Powered implements can be used as a risk-management tool. For intensive cropping where planting and harvesting follow one another closely, there often isn't time for several tillage passes all at the right moisture content or for long fallows where natural weathering does the work. Gentler implements can be used most of the time, while the powered implement is there when the 'instant seedbed' is urgently required. Powered implements can be used to shallow chip and semi-incorporate surface cover or desiccated pasture. Deep, slow powered implement passes are worst. These maximise loss of organic matter and destruction of natural structure. Do not use these implements for deep working. Use tines such as the Agroplough for minimal surface disturbance or the chisel plough for disturbance right to the surface.

Sands and sandy loam duplex soils
Overworking to a 'clods and powder' seedbed is a major problem for these soils. Use of powered implements tends to make this scenario more likely, bringing on associated problems of rapid loss of organic matter, wind erosion, waterlogging and surface crusting. All these are exacerbated by intensive tillage.

Clays and loams
Powered implements can be used with care in these soils, particularly as a shallow, low energy pass before sowing, as a 'power harrow'. In an intensive cropping system where incorporation of large amounts of green manure and stubble is necessary, use the mouldboard plough rather than a deep, high energy powered implement pass.

Black cracking clays
Use of powered implements gradually reduces this soil's ability to form a natural self-mulching seedbed. Large clods, which indicate a black cracking clay is in poor condition, tend to disintegrate the implement rather than vice versa.

Guidelines for using powered implements:
• Avoid overworking - adjust rotary speed and forward speed to produce no finer seedbed than the next crop requires.
• Check soil moisture before starting work - if you can roll a sausage it's too wet.
• Use as a shallow (50 - 100 mm) working implement to chop and incorporate organic matter and to produce the seedbed finish.
• Do NOT use as a deep working implement (over 100 mm). Use tines for deep loosening and your powered implement for the surface finish.

Deep ripping
To ensure that a deep ripping operation is effective, farmers need to consider a number of factors:
• Is soil moisture appropriate for deep ripping?
• Is the whole paddock compacted or is it only gateways and headlands where compaction exists?
• How deep is the compaction?
• Are the tines correctly spaced on your ripper?
• On investigation is the operation effective? (Figure 14).

Figure 14. Incomplete soil shatter across the implement width.

A recent United Kingdom study of ripping between 300 and 375 mm depth, found a positive response of crop yield in only 3 out of 76 paddocks. Unless a hard layer is *very* obvious from an examination of the profile, there is unlikely to be any benefit. According to the Kondinin Group, in Australia deep ripping is mainly applied to sandy, light textured soils where a traffic pan has developed. The lower the clay content of a soil, the deeper the hard layer. Deep sands develop a layer at about 30 cm depth, and loamy sands about 20cm depth. Duplex soils will have traffic pans if the clay is deep enough, but generally do not respond to ripping unless the clay is deeper than 25 cm. Ripping at a shallower depth is a more effective process as soils with high clay content, like the Red Ferrosols, tend to compact at much shallower depths. Ripping between 200 mm and 250 mm also reduces the likelihood of further compaction and smearing of soils due to below-critical-depth-tillage.

Your implement set up will also affect the ripping operation with winged rippers giving the best result (Figure 15). Recommended spacing between tines are:

	Tine spacing
Conventional Narrow Tines	1 - 1.5 times working depth
Winged Tines	1.5 - 2 times working depth
Winged Tines with Shallow leading Tines	2 - 2.5 times working depth

Figure 15. Winged rippers achieve the optimum soil shatter.

After the ripping operation soil is highly susceptible to re-compaction and so make your deepest working the last in the paddock preparation sequence. Unless actively growing roots grow into the new cracks created in the ripping operation, the effects are quite temporary - just a few weeks or months. Rip during peak growth of a ryegrass green manure to make the most of the ripping operation. The longer you can avoid recompaction the better. Duplex soils, with a pale A_2 horizon between the topsoil and the subsoil clay, are very unstable and tend to become slushy when wet. Ripping disrupts any natural pores in this layer and waterlogging is likely to be worse after deep ripping. Subsoiling into the clay can cause permanent degradation of the soil's cropping capability.

Choosing the right implement

Operation	Objective	Implement	Comments	Potential Problems	Draft* kN/m of width	Potential Soil damage
Loosening	Subsurface cracking & heaving	Deep ripper Agroplough	Rigid tines designed to work at or below plough depth (10-18"/ 250-450mm). Alleviates compaction caused by trafficking and stock in wet conditions. Breaks plough pan if one exists (see soil inspection). Two passes required using standard narrow tines, one pass using winged tines.	High soil moisture, smearing & compaction below the surface – check before working.	up to 17 per tine at 450 mm depth	✓✓✓✓
	Subsurface cracking & heaving	Paraplough	Rigid tines designed to work at or below plough depth. Tine leg is slanted sideways at 45 degrees rather than vertically. Draft is significantly reduced by having the tine follow the natural line of soil fracture.	High soil moisture, smearing & compaction below the surface – check before working.	14 per tine at 450 mm depth	✓✓✓
	Complete disturbance	Chisel plough	Stiffly-sprung tined plough, wide points (100 mm). Leaves coarse organic matter on the surface. Good topworking implement. Two passes usually required.	High soil moisture, smearing &compaction below the surface – check before working.	7	✓✓✓
Mixing & cutting	Cut/mix clods & surface organic matter	Off set discs Disc plough One way plough	Semiburial of organic matter leaving some on the surface for erosion control. Good topworking implement. Very detrimental to soil structure if used in moist or wet conditions	High soil moisture, smearing - check before working	7.5 for primary discing	✓✓✓
		Drill	Sows the seed by opening a furrow using a disc or tine and boot.	High soil moisture, smearing under seed	2.9	✓✓
Inversion	Invert soil Incorporate residues	Mouldboard plough	Complete or partial burial of organic matter, rough or smooth finish, firm or loose finish, depending on adjustment of coulters, skimmers, depth and speed.	High soil moisture, smearing – check before working.	12	✓✓✓
Compaction	Increase soil density	Rollers tyres	Conserves moisture in the seedbed and increases soil/seed contact for even germination. Tow behind the drill. Best at low speeds.	Water erosion	1.5	✓
	Increase soil density & break clods	Furrow press	Heavy cast iron rings with a sharp cutting angle. Commonly towed behind mouldboard plough in Europe. Reduces number of secondary tillage passes. Reduces erosion risk.	High soil moisture – check before working	2	✓

Operation	Objective	Implement	Comments	Potential Problems	Draft* kN/m of width	Potential# soil damage
	Finer surface tilth	Harrows	For disintegration of surface clods. More effective at higher speeds	High soil moisture – check before working	1.5	✓
	Break clods, level surface	Dutch harrow	Smudge with short vertical spikes extending into the plough layer. No trash handling ability. Good secondary implement to follow mouldboard plough. Preserves moisture. Levels surface.	High soil moisture – check before working.	3.0	✓✓
Disintegration	Break clods & incorporate surface residues	Roterra	Tractor powered. Vertical spikes or blades rotating about a vertical axis. Stirring and clod breaking action. Fineness of tilth depends on forward speed. Leaves more coarse organic material on the surface than the rotary hoe. Severely damaging to soil structure if used incorrectly (tilth too fine or soil too moist).	Overworking. High soil moisture, smearing & compaction below the surface - check before working.	30 for primary pass, 10 for secondary	✓✓✓
	Break clods & incorporate surface residues	Rotary hoe	Tractor powered. Horizontally angled blades rotating about a horizontal axis. Mixing and clod breaking action. Fineness of tilth depends on forward speed. Leaves less coarse organic material on the surface than the power harrow. Severely damaging to soil structure if used incorrectly (tilth too fine or soil too moist). Can cause a hoe pan to develop.	Overworking. High soil moisture, smearing & compaction below the surface - check before working.	30 for primary pass, 10 for secondary	✓✓✓
	Sort clods to the surface. Break clods. Improve burial or allow direct drilling	Rotary spikes	Tractor powered. Spikes rotating about a horizontal axis. Mixing and clod breaking action. Fineness of tilth depends on forward speed. Chops and incorporates clods and coarse organic material. Severely damaging to soil structure if used incorrectly (tilth too fine or soil too moist).	Overworking. High soil moisture, smearing & compaction below the surface - check before working.	30 for primary pass, 10 for secondary	✓✓✓✓
Rearrangement		S tine cultivator	Springy, forward inclined tines sort and break clods with low input energy. 4 or 5 rows of tines give a levelling effect while crumble roller firms the seedbed. Excellent as final pass before drilling.	High soil moisture – check before working.	3	✓✓
Chop Organic residues & stubbles		Flail mulcher or slasher	Smashes standing cereal straw, green manure or crop residue into smaller pieces on the soil surface for incorporation. For direct drilling into cereal stubbles, mulching improves flow of stubble past drilling tines.		3-5	✓

* kN per metre of working width of implement, from Soil Management, 5th Ed, Davies, Eagle & Finney, Farming Press, U.K., 1993.
# Refers to the implement's soil degrading capability if used incorrectly or inappropriately

5. Organic matter and soil life

"The germ is nothing, the environment within is everything" (Louis Pasteur)

Organic matter is a vital component of a healthy soil as it contributes to soil physical, chemical and biological fertility. Soil organic matter comprises all living soil organisms and all the remains of previous living organisms in their various degrees of decomposition. The living organisms can be plants, animals or micro-organisms, and can range in size from single cell bacteria only a few microns long, to small animals such as earthworms. Non-living organic matter can be considered to exist in 4 distinct pools:

- organic matter **dissolved** in soil water.
- **particulate** organic matter including plant litter, relatively large plant and animal debris that is partially decomposed but which has identifiable cell structure. Particulate organic matter can constitute from a few percent up to 25% of the total organic matter in a soil.
- **humus** which comprises both organic molecules of identifiable structure like proteins and cellulose, and molecules which do not have identifiable structure (humic and fulvic acids and humin) but which have reactive regions which allow the molecule to bond with other mineral and organic soil components. These molecules are moderate to large in size (molecular weights of 20,000 – 100,000). Humus usually represents the largest pool of soil organic matter, comprising over 50% of the total.
- **inert** organic matter or charcoal derived from the burning of plants. Can be up to 10% of the total soil organic matter.

Biological activity continuously breaks down coarse crop and pasture residues into humus which gives the topsoil its dark colour. About 25% of the coarse organic matter entering the soil forms humus, while 75% is respired to the atmosphere as carbon dioxide. The rate of decay of plant material varies with woody materials sometimes taking many years to decompose while fresh green material can decompose within a few weeks. Burnt material or charcoal can remain unchanged in the soil for thousands of years. Decomposition is enhanced when soils are moist and there is good mixing of the plant residues with soil so that the soil microbes are in contact with the residues.

Measuring soil organic matter

Most methods used for measuring soil organic matter actually determine the content of soil organic carbon. This is done by oxidising the carbon and measuring either the amount of oxidant used or the CO_2 given off in the process. Laboratories generally report results as soil organic carbon but some report soil organic matter by converting the carbon to organic matter by multiplying by 1.72. However, this conversion factor is not the same for all soils, and it is more correct to report soil carbon rather than organic matter.

The amount of organic matter in soil

The amount of organic matter in a soil depends on a range of factors, and is determined by the balance between accumulation and loss. The main factors are:

Climate – soil carbon tends to be greater in areas of higher rainfall due to greater amounts of plant growth providing greater inputs. Soil organic matter content is greater in areas with cooler temperatures due to reduced rates of breakdown. Tasmania has a relatively wet and cool climate compared to much of mainland Australia and so soil organic matter contents are relatively high.

Soil type – clay helps protect organic matter from breakdown, either by binding organic matter onto the clay or by forming a barrier around organic particles within soil aggregates which limits access to metabolizing organisms. Clay soils in the same area under similar management will tend to retain more organic matter than sandy soils. Hence the sandy Sodosols of the northern Midlands have less organic matter than the clay loam Dermosols regardless of management (Table 3).

Vegetative growth – the more plant production there is, the greater are the inputs of organic matter. Also, the more woody this vegetation is (greater C:N ratio), the slower it will breakdown leading to greater retention of organic matter.

Topography – soils at the bottom of slopes generally have higher soil organic matter contents because these areas are generally wetter, have higher clay contents and are where the finer soil particles including organic matter tend to be deposited by erosion. Poorly drained areas also have slower rates of organic matter breakdown.

Tillage – tillage will increase organic matter breakdown by increasing the exposure to air and the metabolism by micro-organisms. However, the impact of tillage is not as great as the effect of other management factors, such as length of fallow and the type of crops, on the amount of organic matter grown and returned to the soil. An exception to this is where tillage leads to increased erosion.

Under Tasmanian conditions, average values of soil organic carbon for different soil orders have been reported (Figure 16) as well as the effects of different management (Table 3). These results confirm that clay textured soils (Ferrosols, Dermosols, Vertosols) have greater soil carbon contents than sandy textured soils (Tenosols, Sodosols). Perennial plant systems such as permanent pasture result in greater soil carbon contents than cropping systems due to greater inputs over the long term. Consequently there can be considerable variation of soil carbon content within soil types. Target levels of soil organic carbon have been developed for different soil textures, land uses and rainfall zones in Tasmania (Table 4).
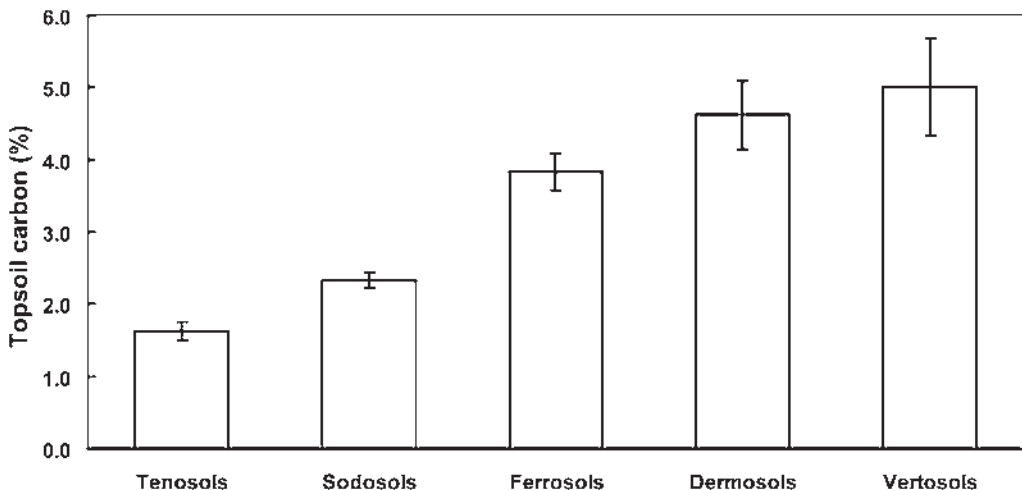
**Figure 16. Organic carbon concentrations in
Tasmanian soils used for intensive agriculture.**

Table 3. Organic carbon concentrations (%) in Tasmanian soils subject to different management.

Soil (depth)	Pasture	Intermittent cropping	Frequent cropping
Ferrosol (0-150 mm) Red soil on basalt	6.4	4.9	3.8
Dermosol (0-75 mm) Cressy clay loam	7.0	4.3	4.2
Sodosol (0-150 mm) Sandy soil over clay	2.7	2.3	1.8

Table 4. Target levels of soil organic carbon in the surface 75 mm of soil.

Topsoil texture	Land use	Annual rainfall	Target soil carbon (%)
Sandy loam or loamy sand	Pastures & cropping	All	> 2
Clay loam or clay	Cropping	> 800	> 3
		< 800	> 2
	Pastures	> 800	> 4
		< 800	> 3
Heavy clay (cracking soil)	Pastures & cropping	All	> 4

Benefits of organic matter

Organic matter is a critical component of the soil because of its role in physical, chemical and biological processes (Table 5). Many of these functions interact. Organic matter has a large surface area compared to mineral particles and it has the ability to react with cations (positive charge, e.g. Ca^{2+}, K^+) in the soil solution. Consequently, organic matter is a major contributor to a soils cation exchange capacity (CEC). Organic matter is a reservoir of nutrients including phosphorus, sulfur and nitrogen. These elements are bound within the organic structure, and are released to the soil solution when microbes break down organic matter. The ratio of carbon:nitrogen:sulfur:phosphorus in organic matter is roughly 100:10:1.5:1.5. A hectare of soil 10 cm deep with a bulk density of 1 tonne/m^3 weighs 1,000,000 kg. Therefore, soil with a carbon content of 3% would contain 3,000 kg of organic nitrogen, and 450 kg each of organic phosphorus and sulfur per hectare. Not all of this is mineralised each year, but there is considerable potential for nutrients in organic matter to contribute to plant requirements, particularly the nitrogen.

Table 5. Functions of soil organic matter.

Physical functions	Chemical functions	Biological functions
• bind soil particles together in stable aggregates • influence water holding and aeration • influence soil temperature	• major source of cation exchange capacity • source of pH buffering • binding site for heavy metals and pesticides	• food source for microbes and small animals • major reservoir of plant nutrients

Research in Tasmania has shown strong associations between soil carbon and a range of soil physical, chemical and biological properties in all the main soil types. Greater levels of organic carbon are associated with improved soil physical properties in the form of reduced bulk density, more stable soil aggregates, greater porosity, better water infiltration and improved workability at high moisture content (plastic limit). Organic matter was associated with increased CEC, improved soil pH and increased levels of microbial activity. Research in Tasmania has also found that greater soil carbon content was associated with higher crop yield when yields were measured at a number of points within individual paddocks. However, when crop yields from different paddocks were measured together with an average soil carbon content for those paddocks, there was no clear relationship between soil carbon and yield. This is perhaps not surprising because other important factors such as irrigation, fertiliser, pest and disease management also varied from paddock to paddock. Good management of these factors would tend to even out any differences due to soil organic matter.

Long-term changes in soil carbon
Soil carbon content will tend to reach an equilibrium over the long term if all of the major factors affecting soil carbon are kept the same. At that equilibrium, additions of carbon through plant production will be balanced by losses due to decomposition of humus. Such an equilibrium will be upset if one of the influencing factors changes. For example, changing from a pasture system to cropping usually means less carbon is being produced and so less carbon is returned to the soil. The soil carbon level will drop (Figure 17) until the equilibrium for the new rotation is reached. Reaching the new equilibrium can take 50 to 100 years but changing from a perennial system to an annual cropping system can result in most of the change happening in the first few years. Farmers are constantly adjusting their rotations and there are changes in the weather with wetter or drier than average years which means that equilibria are hardly ever reached before the system changes.

The evidence that soil carbon concentrations have decreased in Tasmania's major cropping soils (Figure 16) has resulted in concern about how low soil carbon concentrations might go over the long term, and what condition our soils may be in as a result. To answer these questions, a computer model of soil carbon change was developed to suit Tasmanian conditions. The model uses local data on climate, soil type and crop production (i.e.. the main factors affecting carbon change) to predict changes in carbon over long periods of 50 to 100 years. The model can be run with any rotation of crops and pasture that the user defines, and it can also account for short periods of green manures and different ways of dealing with crop residues. While the model predictions must be treated with caution because they are based on limited data and lack local verification, they demonstrate the potential effect of a range of common cropping practices (Figure 18). Crop residue incorporation and the inclusion of a green manure or a pasture in the rotation are important for maintaining or increasing soil organic matter. The model predicts equilibrium concentrations of organic
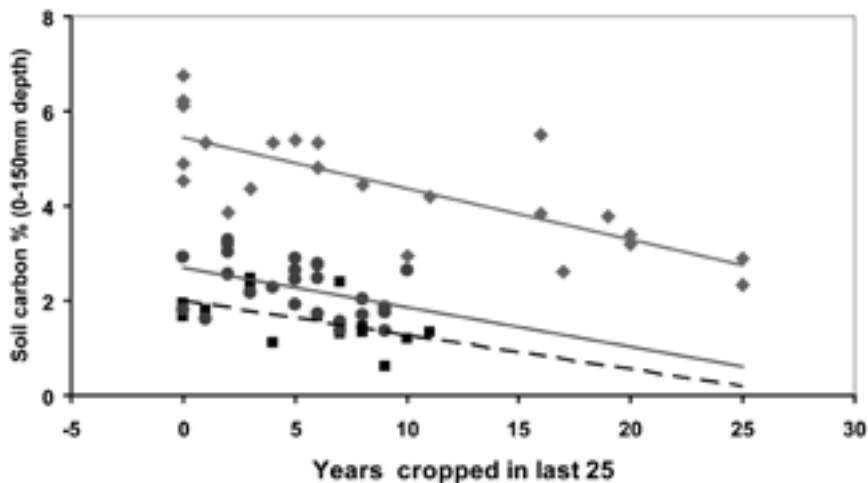
Figure 17. Soil carbon change with increasing cropping in Tasmanian soils
(diamonds = Ferrosols; circles = Dermosols; squares = Tenosols)

carbon in our rotations that are higher than the concentrations found in comparable soils in warmer parts of Australia. This natural advantage may help protect our soils against severe physical, chemical and biological degradation.
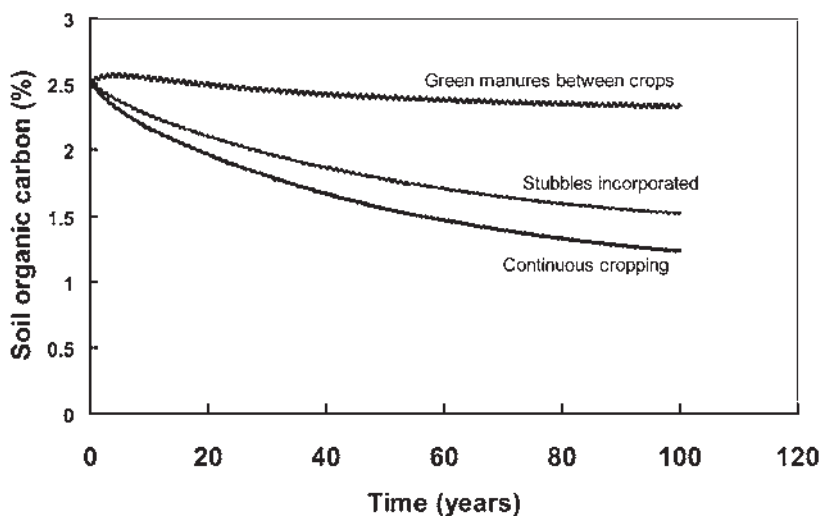
Figure 18. Modelled changes in soil carbon showing effects of incorporating stubbles and green manure growing in a barley, potatoes, peas and poppies rotation on a sandy loam soil in the northern Midlands (Rayner and Sparrow unpublished data).

One of the most significant factors found to be influencing soil organic carbon levels in cropping rotations is the length of time the soil is left as bare fallow. When the soil has nothing growing on it, there is no input of organic matter but the soil microbes continue to metabolise remaining organic matter into CO_2 resulting in decreasing organic carbon levels. The understanding of the relative influence of different soil management practices on soil carbon levels is presented in Figure 19.
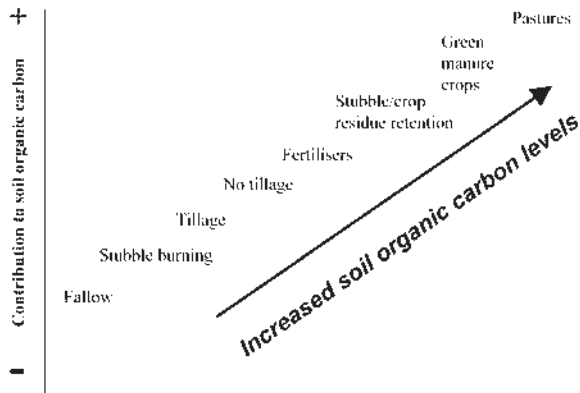
Figure 19. Relative effect of different management practices on soil carbon levels.

Soil biology

Most organisms are found in the topsoil, since this is typically where most of the organic matter is and soil organic matter is necessary to feed soil organisms. You don't need *magic products* to boost soil microbial activity, just plenty of organic matter. Maximum soil biological diversity depends on the diversity of organic matter and habitats i.e.. having a rotation of crops will aid in diversity. The organisms in soil are often commonly found close to root surfaces (the rhizosphere), within living and dead roots, on soil particles, or amongst aggregates of soil particles. Soil organisms can influence plant roots in a number of ways. The burrows of earthworms in soil provide an easy route for plants roots as they grow through the soil. Various root microorganism associations can increase nutrient uptake by plants in nutrient poor environments, such as symbiotic (e.g. mycorrhizae) as well as nitrogen fixing associations and rhizobia. Arbuscular mycorrhizal fungi can increase phosphate uptake into plants in P-deficient soils but some tillage practices and crop rotations decrease the suitability of soil for micro organisms. Mycorrhizal fungi are particularly sensitive to tillage.

Organisms in the rhizosphere can affect plant roots by altering the movement of carbon compounds from roots to shoots when organisms compete with root cells for carbon that is fixed by photosynthesis. Some soil organisms are pathogenic and attack living plant roots. Good soil structure is essential for a healthy microbial population with research in Tasmania finding that large microbial numbers are associated with higher soil structure scores. Soil amendments (fertilisers, lime, stubbles, manure, compost) can alter the physical and chemical environment for soil organisms which in turn can affect nitrogen mineralization by microorganisms and associated crop performance. Soil biological processes develop slowly, and the time required to measure a change will differ for different soils, environments and land management practices.

Soil animals

All soil animals, require sufficient carbon and nutrients, moisture, oxygen and an optimum pH and temperature and these vary between species. Some organisms do not survive dry or very cold conditions, but they may leave eggs in the soil that hatch when conditions become more favourable. Other soil animals remain in the soil in an inactive state and become active again when conditions become favourable. Larger soil animals such as

earthworms may live deeper in the soil when there are unfavourable conditions near the soil surface. Generally, the most common soil animals are protozoa, nematodes, mites and collembola.

Microfauna -   smallest of the soil animals ranging from 20 – 200 µm. Mainly protozoa.
Mesofauna -   range in size from 200 µm – 10 mm. Mites, collembola (or spring tails) and nematodes.
Macrofauna -   largest soil animals such as earthworms, beetles and termites.

Soil animals are involved in a number of soil processes including: degradation of organic matter and mineralisation of nutrients; controlling populations of pathogens; improving and maintaining soil structure by forming channels and pores; concentrating fine soil particles together into aggregates; and fragmenting and mixing organic matter through the soil.

Soil fungi
Soil fungi are microscopic plant-like cells that grow in long threadlike structures or hyphae that make a mass called mycelium. The mycelium absorbs nutrients from the roots it has colonised, surface organic matter or the soil. Decomposers or saprophytic fungi convert dead organic matter into fungal biomass (ie their own bodies), carbon dioxide and organic acids. Mycorrhizal fungi are characterised by very thin hyphae, which are between 1 and 10 thousandths of a millimetre in width. Up to 5 m of living hyphae of mycorrhizal fungi can be extracted from 1 g of soil. These hyphae explore the soil for nutrients, transport them back to the host-plant, and help bind soil particles into aggregates. The hyphae form networks between neighbouring soil particles, between roots and soil particles, between roots on the same plant, and between roots of different plants (even different types of plants). They also form networks inside the roots they colonize. These networks of hyphae are also referred to as mycelium. Pathogenic fungi include the well known fungi such as V*erticillium, Phytophthora, Rhizoctonia* and *Pythium.* These organisms penetrate the plant and decompose the living tissue, creating a weakened, nutrient deficient plant, which may die.

Tillage has a disastrous effect on fungi as it physically severs the hyphae and breaks up the mycelium. Broad-spectrum fungicides are toxic to a range of fungi. Their use will result in a decline in the numbers of beneficial types. Herbicides are not generally thought to affect fungi directly, though the removal of some plant types may affect the distribution of different fungi types.

Soil bacteria
In general, bacteria are the organisms in soil that are mainly responsible for transforming inorganic constituents from one chemical form to another, for example, conversion of nitrate to nitrite, sulfate to sulfide and ammonium to nitrite. Bacteria are able to perform an extremely wide range of chemical transformations, including degradation of organic matter and nutrient transformations inside roots. Most bacteria in soil are about one micron in length or diameter and usually occur as single cells. Soil bacteria populations are depressed by dry conditions, acidity, salinity, soil compaction and lack of organic matter but are largely unaffected by cultivation. Aerobic bacteria are those that need oxygen, so where soil is well drained aerobes tend to dominate. Anaerobes are bacteria that do not need oxygen and may find it toxic. This group includes very ancient types of bacteria that live inside soil aggregates. Anaerobic bacteria prefer wet, poorly drained soils and can produce toxic compounds that can limit root growth and predispose plants to root diseases.

Rhizobia are bacteria that take nitrogen from the air (which plants cannot use) and convert it into a form of nitrogen called ammonium (NH_4^+), which plants can use. The nodulation process is a series of events in which rhizobia interact with the roots of legume plants to form a specialised structure called a root nodule. These are visible, ball-like structures that are formed by the plant in response to the presence of the bacteria. Most plants need specific kinds of rhizobia to form nodules. Nodulation can be impeded by low pH, Al toxicity, nutrient deficiencies, salinity, waterlogging, and the presence of root parasites.

Fungi : bacteria ratios

Fungi and bacteria differ in their responses to changes in agricultural management practices. Fungi are usually more sensitive to these changes. The fungal-to-bacterial ratio is therefore an indicator of environmental changes in the soil.

- When plant residues are applied as mulch, fungi prosper because their hyphae are able to grow into the litter layer.
- Tillage severs the hyphae and breaks up the mycelium thus decreasing the mass of fungi.
- Fungi are the predominant cellulose decomposers. Cellulose has a high carbon content and a corresponding high C:N ratio, making it the ideal food source for fungi. Adding organic material with a relatively wide C:N ratio (e.g. dry stubble) enables growth of the fungal population.
- Usually fungi depend on a sufficient amount of water in the soil and are expected to be less active under dry conditions (see February in Figure 5).
- In many cases a low pH is associated with fungal dominance whereas a higher pH might be related to bacterial dominance.
- Bacteria, which have a smaller C:N ratio than fungi, need food rich in nitrogen (e.g. green manure, legume residues). Adding fertiliser rich in nitrogen therefore favours the bacterial community in a soil.
- Incorporation of plant residues into the soil favours the bacterial population because the contact surface between the substrate and bacteria is increased.

Monitoring soil biology

Soil biology test results are hard to interpret but they can be useful if the influence of rainfall, temperature and organic matter supply are taken into account. Results will vary widely according to soil type, topography and vegetation (Table 6). Avoid mixing samples across these ranges. Results from different laboratories can not be compared as different laboratories use different tests and even a small change in analysis procedure can mean that results are not comparable. The activity of the soil microorganisms varies greatly with the seasons as activity increases markedly with increasing temperature and soil moisture (Figure 20 & 21). If you get a test result indicating suppressed activity at a time when you would expect it to be active then the first thing to do is to look for an underlying problem such as salinity, acidity or compaction. If there is no clear underlying problem then you may need to consider changes in soil management such as minimum tillage, strategic grazing, green manure crops or different crop rotations. Additions in the form of soil inoculants are only effective in certain circumstances. Where a test result is only partly unsatisfactory there is as yet insufficient data for clear recommendations. A trend in test results observed over several seasons can be a valuable indicator for soil management.

Table 6. Microbial measures from soil microbial indicator tests on Tasmanian soils.

| | Microbial biomass (kg/ha) | | | | | Microbial ratios | |
	Total Microbes	Bacteria	Fungi	Yeast	Anaerobic	Fungi: Bacteria	Fungi: Yeast
Cereals Cradle Coast	12300	5000	3700	3600	390	1.6	1.0
Pasture Cradle Coast	12000	4800	3700	3800	230	1.7	1.5
Potatoes Cradle Coast	11800	3900	5300	2600	560	2.5	2.5
Cereals northern Midlands	11300	3800	5500	2100	120	2.0	2.7
Pasture northern Midlands	10700	3700	4500	2400	260	1.9	2.0
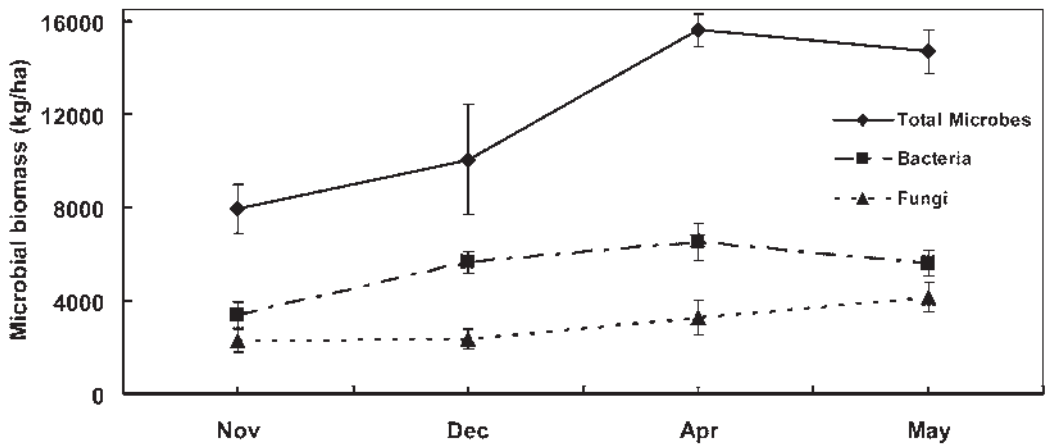
Figure 20. Microbial biomass under pasture in the Cradle Coast Region.

A study was undertaken in northwest Tasmania to examine data on soil microbiological, chemical and physical properties and field information that may relate to soil health, in order to gain a better understanding of their impact on carrot crop health and yield. Results showed that in general, higher levels of total microbial activities were recorded under long term pasture than in carrot sites, regardless of the different methodology used at three different laboratories. The differences in microbiological indicators, such as total bacteria, total fungi and mycorrhizal fungi, followed a similar pattern to total microbial activity, with all carrot sites having lower values than reference sites. The significant correlation of many of these microbial indicators with total nitrogen, total carbon, and labile carbon demonstrated the interconnections between all these attributes. This indicates that relatively common and simple types of tests, e.g. total carbon, are as effective as complicated test methods.

Points to remember:
- Living organisms will occur wherever there is food. Feed soil biota organic matter and they will flourish.
- Avoid bare fallows as these contribute the most to organic matter decline. Grow green manure or cover crops over autumn and winter.
- Maximising inputs of organic matter by incorporating crop residues and including green manures and pastures in the rotation, where practical, should be a goal for all farmers.
- To increase organic carbon by 1%, approximately 40 t/ha of dry matter will need to be applied to the soil.
- Provide a variety of organic materials through crop rotation as this builds a diversity of soil organisms which gives resilience to protect against disturbance such as cultivation.
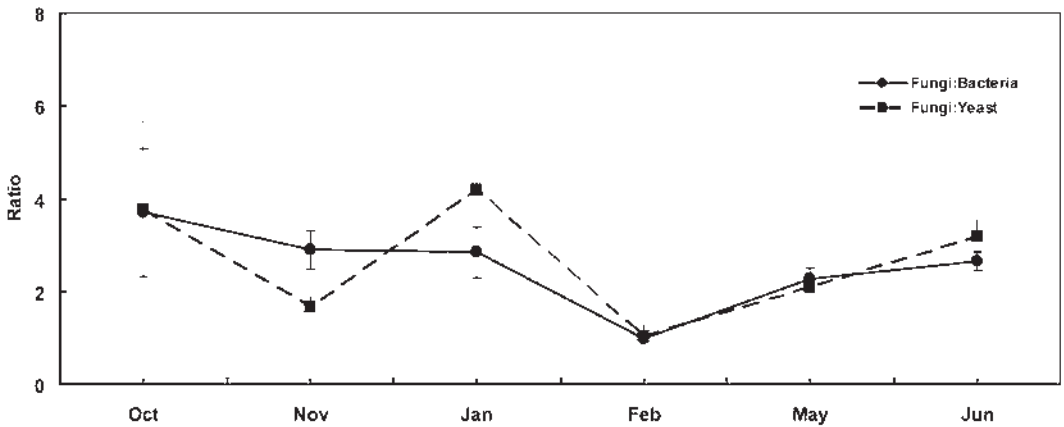
Figure 21. Soil microbial ratios under potatoes in the Cradle Coast Region.
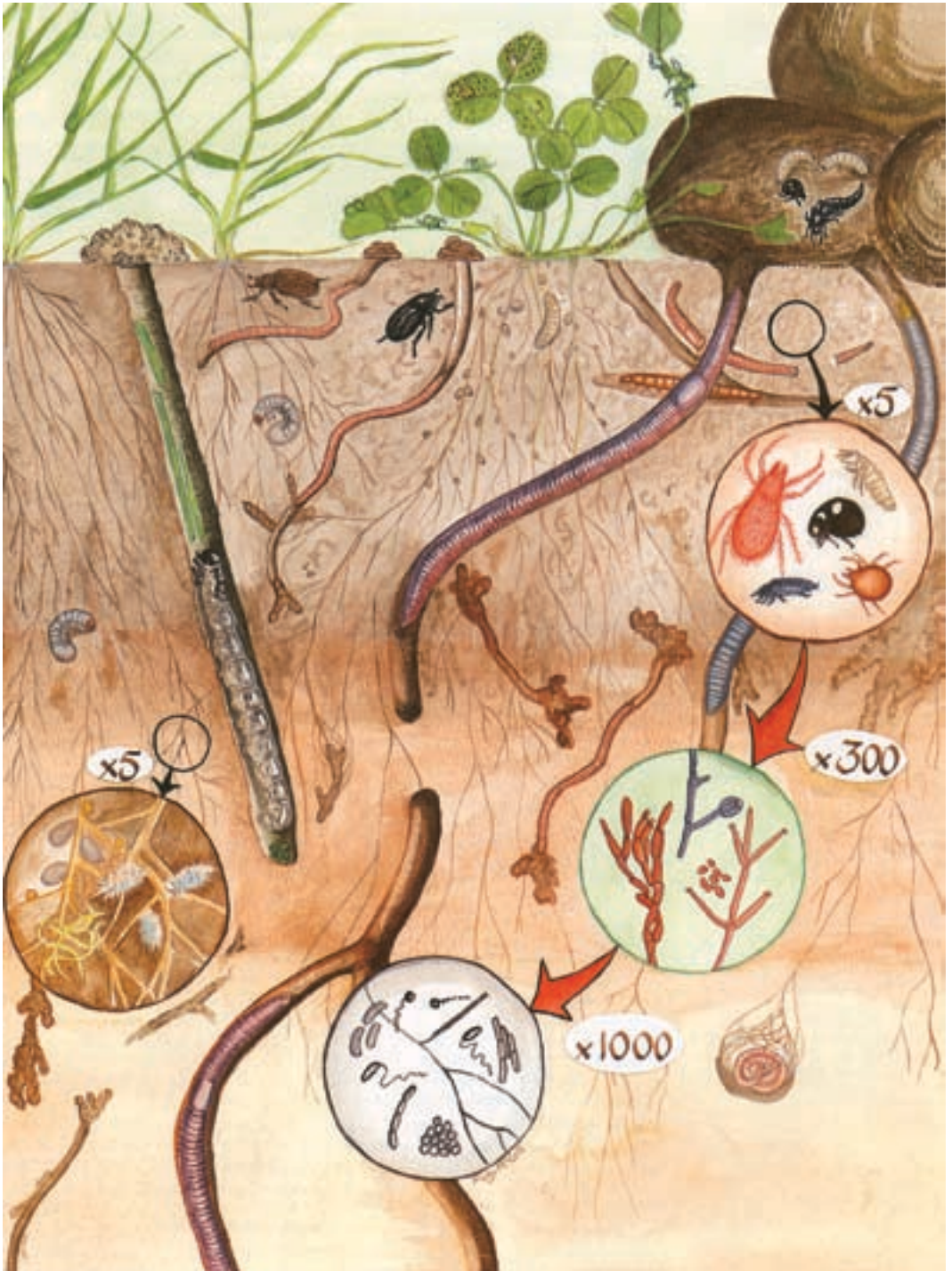
6. Soil erosion

"The land does not lie; it bears a record of what men write on it"
(WC Lowdermilk)

Soil erosion mostly happens over brief periods, is often confined to only a few paddocks on a farm at any one time, and many visible signs are lost from view by subsequent cultivation. In one farmer's lifetime on the land, the effects of erosion may be progressive but masked by improved plant cultivars, greater fertiliser and irrigation inputs and larger machinery. Declining yields may not occur over entire paddocks and may be put down to seasonal differences. The cumulative effects of erosion will only become obvious after many generations. Soil formation happens so slowly that even in 1000 years only 20 mm of new soil will be formed according to optimistic estimates. This amount of soil can be lost in only a few rainfall events if the soil is left unprotected and rates of erosion in excess of 140 tonnes/ha (14 mm depth) have been measured after a single event in Tasmania.

Soil on steep paddocks has a high potential to erode. A millimetre of soil eroded is the same as trucking 10 to 15 tonnes per hectare and dumping it elsewhere, most often into a local river or stream. The rate of soil erosion depends on climate (precipitation and wind), topography (angle and length of slope), soil properties (soil texture, soil structure and organic matter), vegetation cover and management. Climate, slope angle and certain physical characteristics of the soil cannot be directly controlled. However, their effects may be modified indirectly through improved management practices. Soil conservation to stop erosion is like taking out insurance against being caught out. You hope you don't need the insurance, but it helps you to sleep at night.

Forms of water erosion

Splash erosion or raindrop impact represents the first stage in the erosion process and results from the bombardment of the soil surface by raindrops. Rain drops behave as little bombs when falling on exposed or bare soil, displacing soil particles and destroying soil structure. Splash erosion results in the formation of surface crusts which reduce infiltration resulting in the start of runoff.

Rill erosion results from the concentration of surface water (sheet erosion) into deeper, faster-flowing channels. As the flow becomes deeper the velocity increases detaching soil particles and scouring channels up to 30 cm deep. Rill erosion represents the intermediate process between sheet and gully erosion.

Gully erosion is an advanced stage of rill erosion where surface channels have eroded to the point where they can not be removed by tillage operations. A gully head forms as rill erosion deepens and widens creating a characteristic nick point or headwall. Most gullies extend up slope as a result of headwall migration. However it is the collapse and slumping of the sidewalls which usually contributes the greatest proportion of soil loss. In most cases repairing the damage caused by gully erosion is either not possible or difficult to justify economically. Efforts are usually directed toward stopping or controlling the erosion process rather than repairing the damage. Prevention involves ensuring drainage from roads, buildings and stock routes is not concentrated into gullies, minimising tree clearing and fencing out stock from susceptible areas.

Tunnelling is an insidious form of sub-surface erosion, resulting in considerable damage even before surface manifestations are evident. Tunnel erosion is caused by the movement of excess water through a dispersive (usually sodic) subsoil. Sheet erosion is often a precursor to the onset of tunnelling. Compacted bare areas generate runoff which flows directly into the subsoil via surface cracks, rabbit burrows, or old root holes. Once concentrated in the subsoil the runoff causes the sodic clays to disperse and form a suspension or slurry. Provided there is sufficient gradient, the slurry is able to flow beneath the soil surface. Once formed, tunnels continue to enlarge during subsequent wet periods. Eventually tunnels reach a point where the roof collapses resulting in potholes and formation of erosion gullies. Tunnel erosion is particularly difficult and expensive to control and not always successful. A combination of mechanical, chemical and vegetative measures are usually required to control or prevent tunnel erosion. Stabilisation of areas with dispersive sub-soils requires permanent vegetation cover, such as perennial pasture, shrubs and trees. Grazing is not recommended if the protective vegetation is susceptible to over-grazing. Such areas require fencing and permanent exclusion from stock.

Control of water erosion

Cut-off drains, in conjunction with grassed waterways, effectively divert water flowing towards a paddock or a cultivated area. Installing cut-off drains located along farm tracks or fence lines will help to minimise interference to farming operations. Grassed waterways are most applicable for crop and short-rotation pasture on sloping paddocks. Grassed waterways transport water along natural drainage lines. Raised beds with adjoining furrow drains are most applicable to control surface water for continuous cropping systems, where livestock are excluded from the cropping area and where the gradient is no greater than 3%. Shortening the length of beds can reduce the risk of erosion resulting from high volumes of water flowing along the furrows. Cut-off drains incorporated within raised bed systems can divert drainage before accumulating along the furrows.

Mulched-rip lines are best used to prevent erosion in annual crops on sloping paddocks (Figure 22). This system allows for increased infiltration of water into the soil, rather than draining run-off, thereby improving sub-soil moisture levels and reducing the need for other surface drains. On slopes of 12–14 % the mulched rip lines are spaced at approximately 40 m intervals (Figure 23) - on steeper slopes the lines may be as close as 25 m apart while on flatter slopes they can be up to 80 m apart. The straw and rip lines are designed to retain run-off water on the paddock by slowing water movement downslope with the straw and getting the water to infiltrate into the soil through the rip lines. The rip lines create a zone of loose soil that acts like a 'sponge'. Any soil moving downslope is also trapped by the straw and so prevented from leaving the paddock.

Previous erosion control techniques relied on catching run-off water in sloping contour drains and directing it into grassed drains to remove the water from the paddock. These drains were unpopular with farmers and contractors because they give a rough ride when spraying by tractor, crops have to be pulled either side of the drain prior to harvest, drains have to be filled in before harvest and spray and harvesting equipment suffer breakages. The new technique not only overcomes these problems, it also occupies about half the land compared to drains.

Figure 22. Installing mulched rip lines

Figure 23. Mulched rip lines prevent soil from leaving the paddock.

Adoption of sustainable land management practices

Agricultural extension staff are always looking for the magic way of getting adoption of new farming practices or technology without the cost of one-on-one methodologies. There is a considerable volume of theory on the subject but there are still difficulties in getting change on the ground. The uptake of the ripper-mulcher technology for erosion control in northwest Tasmania is an example of the adoption of a sustainable land management practice that required the development of new technology and a change from past methods.

One of the factors working in favour of adoption of the new technology was that I had been working closely with farmers over the previous 6 years in soil management issues, including soil erosion control. This had built up my level of credibility with the farmers allowing for greater acceptance of my new idea. Supplementary resources were accessed through community group initiatives which allowed for the purchase for several ripper-mulcher implements and the employment of a specialist Project Officer to work one-on-one with farmers.

There was a considerable time lag from the original idea to developing a workable technology and then adoption on a broader scale. The lessons learnt for the successful adoption of new technology by farmers are:
• Farmers can fit the practice into their current farming system.
• The practice/technology works.
• The practice is cheap to adopt (both dollars and time).
• Those pushing for adoption have established credibility with the farmers.
• One-on-one assistance is required for some time to familiarise farmers with the practice.

Putting on a field day will at best create awareness but will not achieve adoption. Farmers might see the theory of how the practice works but they inevitably will resist change – it is human nature – and they will see even small obstacles to the use of the practice on their farm. Farmers usually need one-on-one advice to tailor the practice to their farm and their management style. This is because, even if the technology is simple, it must be

implemented into a complex farming system. After an initial period of one-on-one advice, farmers can be weaned off this reliance and they are able to include the practice as part of their day to day operations. The practice becomes part of their new culture.

Wind erosion

Wind erosion is common on flat, bare areas with dry, sandy soils, or anywhere the soil is loose, dry, and finely granulated. Sandy soils are very susceptible to erosion, however clay soils which have been pulverised by powered tillage implements or worked when they are too dry are also susceptible to wind erosion.

Most soils require at least 30% ground cover to prevent wind erosion. Vegetation and crop residues prevent wind erosion by reducing soil drying by evaporation, reducing wind speed at ground level and anchoring soil particles. In crop areas methods such as stubble retention, direct drilling, herbicide weed control and chemical fallows reduce the risk and extent of wind erosion by maintaining residue cover. Cereal stubble can protect soil (before and after sowing) from wind erosion. Effective stubble management requires appropriate implements, such as direct drills. Drills specifically designed to handle stubble interference can reduce the incidence of machinery blockages. To further overcome machinery blockages, stubble can be chopped into shorter lengths. Shelterbelts can provide extra protection against wind erosion, they tend to reduce the wind velocity for distances up to 30 times the height of the trees. Field shelter belts usually have yield or quality benefits which help to offset yield losses associated with taking land out of crop production.

Landslips and slumps

Soil creep, earthflow, slumps, landslips and landslides are all forms of mass movement. Although relatively infrequent in Tasmania, large mass movement events are dramatic that can result in permanent loss of houses, roads and agricultural land. Landslip prevention and control usually requires revegetation of cleared areas with dense plantings of trees to de-water and stabilise soils and remove soil water by evapotranspiration.

Rates of erosion in Tasmania

Rates of soil loss have been assessed by measuring the levels of the radioactive isotope Caesium - 137 present in the soil. Nuclear tests in the atmosphere have distributed radioactive Caesium across the earth since the 1950's. This radioactive Caesium can be used as a tracer of soil movement and has allowed for the calculation of soil movement down slopes and off paddocks. Paddocks kept under full pasture cover for grazing are losing soil by erosion at the rate of 0.3 - 0.8 T/ha/yr and sloping cropped paddocks are losing 2.5 - 8.2 T/ha/yr (Table 7). These rates of soil loss are an average for every year since the 1950's and so the total soil lost could be as much as 300 tonnes per hectare from cropping ground or the equivalent of 30 mm of soil. When this figure is considered in light of the depth of topsoil existing on most paddocks today, which is 200 - 250 mm, and the best estimate of soil formation rate is about 0.02 mm/yr, the alarm bells should start ringing.

Table 7 also shows that soil movement within a paddock varies considerably with steeper parts of a paddock suffering the most soil movement and some parts of a paddock are accumulating soil. The implication of these results is that some cropping farmers are losing their capital resource base, their soil, at rates which will inevitably impact upon their operations and productivity if they aren't already doing so. Sustainable land management practices need to be adopted to keep their soils on the paddock rather than have it pollute streams, silt up dams and block roadways.

The rates of erosion are less in Tasmania than in other States under both grazing and cropping Table 8) but erosion at rates greater than soil formation (>0.3 T/ha/yr), on land used for cropping occurs as frequently in Tasmania as in NSW, and more frequently than in Queensland. Erosion at rates greater than soil formation (>0.3 T/ha/yr), on land used for grazing, occurs as frequently in Tasmania as in other States.

Table 7. Soil erosion on Ferrosols as measured using radioactive Caesium (modified after Richley *et al*. 1997).

Tasmanian Region	Overall paddock slope (%)	Landuse	Rate of soil loss from paddock (T/ha/yr)	Range of soil movement within paddock (T/ha/yr)
Northwest	13	Intensive cropping	5.3	0.9 - 18.7
	15	Cropping	2.5	0.4 - 4.7
	23	Mostly pasture/ some crop	0.3	0.02 - 2.1
Northeast	15	Crop/pasture	8.2	0.7 - 18.7
	25	Pasture	0.8	0.09 - 1.7
	27	Dairy pasture	0.4	0.03 - 1.1

Table 8. Soil erosion as measured using radioactive Caesium (modified after Richley *et al*. 1997).

State	No. of sites sampled	Range (T/ha/yr)	Mean (T/ha/yr)	% of sites < 0.3 T/ha/yr
Grazing or forestry / unused				
Queensland	8	0 – 4.1	1.1	53
New South Wales	17	0 – 7.3	0.8	50
Western Australia	10	0 – 3.8	0.9	40
rangelands	9	1.9 – 25.4	13.5	0
Tasmania	16	0 – 3.5	0.6	53
Cropping + Cropping/grazing rotations				
Queensland	6	1.3 – 14.7	6.3	17
New South Wales	12	0 – 41.2	7.3	8
Western Australia	4	0.1 – 46.0	7.9	< 1
Tasmania	8	0 – 8.2	3.0	13

7. Soil water and irrigation

"If you run out of water, you pray for rain. If you run out of soil, you pray for forgiveness"
(Bob Kerrey)

Two important functions of soil are to store moisture and nutrients and to supply these to plants between rainfall or irrigation events. How much water the soil can store can vary greatly within very short horizontal and vertical distance. Knowing how much water soil can hold makes irrigation planning easier and can improve water use efficiency. If you can minimise the time that soil is too dry or too wet, the benefits of the organic matter and nutrients in the soil and the activity of the living organisms in it, can be maximised. Efficient irrigators should aim to minimise the time soil is in a saturated or dry state, and maximise the time when water is readily available to the plant (Figure 24).

Soil water

Soil is like a big sponge - it can only soak up a certain amount of water and it can only do it at a certain rate. When soil is saturated there is no benefit in applying more water. Excess water only produces plant stress, waterlogging, drainage to watertables below the rootzone, run-off and leaching of fertilisers. Soil water is held in soil pores (the spaces between soil particles). There are two forms of soil water:
• water held tightly to the soil particles (adsorbed water)
• water held in the pores between the soil particles (capillary water)
Roots remove water from the soil pores by creating suction. Plants use water from large soil pores first because it is more difficult for the roots to remove water held by the small soil pores. Some plants can extract water from drier soil more easily than others. How 'tightly' the soil holds onto its water, and how much effort the plant has to exert to extract this water, can be described as 'soil moisture tension'. We use a negative pressure (in centibars) to describe this tension. By measuring soil water, we can describe the condition of the soil at each stage of irrigation and crop use: from 'saturation point' to 'permanent wilting point', and the stages in between: 'field capacity' and 'refill point'.

Saturation point
After heavy rain or over-irrigation, soil may become saturated. This is when even the largest pores are filled with water. Applying more water causes ponding, run-off or deep drainage. When the soil is saturated there is no air for the plant roots. This will stress most actively growing plants.

Field capacity
Once rain or irrigation stops, large soil pores (macropores) drain due to gravity. Depending on the type of soil, this drainage may take 1 to 4 days. When the large pores have drained, the soil is still wet, but not saturated. The soil is at field capacity. Field capacity in most soils is at a soil-water tension of -8 to -10 kPa. The small pores resist gravity and hold onto their water through capillary force. The water they provide is the main source of readily available water for the plant. It is easy for plants to extract water when the soil is at or near field capacity.

Permanent wilting point
As water is used by a plant, and evaporation also takes place, the plant has to work harder to extract water from the soil. The harder the plant has to work, the higher the soil water

tension. If a plant has to work too hard, it will start to wilt, reducing growth and yield. Eventually the soil reaches a point when the plant can no longer extract any water. This is called the permanent wilting point. Once the soil has passed this point, water is held by the soil so tightly that the plant will be dead due to a lack of water.

Total water-holding capacity of soil
The total water-holding capacity of saturated soils is generally 400 – 600 mm of water per metre of soil depth, but this depends very greatly on the soil texture. For example:
- Sand holds about 70 mm of water per metre of soil depth below permanent wilting point, 60 mm is the total water available to plants, and the remaining 270 mm is the free-draining water between field capacity and saturation.
- Medium to heavy clay holds slightly more water, but 250 mm is held below permanent wilting point, 140 mm is available to plants, and only about 20 mm is free-draining above field capacity.
- Sandy loams, loams, clay loams and self-mulching clays hold a similar total volume of water. Self-mulching clays have the most total available water which plants can use, followed by the loams, clay loams and light clays.

Readily available soil water
A plant cannot use all of the water held in the soil. For practical irrigation planning, irrigators must work with the water that can be readily removed from the soil by the plant, i.e. the readily available water (RAW). RAW is the depth of water held in every metre of soil depth (mm/m) that can be readily removed by a plant. RAW can be calculated for the total profile depth, or more usefully just down to the depth of the plant's effective root zone. To achieve high yields without creating excess drainage you need to know the RAW for each crop. Soil texture determines that only 15 to 50% of the total available water is readily available water and when this is used irrigation should be applied (Table 9).

Refill point
After the readily available water has been used, plant roots cannot as easily extract water from the soil. This point is referred to as the refill point. As its name suggests, refill point is the time to irrigate. The drier the soil is, the more water it needs to return to field capacity. The field capacity and refill point values are critical for the correct use of many of the soil water monitoring technologies such as gypsum blocks, or tensiometers. These values vary according to soil type and crop grown. Examples of values used successfully over past seasons in Tasmania are presented in Table 10.

Figure 24. A centre pivot irrigator that applies water efficiently.

Table 9. Readily available water for a range of soil textures.

Soil texture	Readily available water (mm/m)
Sand	30
Loamy sand	50
Sandy loam	70
Sandy loam rich in organic matter	90
Loam	90
Clay	50
Clay loam (Ferrosol)	80
Well structured clay	60

Table 10. Field capacity and refill point for Tasmanian soils.

Soil type	Crop	Field capacity (mm)	Refill point (mm)	Tensiometer reading at 30 cm depth (kPa or cb)
Red Ferrosol	Pasture	40	30	35
Red Ferrosol	Potatoes, peas, poppies	40	30	40
Red Ferrosol	Pyrethrum	40	25	60
Duplex soil (Sandy loam topsoil)	Poppies	28	18	35
Deep sand	Potatoes	24	14	25
Cressy soil	Potatoes	40	30	40
Black cracking clay	Poppies	45	35	45

Effective root zone

The effective root zone is that part of the plant's root zone where the main mass of a plant's roots that contribute to crop growth are found. Below the effective root zone there may be a few roots, but any water they extract is not significant for the plant's growth. The effective root zone is typically two-thirds the depth of the deepest roots. Some crops, such as irrigated pasture and grass seed crops, develop a mass of shallow roots with only a few roots penetrating into deeper soil layers. When calculating the readily available water for these crops it is important to only use a shallow depth as the effective root zone. For annual crops, the root zone increases during the irrigation season. The depth of the root zone for commonly irrigated annual and perennial crops is shown in Table 11.

Table 11. Rootzone depths for a range of Tasmanian crops.

Crop	Root zone depth when fully developed (m)
Potatoes	0.6
Poppies	0.5
Peas	0.5
Green Beans	0.5
Pyrethrum	0.8
Buckwheat	0.4
Carrots	0.5
Onions	0.3
Broccoli	0.5
Squash	0.5
Lucerne	1.2
Pasture	0.3
Stone/pomme fruit – mature trees	1.0
Vines	0.7

When to irrigate and how much to apply

A number of options are available to farmers to decide when to irrigate. 'Hit or miss' usually means watering too frequently to make sure the crop gets plenty. Farmers 'hit' the problem but 'miss' out on some money from excess pumping costs, leaching of fertilisers and possible yield reductions. Careful observation by some farmers over a number of years means that they are able to decide when to irrigate based on subtle changes in plant colour and appearance resulting from water stress, an appreciation of the effects of different weather conditions on water loss, and knowledge of their soils. Feeling the soil in the hand is often used because if the soil is powder dry or crumbly and will not hold together it obviously needs irrigating. If the soil is a bit crumbly but will hold together it probably needs irrigating and if it forms a ball and sticks together it is wet enough. However, by the time a farmer sees visual symptoms of stress, plants have often been under yield-influencing stress for some time. Also, it is impossible to know how much water is in the soil just by feeling the surface soil as plant roots extend well below the surface, and we can not tell if too much irrigation has been applied to subsoils.

An evaporation pan together with rainfall records can be used to schedule when to irrigate. An evaporation pan is used to measure the amount of water evaporated from a free-water surface. The reading closely approximates the amount of water lost from a growing crop or pasture with full ground cover and can be used as a guide to the need for irrigation. Evaporation increases with greater sunshine intensity, air temperature and wind speed, and decreases with increased air humidity. Recording of evaporation pan data must be combined with rainfall records using a rainguage. An simple but effective evaporation pan can be constructed from a half 200 litre drum. A 'V' notch 12 - 15 mm deep is cut in the

rim to drain water added to the drum during irrigation or by rain. The bottom point of the 'V' notch represents the field capacity level. Horizontal lines marked off at 10 mm intervals can be helpful to show the amount of water drawdown. The drum should be covered with netting to prevent birds, dogs or other animals affecting the water level. Place the drum in a paddock, making sure it is not sheltered by fences, posts or trees. It should not be placed in a hollow, nor on a high spot, but freely exposed to the sun and wind. The rim should be at about the same height as the crop at full ground cover. Every 2-3 days measure the depth of the water below the base of the 'V' notch and top up the pan. This depth in millimetres is the amount of water used by the crop with full ground cover which needs to be replaced by irrigation. If your crop doesn't have full ground cover, then an estimate of water use is obtained by multiplying the evaporation pan number by the proportion of ground covered by green crop which is estimated from the amount of shadow under the mid-day sun. Add up the daily evaporation since your last irrigation or good soaking rainfall which would have left your soil water storage full (field capacity). This gives you an 'accumulated deficit'. If the evaporation pan has been overtopped by rainfall, then the amount of extra rainfall needs to be deducted from the total deficit.

Evap(day 1) + Evap(day 2) +......... minus rainfall(mm) = soil water deficit(mm).

Evaporation figures are usually published daily in local regional newspapers for a few locations which record this data or they can be obtained from the Bureau of Meteorology website. Use the figures from the recording station closest to your farm, together with your own rainfall records, to work out your soil water deficit. If your farm isn't local to one of the published locations then you are best to install your own evaporation pan in the paddock you are irrigating because of differences in wind exposure for individual sites and local microclimate variations.

The interval between irrigations and the amount of water to apply at each irrigation depends on how much water is held in the root zone and how fast it is used by the plants. This is determined by the depth of the effective root zone, the soil texture within the effective root zone, and the rate at which water is being removed from the soil. There are four steps involved in calculating when to irrigate using knowledge of the effective root zone and evapotranspiration rate.

Step 1 is to determine the effective root zone. For example the effective root zone of pasture is generally between 20 cm and 40 cm. This can vary depending on soil type and pasture species. For a well managed irrigated perennial ryegrass pasture on a uniform soil type it is generally 30 cm. Dig some holes to check the plant rooting depth or use the values in Table 3.

Step 2 is to identify and measure the thickness of the different soil layers within the effective root zone. Again dig some holes to find out. Many soils will have only one soil layer within the effective root zone, but in some soils there is a change in soil texture within the effective root zone. It is important to know the depth of these layers within the effective root zone as this will determine the amount of water held within the effective root zone.

Step 3 is to determine the texture of the soil in each layer of the effective root zone as this determines the amount of water that is available to plants within their effective root zone. Texture is assessed by the feel of a sample of moist soil when worked between the finger and thumb (see Chapter 4).

Step 4 is to calculate how much readily available water is in the effective root zone from the thickness of each soil layer and the relevant RAW from the texture (Table 1). Multiply the thickness of each soil layer by its RAW value to give amount of readily available water in each layer.

Total RAW (mm)= RAW layer 1 (thickness x RAW) + RAW layer 2 (thickness x RAW)

Calculating irrigation intervals

Evapotranspiration is the combined loss of water vapour from soil (evaporation) and through plants (transpiration). Average daily evaporation for different regions in Tasmania for each month is given in Table 12.

Table 12. Average daily evaporation (mm/day) for each month for Tasmanian Regions.

	South	Midlands	NE	NW	Far NW
Jan	5.0	6.0	4.7	5.4	5.3
Feb	4.4	5.6	4.3	4.9	4.8
Mar	3.0	3.8	3.2	3.6	3.7
Apr	1.7	2.3	1.9	2.3	2.3
May	1.0	1.2	1.2	1.4	1.4
Jun	0.6	0.8	0.9	1.2	1.1
Jul	0.7	0.8	1.0	1.2	1.2
Aug	1.2	1.3	1.4	1.6	1.6
Sep	1.9	2.2	2.0	2.2	2.3
Oct	2.9	3.2	2.9	3.3	3.3
Nov	3.9	4.3	3.6	4.2	4.2
Dec	4.7	5.2	4.4	4.9	4.9

As a first estimate, the amount of Readily Available Water in the effective root zone and the evaporation values from Table 4 should be used to determine the irrigation interval.

Irrigation interval (days) = Total RAW in root zone / daily evaporation

The effectiveness of this interval will need to be checked with on site soil moisture monitoring. The lower the RAW value and the higher the daily evaporation, the shorter the interval between irrigations needs to be. The amount of water applied in each irrigation should be enough to refill the available water in the effective root zone.

Water infiltration into soil

Water can only infiltrate into the soil at a certain rate, and the longer water is applied the slower this rate becomes. The rate that water can enter the soil is called the infiltration rate of a soil.
- With pressurised irrigation systems the rate at which you apply water must not exceed the soil's infiltration rate.
- With surface systems, the application at any one point must be long enough to allow enough water to enter the soil profile.

Exceeding the infiltration rate can result in soil damage and run-off. It can also cause erosion, loss of fertilisers, and excessive waterlogging of the root zone in low-lying areas. Infiltration rates can vary within a field as well as between fields. Infiltration mainly depends on soil texture, structure, porosity and bulk density, but groundcover, slope and dispersion also influence it. Table 13 shows the range expected for the main texture classes.

Table 13. Average infiltration rates for different soil textures.

Soil texture	Suggested application rate (mm/h)		Infiltration rate range (mm/h)
	Average soil structure	Well-structured soil	
Sand	50	-	20 - 250
Sandy loam	20	45	10 - 80
Loam	20	45	1 - 20
Clay loam	20	40	2 - 15
Light clay	2	5	0.3 - 5
Medium-heavy clay	0.5	5	0.1 - 8

Application rates can safely be increased if the soil is well structured (especially red Ferrosols and self-mulching clays) and the soil is resistant to erosion. Application rates should be reduced if the soil has weak or unstable structure, the soil is bare, slope is more than 5%, or the soil is sodic with an ESP greater than 6%). The infiltration rate of a soil may be increased by management techniques such as:
- Opening up the surface (breaking up crusts, hardpans and hard-setting layers, adding gypsum to sodic soils).
- Relieving compaction (cultivating, coring, spiking).
- Improving soil structure (increasing organic matter, including a pasture phase in rotation, growing deep-rooting plants such as lucerne).
- Breaking up impermeable layers by subsoil cultivation if appropriate.
- Retaining more surface cover (stubbles, pastures).
- Overcoming water repellency by the methods above, especially organic matter in the topsoil.

Monitoring soil water
Calculating when to irrigate and how much water to apply should be considred a starting point in getting irrigation right. Monitoring soil water allows you to confirm your calculations or to adjust both the irrigation interval and the amount applied. Without monitoring soil water it is easy to over or under water soils. Over watering is applying too much water, or watering too often, causing soils to become over wet. This results in poor aeration, restricted root growth, higher incidence of root diseases, leaching of fertilisers out of the root zone and soil erosion when irrigation rates are higher than infiltration rates. Continuing to irrigate potatoes unnecessarily at the end of the season when plant water use is minimal, results in soils being too wet at harvest resulting in higher harvest costs and potential soil compaction. Under watering occurs when irrigations are spaced too far apart or when insufficient water is applied at irrigation.

Gypsum blocks and tensiometers monitor changes in soil water without disturbing the roots of growing plants. They need no calibration and they measure the actual availability of water in the soil. They are designed to complement regular field inspections and not replace them. Each site you monitor should be representative of the crop being irrigated, the soil type, the land slope and timing of irrigation. Avoid wet hollows or dry banks. One monitoring site to represent about 4 hectares should be sufficient, provided the soil,

the crop and the irrigation are uniform. If it takes more than 3 days to irrigate the whole crop, you will need to monitor the soil water at a site representing early irrigation and at another site representing irrigation later in the cycle. More than one monitoring site is advantageous when the irrigation cycle is interrupted by rainfall to provide information which may modify where and when in the paddock to start irrigating again. Under travelling gun irrigators, the site chosen should be midway between the irrigator and the limit of it's throw whilst under a centre pivot irrigator the site should not be in the inner or outer most sections. Each site should have two gypsum blocks or tensiometers; a shallow one to guide when to start irrigating and a deep one to make sure enough water is applied and to prevent over-irrigating.

Install gypsum blocks or tensiometers early in the spring before water demand increases. Install one at a depth of 30 cm and another at 60 cm below the ground surface or top of the mould for potatoes. If the crops are growing on a shallow duplex soil, then deep monitoring may not be needed or else the block should be placed immediately above the heavy clay subsoil. Remember to mark clearly where the monitors are in the paddock. A white fibreglass electric fence pole is ideal. The instruments are easy enough to see when plants are just emerging but tensiometers are easily lost under full plant cover.

Take readings at the same time each day. Early in the morning is recommended so as to avoid any fluctuations caused by heating up of the tensiometer and the water inside. If a tensiometer has been installed after an overnight soaking, a reading can be taken 30 minutes after installation. Check gypsum blocks and tensiometers and take readings at least twice a week in the early part of the growing season. During the main part of the growing season and when the tensiometer readings are above 40 kPa, readings need to be taken every couple of days and daily on sandy soils. Read the instruction manual for details on operation. When visiting the site for a recording do not repeatedly stand too close to the instrument as this will compact the soil which can directly affect readings and also affect water infiltration into the soil and runoff. Do not tread on or damage plants near the instrument as readings will no longer be indicative of the rest of the crop.

Most gypsum blocks and tensiometers have built in data loggers to record data, but if not, then write down the readings showing on the gauge for both the shallow and deep tensiometers plus the date, the amount of rainfall and/or irrigation if any has been applied, and the date it was applied. Results can be kept in a table or plotted on a graph for better visual interpretation. The record will allow for interpretation of readings and the modification of irrigation decisions as the season progresses. It will also indicate the success or otherwise of previous irrigations. Your records will lead to a fuller understanding of your soil and the use of water by the crop.

Interpreting soil water readings
The readings on gypsum blocks and tensiometers show the relative suction energy (and thus wetness) of the soil. Readings and a generalised interpretation are presented in Table 14 and Figure 25. Evaporation and the activity of surface roots normally cause surface soil to dry out more rapidly than soil deeper down the profile. This is shown by the shallow instrument readings rising more rapidly than the deeper readings. Readings from the 30 cm depth are used to indicate when irrigation is necessary. On clay and clay loam textured soils (Ferrosols), irrigate at 40 - 50 kPa. On sandy loams and sandy duplex soils irrigate at 30 - 40 kPa and on coarse sand textured soils (Tenosols) irrigate at 20 - 30 kPa. Sandy soils are irrigated at lower suction because soil water tension increases rapidly due to of their low water-holding capacity. Remember, if the instrument is located on the side of the

paddock which is irrigated first, by the time the irrigator has been moved from one side of the paddock to the other, the last run to be irrigated will be much drier than the 50 kPa. Consequently it may be desirable to start your first irrigation of the season at readings 5-10 kPa below those recommended above.

Table 14. Interpretation of soil water readings.

Reading (kPa or cb)	Interpretation
0 – 5	Saturated soil. Plants will suffer from a lack of oxygen in the root zone.
10	Field capacity. After one or two days of draining a saturated soil, free water has drained away leaving a good balance between water filled and air filled pores in the soil.
10 – 25	Ideal soil water and aeration conditions for most plants.
25 – 80	As moisture is removed from the soil, the thickness of the water film surrounding soil particles becomes thinner and is held on with greater tension. Decreased availability of soil water to the plant at this stage results in evaporative forces drawing moisture from plant cells quicker than the soil can provide it, with consequent reduction in plant turgor. This water loss can be reduced to some extent by stomatal control, however, stomatal closure also restricts uptake of carbon dioxide necessary for photosynthesis. Consequently, when soil water is limiting, plant growth is not optimised due to reduced starch production (photosynthesis) and lowered cell metabolism (turgor).
80 – 100	Plants are under water stress unless they can access water from roots deep in the soil. Gypsum blocks function normally in this range but excessive quantities of air enter the tensiometer. Eventually the water column in the tube will be broken and the vacuum lost. The tensiometer will then show a zero reading, despite the soil being very dry. If this happens, remove and clean the tensiometer, resoak and reinstall.
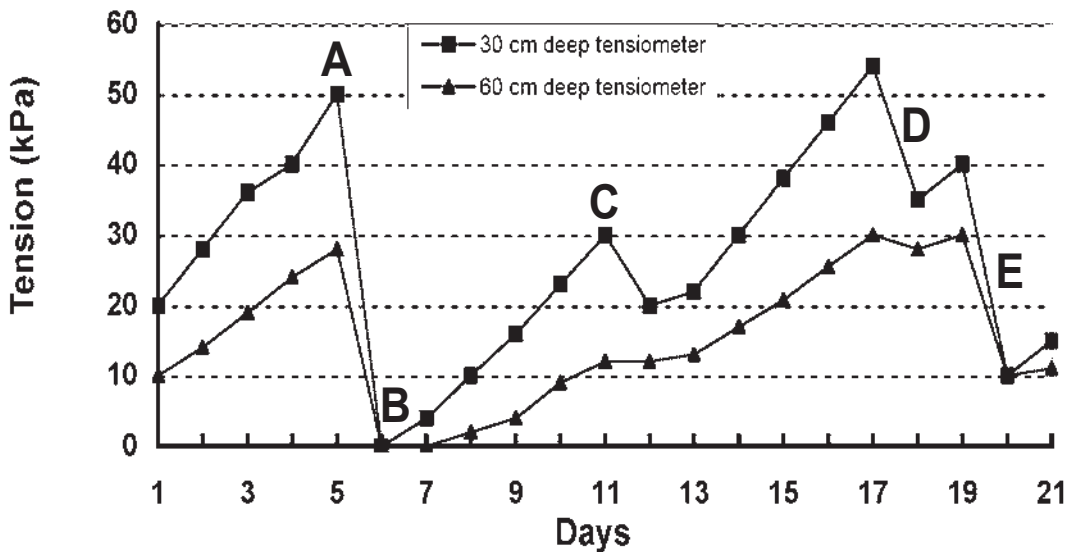
Figure 25. Idealised soil water readings during an irrigation season.

A   Crop using water rapidly from the entire root zone as shown by the rapid changes in the readings from both tensiometers. Reading on 30 cm deep tensiometer (50 kPa) indicated that irrigation was needed.

B   50 mm of irrigation water applied which brought both tensiometers back to zero. 60 cm deep tensiometer remained on zero for 24 hours and both tensiometers had readings below 10 kPa for several days indicating too much water had been applied and resulted in saturated soil conditions in the root zone.

C   Crop using water steadily from the entire root zone and 10 mm of rainfall resulted in 10 kPa drop in upper tensiometer but no change in the deep tensiometer reading.

D   Steady water use by crop from the entire root zone with soil becoming drier than recommended irrigation start-up reading. Twenty mm of irrigation applied which reduced the 30 cm deep tensiometer reading by 20 kPa but had no effect on the 60 cm deep tensiometer, i.e. not enough water had been applied to wet the entire root zone to optimum water content.

E   Soil continuing to dry out. Another irrigation of 30 mm applied which rewetted the entire root zone and returned both tensiometers to 10 kPa.

8. Drainage

*"Soil has a pleasant smell. I like to sit on bare, sun-drenched ground
and take in the fragrance of soil" (Hans Jenny)*

Poor drainage can limit agricultural productivity in many areas of Tasmania as the State enjoys relatively high rainfall which normally occurs with an excess of rainfall over evaporation in winter and spring. A range of soil orders experience parts of the year when they are saturated due to high regional water tables, low rates of water conductivity, perched water tables or seepage. The soil orders which can experience periods of saturation expressed as imperfect to poor drainage include Hydrosols, Podosols, Kurosols, Sodosols and Vertosols which collectively cover 20% of Tasmania.

Benefits of improved drainage
Reducing the length of time soils remain waterlogged by the installation of appropriate drainage systems, results in greater ease of soil management, increased plant growth by improving aeration and soil temperature, plus control of plant and animal diseases. Improving the drainage results in the soil becoming friable rather than plastic, and less likely to be compacted or pugged. A more aerated soil encourages organisms which metabolise organic matter and stabilise soil aggregates. Improved drainage increases the depth of aerated soil allowing plant roots to explore a greater soil volume. This increases the pool of nutrients available, and with a greater volume of soil to draw on for water, plants are able to continue growing for longer during dry summer periods. Pasture growth and crop yields are increased as a consequence. Increased pasture growth during summer is often one of the unexpected benefits of improved drainage which has its most obvious benefits during wet winter and spring periods.

Drainage can lessen the incidence of fusarium and phytophthora root rots which can occur when plants are stressed by waterlogged conditions and poor aeration. Animal health problems are often reduced by improved drainage. These include mastitis, cracked teats, liver fluke and intestinal worms. Poor soil drainage may be limiting plant growth to the extent that no responses are gained from increased fertiliser use. Drainage is also an important way of improving the working conditions by removing the unpleasantness of muddy, wet conditions. However, different soil types require different solutions to drainage problems. It is important to remember to investigate and plan your drainage in the winter, and install drains in the summer.

What to look for
Diagnosing your drainage problem is the key to achieving success with any drainage. You need to know the source of the water and where it is moving in the soil. This will ensure correct selection of drain type to install and the appropriate depth at which to place drains. In winter it is easier to identify the limits of wet areas, particularly seepage areas, and to identify soil horizons on which a perched watertable occurs. For the initial investigation dig a series of holes up to one metre deep in and around wet areas. A number of pegs are useful to mark out drainage lines and potential drain locations. Signs of waterlogging to look for on the soil surface include ponding, pugging by stock and ruts from machinery, springs and seepage areas, poor crop establishment and growth, and patches of excessive weed growth. Soil properties beneath the surface to look for are described in Chapter 11.

Planning and timing

The first step in farm drainage design is planning for your whole farm because water draining off one part of your farm can flood lower lying areas, or cause serious problems for your neighbours. Drainage can dominate your farm layout. The location of surface drains will influence the location of fences, shelterbelts, laneways and the shape of paddocks. The most satisfactory way of doing this is with an aerial photograph of the farm enlarged to an appropriate scale. The photograph allows you to record the extent of problem areas, where drains are to be installed and estimate distances involved. During winter, a couple of days after a good soaking rain, is the best time to take a closer look at wet areas. You can identify the extent of wet areas and identify soil layers on which a perched water table occurs. Summer and autumn are the best time to install drains. This is when soils are dry and have their greatest bearing capacity for supporting heavy construction machinery. Machines won't become bogged and trench sides smeared.

One of the first things to check is the outfall. You need to check the level of the outfall in relation to where water needs to be drained from to ensure water will flow off your farm, otherwise drainage can create flooding. Arterial drains are the first drains to install for any farm drainage. These major open drains ensure that the water can get away. If the main waterlogging problem is due to run-on or seepage from off site, interception or pipe drains should be installed first and the effect of these monitored before proceeding further. These should be designed to have adequate capacity, be deep enough to intercept the water flow and at grades and batters which will not erode. A surface drain must have a minimum grade of 30 cm in 100 m (0.3%) to ensure that water will flow. Erosion is likely where fall is greater than 1% (1 m in 100 m) for duplex or sandy soils, or 5% (5 m in 100 m) for clay-rich Dermosols, Ferrosols and Vertosols.

Types of drainage

Drainage is carried out either on the surface or underground depending on the diagnosis of the problem (see previously in 'What to look for'). Surface drainage can take the form of open arterial ditches, grassed waterways, reverse bank interceptor drains or hump and hollow drainage. Underground drainage can take the form of pipe drains, mole drains, or deep ripping. Surface drains are a minimal investment, last a long time provided stock are excluded, and can always be deepened or moved. Subsurface drainage schemes are only warranted for intensive cropping or dairying farms. Strategic subsurface drains that use the topography may be worthwhile for less intensive farms but large amounts of money can be sunk in subsurface drainage that may not work. The draining of saline or sodic soils should be considered as special cases.

Open arterial ditches

These are the first component of a farm drainage system to be installed. This is because they are the means by which water is removed from paddocks whether the ditch is collecting water from a pipe drainage system, acting directly as a land drain to lower the watertable (Figure 26), or intercepting surface or groundwater flow. Ditches are usually installed with an excavator. Ensure there is an outfall for ditches so that there is sufficient gradient on the ditches to keep water flowing. Open ditches have flat bottoms and are not V-shaped, to prevent scouring. A ditch with a bottom width of 40 - 50 cm requires a gradient of 0.15 - 0.25% (1 in 600 to 1 in 400) to maintain sufficient velocity to prevent weed establishment. Ditches are normally 1 - 2 m deep. Side batter slopes of ditches should be sufficient to prevent the sides collapsing. The batter (vertical : horizontal distance) depends on soil texture. For ditches less than 1.3 m deep the batter required are: heavy clay 1:1½; clay or silt loam 1:1; sandy loam 1½:1; sand 2:1. Where unstable soils are present e.g. very fine

sand, establish grass on the banks as soon as possible. Severe cases may require lining with stone or protective matting. If spoil is stored near the ditch, gaps must be left at short intervals to allow free surface drainage off the land.

Grassed waterways
Grassed waterways promote surface water removal along natural drainage lines and should be used as drainage lines which link up hollows and depressions, particularly on undulating paddocks of duplex soils in the Midlands. Grassed waterways are usually 2.5 m wide, of minimum depth (100 - 200 mm) and should run along the natural water pathway. If they are on a side slope, they will need to be deeper and more carefully constructed. Ensure that the base is level and that spoil does not create a levee along the sides of the waterway - it should be spread out across the paddock. They can be made using an excavator, road grader or spinner drainer. A grassed waterway is left unploughed during cropping and should cause minimal disruption to cultivation operations as it is wide and shallow enough to drive across once established.

**Figure 26. Open arterial ditches lower the water table
and remove water from paddocks.**

Reverse - bank seepage interceptor drains
This design of drain intercepts surface run-off as well as subsurface seepage. The spoil from the drain is taken upslope to collect surface run-off in a contour style bank which is surveyed at 0.6 - 1.0 % to lead water off to a safely grassed waterway. By intercepting surface flow, upslope batter erosion and channel silting are prevented which can be critical for drain stability in unstable or dispersive soils such as many of the duplex soils of the Midlands. These drains can be installed using an excavator or road grader.

Hump and hollow drainage

Hump and hollow drainage is where major land surface reshaping creates parallel ridges with even side slope to shallow drains. This form of surface drainage is appropriate when water either perches on the soil surface or winter water tables are at or near the surface and subsoil drainage is limited by restricted outfall. There is a need to either shed water off the surface by creating a slope on the ground, or elevating the soil above the watertable. Hump and hollow drainage (Figure 27) is most appropriate in swamp areas with large flat areas having a regionally high watertable. It is also used on sandy soils with surface water perching. Sandy soils cannot normally be subsurface drained because the pipes become blocked with inflowing sand. Hump and hollow drains only work in conjunction with a good system of arterial drains requiring suitable outfall.

**Figure 27. Hump and hollow drains are suitable
for areas with a high water table.**

Hump and hollow drainage can be installed using an excavator with a 3 m wide bucket or a road grader. Drain spacing depends on soil texture with sandy soils requiring 20 m between drains and clay loams and clays requiring 15 m spacing. A good sequence of operations if using a road grader is to cultivate in spring, sow a crop of turnips, feed off the crop in February, install humps and hollows with a road grader in March when soils are dry and then sow down new pasture in autumn. If using a wide bucket excavator, cultivate in spring, install humps and hollows with an excavator in spring, sow a crop of turnips, feed off the crop over late summer to gain consolidation and then sow down new pasture in autumn. An excavator can operate when soil conditions are moist to wet but due to losing wheel traction in the wet, a road grader only works efficiently when soils are dry.

Installing hump and hollow drainage should be seen as part of a package of drainage and pasture improvement. It also smooths out depressions left from land clearing. Even with hump and hollow drainage installed you should still take care to prevent pugging and

soil compaction by heavy mobs of stock. Maintenance of hump and hollow drains may require rolling the soil surface if cattle have pugged the ground, and the base of the hollows may need to be cleaned out with a spinner drainer every one or two years to keep water flowing.

Pipe Drains

Underground pipe drains can be installed to intercept groundwater flow or to lower the watertable over a wider area. Drains can be laid using clay pipes or PVC plastic pipe and French drains (where the drain is lined with stones), are sometimes laid. The different pipe types have advantages and disadvantages for ease of handling, performance and cost which should be discussed with your drainage contractor. Pipe drains can be laid using an excavator digger, continuous trencher or trenchless drain plough. Continuous trenchers and trenchless drain ploughs are operated by contractors in Tasmania. Tractor mounted backhoes are of sufficient size to excavate trenches for subsurface drains but it is difficult to ensure an even grade on the base of the trench with these machines. Trenchless drain ploughs are large self-propelled tracked vehicles (see Figure 3). The narrow slit created by the passage of the machine makes it the most economic means of installing permeable materials above the pipe. Backfill gravel is often installed above the underground drain to provide for rapid drainage of water to the drain. The gravel depth must be brought up to within at least 450 mm of the soil surface. Good quality clean gravel is required to prevent clogging up of drains. Consequently the backfill can be a significant component of the overall drainage cost.

Mole drains

Mole drains are unlined cylindrical channels (Figure 28) which function like clay or plastic pipes and are formed using an implement called a mole plough which consists of a cylindrical foot attached to a narrow le.g. Connected to the back of the foot is a slightly larger diameter cylindrical expander (Figure 29). The foot and expander form the drainage channel as the implement is drawn through the soil and the leg leaves a slot and associated fissures. The fissures extend from the surface and laterally out into the soil. Any surplus water above moling depth can therefore move rapidly through these fissures into the mole channel. Successful mole drainage depends on the water being able to rapidly enter the mole drain, flow unimpeded down the channel and exit the system either via an open ditch or into a deeply set pipe system.

Mole drains are generally installed at depths between 400 and 600 mm below the surface. It is essential however that the minimum depth of the channel is below the critical depth of the soil. Below critical depth and the mole causes the soil to flow around it in a plastic state. If the mole plough foot is pulled through the soil above the critical depth soil loosing or brittle failure of the soil down to the depth of the foot will occur and no channel will be formed and the system will fail immediately. The critical depth is normally at 350 - 400 mm for a narrow tine in clay soils but it is advisable to check for mole channel formation by digging before extensive areas of mole drainage are undertaken. The spacing between the tyres of the tractor determines the minimum spacing, typically 1.5 - 2.5 m. The soil at moling depth should have a minimum clay content of 30%. The soil must also be uniform across the paddock. If there are lenses of soil with a clay content below 30% at moling depth (e.g. sands, silt or sandy loams) then moling is unlikely to be successful. Many soils with a clay percentage higher than the minimum do not hold stable moles because they shrink and swell excessively between wet and dry cycles or because they are sodic and structurally unstable.

Moles can be drawn directly from an open ditch but the mole drain outlets must remain above the flood flow level of the water in the ditch except under exceptional circumstances otherwise the mole drain channels will collapse. After installation, short lengths of pipe (0.5 m long), the same diameter as the mole channel, should be pushed up each mole channel outlet. This prevents the ends of the channels from drying out and collapsing. Additionally, both sides of the ditch should be fenced to prevent stock damaging the outlets. Mole drains can be installed over pipe systems with the pipe system installed at least 150 mm deeper than the proposed mole drainage. As the pipes are installed, permeable gravel is laid over them to well above the proposed installation depth of the mole drains. The moles are then drawn across the pipes. The moles intersect the permeable fill and this provides a rapid connection for the water to flow from the moles into the pipe system. The maximum mole drain length should be shorter on low drain grades than for steeper grades. Initially farmers should experiment with varying lengths from 30 m (1% grade) to 100 m (6% grade). The ideal time then for moling is in the spring time, as the soil is drying. The soil at moling depth should be plastic or moist enough to be moulded by hand into a ribbon without breaking and the mole channel should remain dry for at least a month after installation allowing the soil to ripen before the mole conducts water.

Deep ripping
Deep ripping will improve drainage only if the operation allows water to move down through a compacted layer into a soil zone of relatively high conductivity. A deep ripper should be designed to lift and shatter the soil as it passes. For optimum results the tine is fitted with wings set at an angle to the horizontal so that a wide band of soil is lifted. A narrow tine will only form a narrow groove with minimal lateral effect. Deep ripping a soil when it is wet and plastic, results in smearing and little shattering. For drainage work, deep ripping may be a once only operation to supplement the effects of underground drains. However, it may need to be repeated on a more regular basis if management has resulted in near-surface soil compaction caused by stock or machinery. Deep rip at right angles to subsurface drains so that water travels the shortest distance through the soil before being collected in a drain.

Maintenance and safety
Drains require regular maintenance including spraying out plant growth in the spring and machine cleaning when the drain becomes clogged with growth or silt. This can often be achieved with a rotary drainer for shallow drains. All arterial ditches should be fenced to exclude stock access. This prevents stock causing collapse of the sides and from damaging end pipes of underground drains. Perhaps the most common soil management problem in relation to drainage is compaction which can prevent water entering the drainage system. Compaction can be caused by heavy machinery operating when soils are wet, or grazing with stock in wet weather.

When installing any drainage system it important to be aware of any underground services which might be encountered including telecom cables, water supply pipes and sewerage/effluent disposal pipes. When operating machinery be aware of any electric fences and overhead power lines. Disruption of any of the above services can result in a safety hazard for operators, inconvenience for those relying upon the services and considerable cost for repair. Consent should be obtained for drainage work which can significantly increase the flows of water into a neighbouring property as the work may result in liability claims.

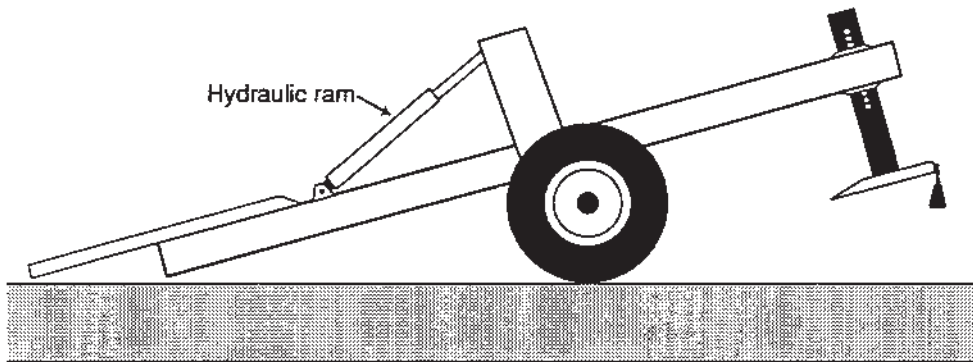**Figure 28. A moledrain which functions like a pipe to carry water.**

Hydraulic ram

Figure 29. Diggramatic representation of a mole plough.

9. Soil pH and lime

"To love soil requires that we see more than dirt. It requires that we become intimately involved with soil – see its life and beauty, smell its rich aroma, hear its voice" (Kirschenmann)

What soil pH means

Soil pH, or soil reaction, is an indicator of the acidity or alkalinity of soil and is measured in pH units. The pH scale goes from 0 to 14 with pH 7 as the neutral point. Soil pH affects the solubility of minerals or nutrients essential for plant growth. Extremely and strongly acid soils (pH_{water} 4.0-5.0) can have high concentrations of soluble Aluminium, Iron and Manganese, which may be toxic to the growth of some plants. Plants such as lucerne, barley and canola are highly sensitive to Aluminium toxicity caused by a strongly acid pH. Soils tend to become acidic as a result of (1) rainwater leaching away basic ions (Calcium, Magnesium, Potassium and Sodium) (2) carbon dioxide from decomposing organic matter and rain water forming weak organic acids (3) decay of organic matter and ammonium and Sulfur fertilisers. Most Tasmanian soils are naturally acid with pH in the topsoil as low as pH 4.5 because of our high rainfall and high organic matter contents.

Soil pH in water is commonly described using the following terms:

Extremely acid:	< 4.5; lemon = 2.5
Very strongly acid:	4.5 – 5.0
Strongly acid:	5.1 – 5.5
Moderately acid:	5.6 – 6.0
Slightly acid:	6.1 – 6.5; cow's milk = 6.5
Neutral:	6.6 – 7.3
Slightly alkaline:	7.4 – 7.8
Moderately alkaline:	7.9 – 8.4; sea water = 8.2

Soil pH is normally reported as pH in water (pH_{water}) and pH in calcium chloride (pHca). The pH measured in 0.01M calcium chloride solution is designed to more closely resemble the conditions experienced by plants in soil. The pH measured in calcium chloride is on average 0.5 to 0.8 units less than pH measured in water.

Measuring soil pH

Soil pH provides various clues about soil properties and is easily determined. There may be considerable variation in the soil pH from one spot in a paddock to another. Your result is only as good as your sample. To determine the average soil pH of a paddock it is necessary to collect soil from several locations, combine and thoroughly mix these before taking a subsample for testing. The timing for collection of the soil sample and the sampling depth are important as the acidity of soil varies throughout the year, and down the profile. The pH in summer is higher than that in winter in most circumstances, by up to 0.5 of a unit. This is important when making recommendations for winter crops based on analysis of samples taken over summer. The pH can vary down the soil profile with the surface soil often being less acidic than the subsoil in Tasmania.

The most accurate method of determining soil pH is with a pH meter. A less accurate result can be obtained using an inexpensive pH test kit available at most plant nurseries or hardware stores. These test kits generally consist of a test tube, some testing solution and a colour chart. You put a

sample of your soil in the tube, add a few drops of test solution, shake it up and leave it for an hour or so to settle. The solution in the tube changes colour according to the pH of your soil. Compare the colour of the sample with the colour chart that came with the kit. Matching colours will tell you the pH of your sample.

Desirable soil pH

While many plants can tolerate pH_{water} ranges between 5.2 and 7.8, most plants grow best in mineral soils when soil pH is between 6.0 and 7.0 (slightly acid to neutral). This general rule applies to most of the commonly grown crops, fruits, vegetables, flowers, trees, and shrubs. Most turf grasses tend to grow best between 5.5 and 6.5. Many evergreen trees and shrubs prefer a pH range of 5.0 to 6.0. Poppies and onions are susceptible to Al toxicity which is prevalent at low pHs, and the contract requirement of only growing these crops on paddocks that meet a minimum soil pH has encouraged lime use in Tasmania. Many cropped topsoils are now at a pH_{water} of 6.0-6.5. There do not appear to be any ill-effects of such liming, but it is doubtful that there are any benefits of liming beyond pH_{water} 6.5. Potatoes tolerate a wide range in soil pH while blueberries require acid conditions between pH_{water} 4.5 and 5.2. Many flowers, such as azaleas and rhododendrons require strongly acid soils and hydrangeas require a pH_{water} lower than 5.0 to induce the blue flower colour.

The signs of soil acidity tend to be subtle and may be seen as acid sensitive crops failing to establish or persist e.g. lucerne, or crop production being lower than expected, particularly in dry years. Shallow root growth and poor nodulation in legumes or ineffective nodules are added signs of acidic soil. A soil test is the most reliable way to assess if soils are acidic. There are three main ways that agriculture can accelerate acidification of the soil and these are: use of fertilisers containing ammonium or urea; leaching of nitrate nitrogen sourced from legume fixation or from ammonium fertilizers; and removal of produce. Pasture, grain and animal products are slightly alkaline and continued removal will lower the soil pH over time.

Types of lime
Agricultural lime (calcium carbonate)
This is the most commonly used liming material in Tasmania. It consists of limestone crushed to a fine powder and is usually the cheapest material for correcting soil acidity. Good quality lime has 37 – 40% calcium.
Dolomite
Dolomite is a naturally occurring rock containing calcium carbonate and magnesium carbonate. Good quality dolomite contains 22% calcium and 12% magnesium. It is good for acid soils where supplies of calcium and magnesium are low, but if used constantly may cause a nutrient imbalance, because the mix is two parts calcium to one part magnesium (2:1), whereas the soil ratio should be around 5:1.
Burnt lime (calcium oxide)
Also known as quicklime, burnt lime is derived by heating limestone to drive off carbon dioxide. It is more concentrated and caustic than agricultural lime and unpleasant to handle and so is rarely used in agriculture.
Hydrated lime (calcium hydroxide)
This is made by treating burnt lime with water, and is used mainly in mortar and concrete. It is more expensive than agricultural lime.
Gypsum (calcium sulfate)
Gypsum is not considered as a liming material, as it does not reduce soil acidity. It is used mainly to improve the structure of sodic clay soils, and these occur only in some low rainfall zones of Tasmania.

Rates of lime to apply

As soil acidity increases (the lower the pH), more lime is needed to ameliorate soil acidity. More lime has to be added to clay soils and peaty soils than to sandy soils to achieve the same result, because different soil types react in different ways to the application of lime. The amount of lime to apply depends on three main factors; neutralising value of the lime, fineness of the lime and soil texture.

Neutralising value (NV)

NV tells you the lime's capacity to neutralise soil acidity. Pure calcium carbonate has NV of 100, which is the standard. Ideally, NV should be over 95. The NV figure is marked on the lime bag or the invoice if you buy bulk lime. All Tasmanian sourced lime and dolomite have NVs greater than 95.

Fineness

The finer the particles of lime, the faster they react with soil. Lime manufacturers have to specify the percentages of different-sized particles in their product.

Soil texture (amount of sand, silt and clay),

It is easier to change pH on a sandy soil than on a clay soil. The estimated pH increases over the upper 10 cm of soil due to the addition of 1t/ha (1 kg/10 sq metres) of 100%NV product to different soil types are:

Sand	0.5 - 0.7
Loam	0.3 - 0.5
Clay	0.2 - 0.3
Ferrosol clay loam	0.04 - 0.1

It is best to apply at least 2.5 t/ha on all soils to get a good pH response but the upper limit for one application is 7.5 t/ha. Lime has to be physically in contact with moist acid soil in order to neutralise acidity. Lime dissolves slowly in the soil, therefore, incorporation in the top 10 cm of soil (or deeper if possible) is best to increase the rate of reaction and leaching of lime to a greater depth. Incorporating lime will increase soil pH in the 0-10cm soil depth within 1-3 years. High rates of lime are needed to change the pH of a Ferrosol because they are highly 'buffered" which is caused by a combination of iron and aluminium oxide clay minerals plus organic matter. Ferrosols are also known as having variable charge, which means that as the pH changes so does the cation exchange capacity. Tasmanian research has shown that as organic matter content declines on Ferrosols, cation exchange capacity can be maintained if pH is increased.

The best way to adjust pH is gradually, over several seasons. Lime should be applied only when tests show it to be necessary. Do NOT over-lime. Lime adjusts soil chemistry, it is not a fertiliser.

Reducing soil pH

High pH soil may be acidified by adding elemental sulfur. Sulfur is transformed by soil bacteria to sulfuric acid which will neutralize soil alkalinity. Like lime, Sulfur should not be applied indiscriminately. Due to the total amount of lime present in alkaline soils, this is a never ending battle. As soon as the Sulfur is "used up" pH will begin to return to original levels. Sulfur is useful for reversing the effects of over liming or for changing soil pH in a small area for specimen trees or shrubs. Addition of organic matter and use of organic mulches can also help acidify soils and lower pH levels. The Sulphur can be broadcast onto the soil surface but it must be mixed into the soil to a depth of 150 mm. Simply spreading the Sulfur on the surface of the soil does very little good, but is not entirely useless, but burying it helps ensure that the sulfurous acid doesn't simply evaporate. Alternatively, you can make holes about 30 cm deep and 50 mm in diameter, and fill them to within about 10 cm of the top with Sulfur, then cover them back up. The Sulfur will slowly turn into sulfurous acid (H_2SO_3), and acidify the soil near it. The amount of Sulfur (95% S) needed to lower the soil pH to pH 6.5 on clay soils varies depending on the existing soil pH. The requirement is 1 kg/10 m^2 at an existing pH of 7.5; 2 kg/10 m^2 required at pH 8.0; and 3 kg/10 m^2 required at pH 8.5.

10. Soil salinity and sodicity

"The land is most generous with those who pay attention to her curves and mood, who are willing to spend time listening and observing and giving back to the soil. To these admirers she has much to say and much to give" (Whitehill)

Salinity and sodicity are caused by too much salt (usually sodium chloride) in the soil but saline and sodic soils have quite different problems and require different management to maintain productivity. Approximately 30% of Tasmania has an average annual rainfall below 850 mm and in these areas rainfall is spread fairly evenly over the whole year with evaporation exceeding rainfall in most months. Under these conditions incoming salt in rainfall is often not washed out and accumulates in the soil, groundwater or underlying rocks. It is therefore not surprising that salinity and sodicity have always been a feature of the Tasmanian landscape. Some local areas and streams in Tasmania, such as near Woodbury in the southern Midlands, have been known to be saline for as long as European settlement.

Understanding salinity

Salinity is the presence of soluble salt in soil, rocks, rivers or groundwater. Most of the sodium in saline soils is in the form of soluble salts, mainly sodium chloride or table salt, which can be easily dissolved and moved in soil water. Soluble salts reduce the availability of water to plants. When rocks that contain salt are weathered over time, or salt is carried inland from the ocean by wind and rain, then salt is left in the landscape. Salt has also been deposited in places that were under the sea in prehistoric times. Salinity can develop naturally, but where human intervention has disturbed natural ecosystems and changed the hydrology of the landscape, the movement of salts into rivers and onto land can be accelerated. Where there is a salt store in subsoils or rocks, or saline groundwater, any process which increases the available water in the soil can increase the leakage of water to groundwater and mobilise salt stores resulting in increased salinity in soils and/ or surface waters. If poorly managed, conversion of land from perennial vegetation to exotic pastures, cropping, irrigation, some forest clearing activities, recycling of effluent water, dam construction, drainage and urban development can all increase salinity. This is because these land use changes can increase the amount of water passing through the root zone and therefore potentially mobilise salt. Salinity can be produced by a variety of distinctly different land management and ground water flow systems and so no one approach to managing salinity will work in all cases.

Dryland salinity

The change from perennial pasture to annual cropping systems in Tasmania is thought to be the main driver of water balance change and increased salinity, rather than the clearing of native vegetation which is the principal driver of dryland salinity in mainland Australia. The groundwater rises to near the ground surface in low-lying areas or on the break of slope (this is known as *discharge*). Groundwater can also flow underground directly into streams. The groundwater carries dissolved salts from salt stores in the underlying soil and bedrock material through which it travels. As saline groundwater comes close to (within two metres) the soil surface, evaporation of this water can occur via capillary rise, transporting soluble salts with it to the soil surface. Over time, this leads to an accumulation of salts in the root zone of crops and pastures with subsequent losses in production. Even where the groundwater does not bring much salt with it, the 'water-logging' of the root zone alone can damage or kill vegetation.

Irrigation salinity

The main cause of irrigation salinity is the application of large volumes of irrigation water, equivalent to as much as twice the average naturally occurring seasonal rainfall, compounded by the replacement of perennial pasture based agriculture with annual cropping systems. Irrigation is applied on a deficit basis so that most if not all is used by the crop during the growing season. However cropping systems have shorter growing seasons and often incorporate a fallow period when there is no water use by vegetation. Irrigated soils do not dry out to as great a depth as unirrigated profiles so that less winter rainfall is required to refill soil profiles and more water is able to flow to groundwater or to be discharged as surface flow.

Salinity effects

Salinity and waterlogging often occur together. The impact of waterlogging and salinisation will vary depending on soil type, climate and land use. Impacts can be barely noticeable to the untrained eye and can include reduced plant vigour or a change in the vegetation mix in a particular area. Economic losses due to the impact of marginal (barely visible) salinity may be the greatest losses as they occur over the greatest area. More dramatic effects include the death of native plants and crops that are not salt-tolerant, and the development of totally bare patches of earth known as salt scalds. These areas act as the focal point for erosion to develop and spread, and for washing salt loads into rivers through run-off. The effects of irrigation are normally very localised – with activation of seeps at breaks in slope or spreading of salt affected drainage lines in lower parts of the landscape. In contrast to dryland areas, where there are usually long lead times before salinity appears, irrigation salinity problems emerge soon after the establishment of irrigation. The effects of using saline irrigation water from rivers or dams are also costly for agriculture. The yields of some crops are affected by saline water at salinity levels as low as 700 μs/cm.

Identifying salinity

Extreme soil salinity leaves soils barren, supporting only isolated patches of the most salt tolerant plants, including bucks horn plantain and samphire. In some places salt efflorescence may occur as white films on the soil surface. In soils only mildly affected by salinity there are often few outward signs of plant stress. Crop or pasture productivity may be affected with more sensitive species such as white clover being absent whilst more tolerant sea barley grass and strawberry clover may remain. Plants can be a good indicator of soil salinity with buck's horn plantain (*Plantago coronopus*) indicating low surface soil salinity (0 – 4 dS/m), sea barley grass (*Hordeum marinum)* indicates moderate surface soil salinity *(4 – 8 dS/m),* and water buttons (*Cotula coronopifolia)* indicates high surface soil salinity (8 – > 16 dS/m). The interaction between stream flow, salt load and stream salinity is dynamic – the greatest salt loads are usually carried at highest flows with low salinity levels but the greatest impacts are mostly caused by excessive salinity levels during periods of low flow.

Testing for soil salinity requires an electrical conductivity (salinity) meter, some rain or distilled water and a small container. Take a soil sample and leave it to dry as long as possible. Crush the air-dried sample so there are no large aggregates. You may need to crush these aggregates with a stone or hammer. Soil particles should be no larger than 2 mm. Remove as much foreign matter, plant material and stones from the sample as you can. Place a small amount of soil in the container and add five parts of rainwater to every one part of soil. So, if you put 50 g of soil into the container, then you need to add 250 mL of the rainwater. Shake the container vigorously for three minutes to make sure the salts dissolve. In clay loam to clay soils, more shaking brings more salts into the solution and

increases the accuracy of the test. Allow the solution to settle for at least one minute before testing. Place the salinity meter in the solution, but not in the soil at the bottom of the jar, and read the display once it has stabilised. Wash the meter electrodes and sample jar with distilled water or rainwater, and dry. Convert your salinity meter readings to soil salinity (EC_{se}) by finding the soil sample texture in Table 15, and multiplying by the value of the conversion factor given. For example, if your soil is a clay loam with a meter reading of 0.5 dS/m, multiply 0.5 by 8.6. The resulting value of 4.3 dS/m is an approximate value for the salinity of the soil (EC_{se}).

Table 15. Soil salinity conversion factors.

Soil texture	% Clay (approx.)	Conversion factor	
		Surface soil (top 15 cm)	Subsoil (below 15 cm)
Sand	<10%	14	17
Loam	25-30%	12	15
Light clay	35-40%	11	13
Heavy clay	50-60%	6	8
Very heavy clay	>60%	4	5

It is accepted practice that saline soils are those which have an EC_{se} of more than 2 dS/m. If your EC_{se} is more than 2 dS/m, seek expert advice on the suitability of your soil for the crops and pastures you want to grow, and for management options to reduce soil salinity. Lower levels of salinity can affect the growth and yields of salt-sensitive plants such as most legumes (clovers, beans and peas), maize and many horticultural crops. If your EC_e is 1 to 2 dS/m, and you intend to grow any of these crops, you should also seek expert advice.

Groundwater flow systems (GFS)
The processes that influence dryland salinity vary from place to place reflecting differences in landscapes and groundwater aquifers. These, in turn, reflect regional geology and geomorphology. Where geological and geomorphic characteristics are similar (i.e. similar systems of groundwater flow) dryland salinity issues and are likely to be amenable to similar interventions. This concept helps scientific and catchment communities across Australia speak a common language with respect to dryland salinity. At the broadest level groundwater flow systems are defined according to scale. If a salinity problem occurs through discharge from a groundwater flow system functioning entirely within a small catchment close to the affected area, then the province is referred to as '**local**'. In most local systems groundwater flow from the slopes of a catchment cause groundwater discharge within or near the adjacent valley floor and the passage of groundwater seldom exceeds 3-5 km. In general terms local GFS have a low storage capacity and respond rapidly to any land use change, which causes an increased groundwater intake. Water tables rise rapidly and new discharges can occur between 5 and 50 years after the increase in groundwater intake. In other systems dryland salinity is manifested through groundwater flow within aquifers that transcend local catchment boundaries and local land management activities within a single catchment cannot address the problem.

Several sub-catchments may share a common groundwater system operating over 10–20 km or more. Since these systems do not comprise the entire region of a river basin, yet operate at a scale larger than sub-catchments, they are termed **'intermediate'**. Intermediate systems have greater storage capacity and take longer to fill following increased groundwater intakes. Increased discharges typically occur within 50 –100 years of disturbance to recharge rate. Where salinity issues are associated with large groundwater aquifers operating on a large scale (comparable with that of major river or groundwater basins), then the processes are said to be **'regional'**. Regional groundwater flows typically range from 50 to several hundred km. Regional systems have a high storage capacity and take more than 100 years to produce increased discharges following disturbance.

The current impact of salinity in the southeast of Tasmania is more of a surface water issue rather than land salinisation. The latter is more prevalent in the northern Midlands. The priority for salinity management of the existing groundwater flow systems in Tasmania has been ranked based upon scale and responsiveness, landscape attributes, quality of land, and water quality. In the northern Midlands the two GFS with high priority for management are the local scale Deeply Weathered Sediments and Alluvial Plains and Slopes while in the southeast the local scale GFS on Alluvial Plains & Slopes is the highest priority.

Local scale GFS in Deeply Weathered Sediments
The Deeply Weathered Sediments GFS is found as the highest terraces within the Longford Basin sediments of the northern Midlands (Figure 30) and occurs from Bishopsbourne in the north to Tunbridge in the south. These terraces are the oldest alluvial terraces and typically contain higher salt stores than the surrounding land. Water movement through the heavy clays that occur in this system is sluggish and so there has been very limited flushing of airborne salt through the system resulting in accumulation of large salt stores. The Deeply Weathered Sediments GFS is dominated by Woodstock, Brickendon and Cressy soils. The Woodstock and Brickendon soils have accumulated the greatest salt stores because they occur on original terraces while Cressy soils occur on reworked sediments. This is seen by the greater extent of saline scalds and drainage lines within these two soils. Salinity discharges are most likely to occur within drainage lines and at the break of slope but salinity is also found at the junction with the Alluvial Plains and Slopes GFS.
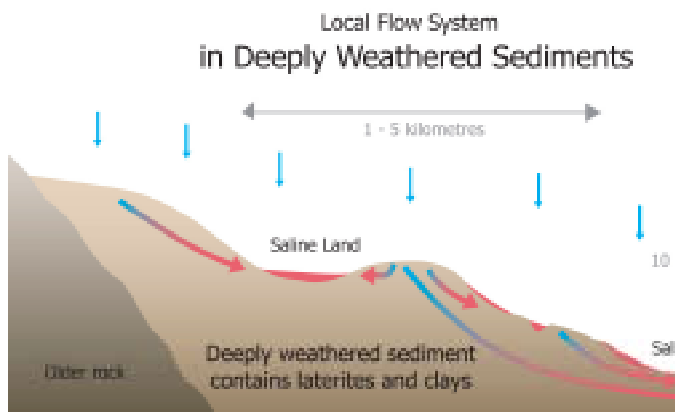

Figure 30. Simplified cross-section of a local flow system in Deeply Weathered Sediments (Hocking *et al*. 2005).

Local scale GFS on Alluvial Plains and Slopes

The Alluvial Plains and Slopes GFS comprises alluvial terraces and neighbouring low angle slopes on a relatively flat landscape, covered by sandy loam over clay duplex soils in the north with some more variable materials in the south (Figure 31). It occurs from Longford in the north to Cambridge in the south. The soil parent materials are mainly reworked alluvium ranging from clays to gravels, some of which are deeply weathered and are thought to contain much of the salt stores. The flat landscape results in concentration of some run-off from higher terraces and longer periods of winter waterlogging than other GFS which results in salt expression in some drainage lines, in poorly drained areas and at the intersection of this GFS with the GFS in Deeply Weathered Sediments.
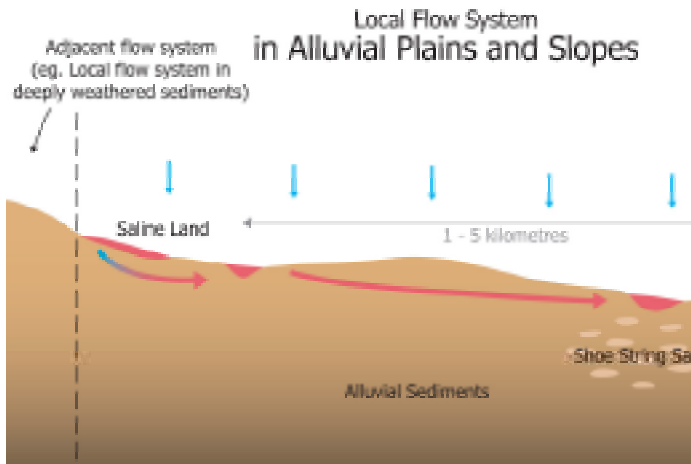

Figure 31. Simplified cross-section of a local flow system in Alluvial Plains and Slopes (Hocking *et al*. 2005).

Soil salinity management

Management of salinity is intimately associated with management of soil drainage. Both the GFS described above have soils with heavy clay subsoils which have inherently low permeability. Groundwater within the heavy clay subsoils migrates downslope, where it either discharges in a depression or at the break-of-slope at the edge of the groundwater flow system unit. Drainage is closely and negatively related to a soil's plant available water holding capacity and there is considerable variability in the water holding characteristics of soils. Groundwater recharge occurs mainly via rainfall but is enhanced when the soil profile is full due to irrigation. The areas likely to be affected are relatively small and the localized nature of the GFS means that it is highly unlikely that large areas will be affected.

The affected soils are likely to show signs of waterlogging (seepage areas and soaks) in the autumn and winter months and be quite dry in the summer months. Drainage typically peaks in spring due to the surplus between inputs of rainfall plus irrigation and outputs of evaporation and plant water use, and the high residual soil moisture conditions post-winter. The Cressy soils respond well to artificial drainage using underground pipes but drainage options are very limited for Brumby, Brickendon and Woodstock soils. Broad, shallow surface drains that link hollows and use the topography will be most effective. Think carefully about planting layout to promote drainage down slope. Do not plant irrigated crops, especially potatoes, through hollows. Subsurface drains following hollows or drainage lines are an option where cropping is more intensive. Mole drains are not appropriate and carry a high risk of failure due to the dispersive nature of subsoil clays.

The best ways to manage current outbreaks of salinity and to avoid increasing outbreaks mainly involve managing the types of crops or pastures in a rotation. Crops and pastures should be grown over winter, rather than leaving the ground as a bare fallow, as these significantly reduce drainage losses during the late autumn/winter/early spring period, compared to a bare fallow. A high proportion of dryland pasture to irrigated cropping can be included in the rotation as pasture typically generates smaller drainage volumes. If seepage areas and outbreaks of salinity are increasing, farmers can reduce the growing of crops that require large volumes of irrigation, such as broccoli. These intensely irrigated crops generate substantial drainage volumes which occur during the cropping period due to high irrigation rates, and shortly afterwards due to the near-full profile conditions at harvest time. If crops such as broccoli are grown, then this should be done in association with a less irrigation intensive, dry harvest crop such as poppies or an increased proportion of dryland pasture. This will result in a drying out of the soil and a potentially large reduction in drainage. The use of irrigation scheduling based on soil water deficit, using rainfall and evaporation records or soil moisture monitoring, can significantly reduce drainage volumes. Growing a deep rooted perennial such as lucerne dries out the soil to considerable depth, allowing for recharge by rainfall without deep drainage occurring. Lucerne may also give greater productivity than some perennial pastures. Installation of strategically placed sub-surface drainage in seepage areas, or in lower parts of the landscape will mean that these areas do not remain saturated for months on end. Carefully check outfall levels on flat areas to ensure that water will run in the drains and to see if subsoils will transmit water to any subsurface drains or open ditches. Areas that are persistently saline may need to be fenced out and salt tolerant species established, such as *Puccinellia* or strawberry clover.

Understanding and managing salinity on King Island
Salinity on King Island is driven by rainfall carrying a high salt load. This salt load is greater in western areas than in the east due to prevailing winds coming from the west. There is a thin layer (3 m) of regolith overlying unweathered hard rock, either granite or metamorphosed sedimentary rock over most of the island and there is little or no potential for salt storage in the ground water flow systems as there is no deeply weathered clay to store salt. Underlying hard rocks are fractured (cracked) which allows for good transmission of ground water to depth and ground water flow systems are local with short response times. Elevated areas in the southern half of island are not subject to as much salinity as the lower relief north because the higher elevation allows ground water to travel to depth and then into incised streams and out of the landscape. Surface expression of salinity is of minor extent covering less than 1% of the island or 1000 ha, and is associated with waterlogging. Waterlogging occurs mainly in depressions or low lying parts of the landscape with some areas of midslope seeps occurring where there is a change in slope of the surface or the underlying rock, which causes water to come to the surface. Plant survival in waterlogged areas is primarily limited by saturated soils and poor drainage rather than salinity. Salt can be flushed through the landscape due to the high rainfall and by keeping water moving and not allowing areas to remain saturated for months on end.

The options for managing saline and waterlogged areas on King Island involve management of stock grazing and drainage. Stock grazing management can be improved by fencing around wet, saline areas with intermittent or seasonal grazing. This would allow for recolonising of scalded areas by plants already growing in these areas, prevent pugging damage by stock, and result in greater water use by plants. Wet saline areas can have all animals excluded with wallaby proof fencing and planting of water and salt tolerant species of grasses, shrubs and trees. Mounding prior to planting of shrubs and trees will aid establishment of plants. Improving drainage can be achieved using drainage techniques

that are specifically suited to each site. Reverse bank interceptor drains can be installed at breaks in slope, shallow surface or spoon drains can remove surface water from flat areas, and underground rock or pipe drains can tap into seeps and spring mounds. Improved drainage in low lying areas is intended to prevent inundation and create an unsaturated zone in the surface 10-40 cm of soil that increases aeration allowing for improved plant growth.

Sodicity

Sodicity is caused by the presence of sodium ions attached to clay in the soil. A soil is considered sodic when the sodium reaches a concentration where it starts to affect soil structure. The sodium weakens the bonds between soil particles when wet resulting in the clay spreading out or dispersing which makes the water cloudy. The dispersed clay particles can then move through the soil clogging pores which reduces infiltration and drainage, and the dispersed clay particles are very susceptible to erosion. Interestingly, a saline or salty soil that is also sodic, i.e. the soil has sodium attached to the clay as well as plenty of soluble salt, will often not show the symptoms of sodicity because the salt prevents the clay particles from dispersing. However, if this soil has the salt leached out, such as after a rain storm, then symptoms of sodicity can start to appear.

Symptoms of sodicity

Sodicity can occur at any depth in the soil but it is more recognisable when it occurs within the top metre and is a significant problem for plant growth when in the top few centimetres. Symptoms of sodicity in the topsoil include poor infiltration and drainage resulting in waterlogging, excessive runoff, surface crusting, poor emergence of crops and pastures, excessive clods when cultivated, and rill or tunnel erosion. Soils with sodic layers at depth often go unnoticed, particularly in low rainfall areas, because there is often no impact on farm management but problems may emerge over time in the form of tunnel erosion and eventually eroded gullies Figure 32). Tasmania has few areas of sodic soils and these are concentrated in the southeast of the state. Subsoils rather than topsoils are sodic, and management problems are mainly due to tunnel erosion. However, some of the sodic soils have thin topsoils, particularly in the southern Midlands, and when these are cultivated too deeply, subsoil clay that is sodic is brought to the surface and mixed into the topsoil giving rise to increased symptoms of sodicity.

A sodic soil is defined by exchangeable sodium percentage (ESP). ESP can be worked out from soil tests using the following calculation:

$$ESP = \text{Exchangeable sodium} / CEC \times 100 \qquad (CEC = K+Na+Ca+Mg)$$

When soil ESP is less than 6, your soil is not considered sodic. A soil ESP of 6-14 is sodic and a soil ESP greater than 14 is strongly sodic. A simple field test for sodicity is to drop an air dry piece of soil into distilled water & leave for 1 hour. If the soil dissolves or forms a cloud in the water, then the soil is sodic.

Figure 32. Tunnel erosion with progressive collapse of surface soil from (a) a few holes appearing to (b) an open gully.

Treatment of sodicity

Good management of sodic soils involves maintaining organic matter levels by retaining crop stubbles, direct drilling crops, and using cover crops. Irrigating with slightly salty water (0.2-0.3 dS/m), and applying gypsum and/or lime can reduce the symptoms of sodicity. Some practices which should be avoided on sodic soils include: mixing subsoil with topsoil, deep ripping or inverting sodic soils, long fallows, over-cultivating to produce fine seed beds, and cultivating when wet. Applying gypsum ($CaSO_4$) to a sodic soil replaces the excess sodium ions with calcium ions. It is relatively expensive in Tasmania with rates of 1.5-5 t/ha needed. Beware of some gypsum products which have high levels of cadmium and lead which can accumulate in soil and be concentrated in some crops. Gypsum may take a few months to work and shallow incorporation gives better results than broadcasting. Lime at up to 10 t/ha can be applied depending on soil pH. It dissolves slowly and also replaces the sodium ions with calcium ions but at a slower rate than gypsum. Applying gypsum and/or lime depends on your soil pH and the nature of the soil sodicity. If your topsoil is sodic and acid, apply a lime/gypsum mixture, and if your topsoil is sodic and alkaline, apply gypsum at 2.5-5 t/ha based on soil ESP. Treatment of subsoil sodicity involves deep slotting of gypsum but the success of this is likely to be limited.

Techniques for the control and repair of field tunnel erosion have traditionally focused on re-establishing perennial vegetation following mechanical disturbance of the tunnel systems. Contour furrows, deep ripping, chisel ploughing and contour ripping have been used to destroy existing tunnels and divert water away from tunnel prone areas. However, use of these techniques has often resulted in further tunnel erosion, or at best only provided short term benefits. A range of vegetative control measures including the use of pastures, trees and shrubs can be used with or without prior mechanical intervention. Dense plantings of radiata pine have been used to successfully control tunnel erosion in Tasmania. A dense healthy pasture promotes even infiltration and minimises soil cracking thus reducing the risk of desiccation and surface soil cracking and uneven infiltration of runoff into the subsoil which promotes the formation of tunnels.

11. Soils beneath the surface

"Soil appeals to my senses. I like to dig in it and work it with my hands.
I enjoy doing the soil texture field test with my fingers or kneading a clay soil,
which is a short step from ceramics or sculpture" (Hans Jenny)

Soils in the landscape
A soil is the product of the five soil-forming factors of parent material, topography, climate, living organisms and time all interacting to produce the unique features you can observe at each particular site. Soil is a complex dynamic system that functions differently at each location. The processes influencing a soil that result from these soil-forming factors impart the characteristics that you can distinguish using your senses of sight, touch, smell and taste. Observation of the above ground features can provide much information on the properties and potential uses of a soil. Examples include; a soil at the base of a hill slope will have more likelihood of seepage water accumulating and poor drainage than a soil on an open plain; poorly growing or stunted plants, either native or exotic, indicate soil restrictions to growth and reduced potential productive uses; a soil on a steep slope will likely be shallower and stonier than one on the flat due to erosion moving soil down-slope over time; a soil near a river will be more likely to be inundated by floodwater than one further away and is more likely to have sandier textures and distinct layers of parent material built up by successive flood deposits.

The investigation of soils is invariably done to assess their suitability for particular landuses rather than for abstract understanding. Soils are one of the foundations for productive farming but interestingly most buyers of farms undertake scant investigation of the range and properties of the soils present before purchase. Consequently, they have little understanding of the productive potential or soil properties that may limit production and which may require considerable investment to overcome. There seems to be an attitude that soil is just soil and it isn't too complex a system that might require detailed investigation and understanding.

Soil profiles
The best way of observing the soil is to dig a pit, large enough to clearly see features to at least 70 cm depth. The digging of the pit will often reveal soil features that are likely to affect plant growth, such as hard pans and rooting barriers. The pit is used to observe the soil profile with its layering, colour and structure and an auger can be used to extend observations beyond pit depth. Most soils consist of several layers or horizons that lie parallel to the soil surface. The uppermost layer or topsoil which is usually darkened with organic matter, passes into underlying lighter-coloured subsoil. Sometimes the topsoil is peaty or made of decomposed plant fragments and is usually spongy. This indicates that the soil lies wet for most of the year. Examining the soil beneath the surface will reveal the conditions that plants will experience and the potential rooting depth for growth. Each layer should be examined to see if is a barrier to root growth as root barriers control the depth of soil that is available for roots to extract water and nutrients, and are likely to have a significant effect on plant growth.

The features to look for in each layer that might indicate good growing conditions or a barrier to root growth include:

- Well developed aggregates and weak strength indicating good porosity. A good distribution of soil pores sizes are required with large pores draining excess water and allowing entry of air to roots, and fine pores that retain water for use by plants. If the soil is very loose and sandy, it may have too much porosity with roots finding it hard to make contact with the soil and there being little storage of water for plant growth. Soils with poor porosity will restrict root penetration, air circulation and drainage of water.
- See where the roots are growing. If they are throughout the soil matrix this indicates good growing conditions. If roots are confined to cracks and between clods this indicates compacted soil and less than optimal growing conditions. Check the depth of root penetration as the total volume of soil the roots occupy determines the water storage plants can draw on in times of water shortage.
- Very compact or tightly packed. This may be in the form of a hard pan, cemented horizon or even rock. An iron pan may be a few millimetres or many centimeters thick but forms a continuous, clearly defined, barrier. A rock barrier may be solid bedrock, hard rock that is cracked or shattered, or rock, like mudstone, that can be easily broken by a hammer, but is impenetrable to roots.
- Very stony as stones and rocks dilute the volume of soil that is available for water storage and nutrients. If the volume of stones is more than about a third of the volume of the soil, then it is likely to have a significant effect on water storage. If the material between the stones is not especially sandy or compacted, then roots will probably be able to penetrate and it may not be a root barrier. If the material is loose and sandy then a few roots will grow down through it only during wetter parts of the year.
- Wetness either as a high water table or a water table in a particular layer that is perched over an impeding lower layer.

Soil colour

Soil colour is a consequence of various chemical and biological processes acting on soil. These processes include the weathering of geologic material, the chemistry of oxidation-reduction actions upon the various minerals of soil, and the biochemistry of the decomposition of organic matter. Colour can be a useful indicator of some of the general properties of a soil, as well as some of the chemical processes that are occurring beneath the surface. Soil colour is usually determined by the amount and state of organic matter, the amount and state of iron oxide, and soil aeration. Two 'rules of thumb' are that the darker the soil is, the more organic matter it contains, and a dry soil that leaves your hands 'dirty and dusty' has a high organic matter content. Soil adds beauty to our landscapes and the different soil colours can be used as different pigments in creating works of art.

Black and brown soils are often associated with high levels of organic matter, although some minerals can also give a dark colouring.

Red and brown soils indicate soils with good drainage. Iron found within the soil is oxidised more readily due to the higher oxygen content. This causes the soil to develop a 'rusty' colour due to the presence of haematite (Greek for blood-like). Large haematite crystals give a purplish-red colour to geologic sediments that a soil may inherit from the geologic parent material. In general, bown (goethite) soil colours occur more frequently in temperate climates, and red (haematite) colours are more prevalent in hot deserts and tropical climates. The colour can be darker due to organic matter in the soil.

Yellow and yellow/ brown soils often have poorer drainage than red soils. The iron compounds in these soils are in a hydrated form (goethite) with relatively large crystals of

goethite giving the yellow colour of aerobic soils. Smaller goethite crystals produce shades of brown.

Grey and blue grey soils have very poor drainage or suffer from waterlogged conditions. When soils are saturated, any oxygen in the water is used rapidly, and then the aerobic bacteria go dormant. Anaerobic bacteria use ferric Iron (Fe^{3+}) in goethite and haematite as an electron acceptor in their metabolism. In the process, Iron is reduced to colourless, water-soluble ferrous Iron (Fe^{2+}). Other anaerobic bacteria use Managanes (Mn^{4+}) as an electron acceptor, which is reduced to colourless, soluble Mn^{2+}. Iron and Manganese compounds are thus in their reduced form due to the lack of air.

Light grey soils are often referred to as bleached or 'washed out'. The iron and manganese particles have been leached out due to high amounts of rainfall or vertical and lateral drainage.

When patches of other colours occur on the overall matrix soil colour, it is called mottled. Mottles occur abundantly in soils having alternate wetting and drying conditions. When the water table drops in summer, oxygen re-enters the soil. Soluble iron oxidizes into characteristic orange coloured mottles of lepidocrocite (same formula as goethite but different crystal structure) on cracks and in pores of the soil. If the soil aerates rapidly, bright red mottles of ferrihydrite form in pores and on cracks. The combination of background soil colour plus the presence of particular coloured mottles at particular depths below the soil surface can be used to indicate the drainage status of a soil (Figure 33). Brown, yellow or red colours with no mottles (colour spots), indicate well drained soils. Red or orange mottles over bluish-grey mottles, indicates imperfectly drained soils. Red or orange mottles indicate alternate waterlogged and dry conditions. Rusty coloured mottles over grey colours in the subsoil with or without coloured mottles indicated waterlogged soils. Bluish-grey subsoils or 'gleyed' soil indicate permanently waterlogged conditions. The drainage status of a soil indicates the degree of wetness that plants will experience in a soil and this can be a limitation to productivity. Most productive plants require moist but well aerated soil but saturated conditions exclude air and restrict the movement of root respiration to the soil surface resulting in a form of 'suffocation' of the roots.
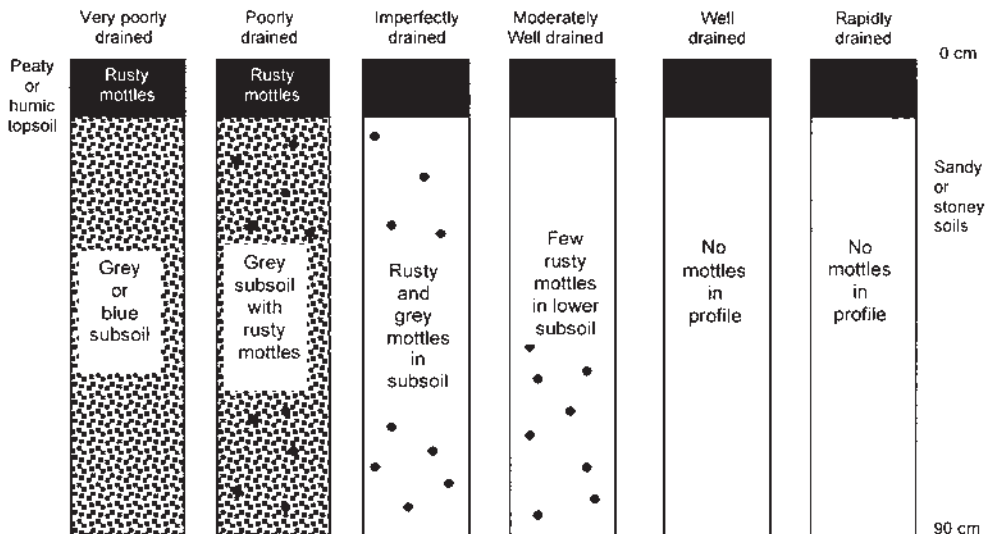

Figure 33. Soil colours and mottles indicate drainage status.

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Soil texture

Soil texture refers to the proportion of individual mineral grains in a soil, i.e.. the proportion of sand, silt and clay particles. In soils, sand, silt and clay are defined by the size of the grains and not by their composition, colour or consistence. Sand particles range from 2 mm to 0.06 mm in diameter and are the grains visible to the naked eye. Silt particles range from 0.06 - 0.002 mm in diameter and clay particles are less than 0.002 mm in diameter. Soil contains particles of all sizes and the proportion of each size grade determines its texture. Soil textures have three main groups. Sands have less than 15% silt plus clay; clays have more than 35 - 45% clay depending on the proportion of silt; loams are intermediate between sands and clays. These groups can be subdivided into texture classes by adding adjectives to the group name, e.g. loamy sand, sandy loam, clay loam, sandy clay and silty clay. Some textures can be referred to as 'light' or 'heavy' which refers to the proportion of sand and clay. Light soils are sandy, whereas heavy soils have more clay. Soil texture can be recognised by feeling the moist to wet soil between the fingers. Some soils are sticky, others will not stick together at all, and others feel doughy or spongey (Table 16).

The relative size of soil particles is important. For example, the finest sand particles are 10 times the diameter of the largest clay particles and this has effects on soil properties. The surface area of a spherical particle 0.02 mm diameter (silt) is 100 times greater than a spherical particle of 0.002 mm diameter (clay). Clays have an even greater surface area than spherical particles if they are made up of sheet-like structures stacked together. This difference in surface area contributes to the differences in adhesion and cohesion of the texture groups as well as affecting the chemical behaviour of soils. Sands have large grain sizes which allows faster permeability of water than in clays. The disadvantages of sands are that they hold very little water that would be available to plants and have little ability to hold onto plant nutrients in the way that clays do. Loam soils contain sand, silt and clay in such proportions that stickiness and non-adhesiveness are in balance, so the soils are mouldable but not sticky. Loams are the "friendliest" soils to cultivate. Clays can absorb and hold onto large amounts of water because of their sheet structure and large surface area. This property causes the swelling and shrinking of clay soils as they wet and dry. Clays are therefore also important in generating cracks in soil through which roots can easily grow. When clays are wet and swollen soil drainage is affected and water cannot move freely. The surfaces and edges of the sheet structure of clay particles carry negative and positive charges. Elements such as Potassium, Calcium and Magnesium are held on these charged surfaces and can be taken up in solution by plant roots. Clays therefore play an important role in soil fertility.

Changing soil texture
The texture of soil is considered to be a stable property. That is, changing the texture of your soil is possible but involves considerable mechanical and financial input. One example is clay delving, where clay from the subsoil is mixed with the sandy surface soil. Clay delving is used in the Mallee and much of Western Australia but it is not recommended in Tasmania because of the potential risk of bringing sodic clays up from the subsoil and mixing them with the topsoil with resulting poor physical structure . For most land managers, changing the texture of the soil is not a viable option for soil management. Texture often changes with depth down the soil profile. It is important to describe texture changes that occur within the soil profile. Many of our soils have loamy surface soils and heavy clay subsoils. This arrangement controls the movement of water through the profile, the clay restricts downward drainage and encourages water movement along the top of the restricting layer. This can result in waterlogging of the surface soil, even though the subsoil may not be saturated.

Table 16. Soil texture classes, behaviour and clay contents.

Soil texture	How the soil feels or behaves	% clay
Sand	Coherence nil to very slight, cannot be moulded; sand grains adhere to fingers.	less than 5%
Loamy sand	Slight coherence; sand grains of medium size; can be sheared between thumb and forefinger.	5–10%
Clayey sand	Slight coherence, sticky when wet,many sand grains stick to fingers, discolours fingers with clay.	5–10%
Sandy loam	Coherent bolus but very sandy to the touch; dominant sand grains are readily visible.	10–20%
Loam	Soil ball is easy to manipulate and forms a thick ribbon. Soil has smooth spongy feel with no obvious sandiness.	about 25%
Sandy clay loam	Strongly coherent bolus, sandy to touch; medium sand grains visible in a finer matrix.	20–30%
Clay loam	Strongly coherent and plastic bolus, smooth to manipulate and slightly sticky.	30–35%
Sandy clay	Plastic sticky bolus, sand grains can be seen and felt.	35–40%
Light clay	Plastic behaviour evident, smooth feel & easily worked, can be moulded and rolled into rod.	35–40 %
Light medium clay	Plastic bolus; smooth to touch; slight to moderate resistance to ribboning and shearing.	40–45%
Medium clay	Smooth plastic bolus; handles like plasticine; can be moulded into rods without cracking; resistant to shearing and sticks to thumb and forefinger.	45–55%
Heavy clay	Smooth, very plastic bolus; firm resistance to shearing; Handles like stiff plasticine; Very sticky and strongly coherent.	over 50%

Diagnosis for soil drainage

Soil investigation for drainage requires digging a series of holes up to one metre deep in and around wet areas (Chapter 8). Soil properties to look for and questions to answer when digging your holes are:

- When waterlogging is obvious, do pits or augered holes fill with water from the bottom, even slowly?
- If they do fill with water, subsurface drainage is a solution.
- If they do not fill with water, surface drains are required as there is no lateral water movement in the soil.
- Where does the water flow into the pit from?
  - from the bottom indicates a ground water problem,
  - from a particular horizon indicates perched water,
  - from the surface indicates surface sealing or perching.
- Soils with layers of contrasting texture or hardness, e.g. sand over clay, lenses of sand, or hard pans. These will result in perching and will require placement of drains at a specific depth. If water perches near the soil surface on a particular layer, then there is only limited potential for significantly improving soil drainage. However, some sites will respond to contour or cross-slope surface drains.
- The presence of hard concretions of various sizes and shapes or soft black segregations, often indicate poor drainage. These are composed of iron and/or manganese and are formed when soils fluctuate between being wet and dry. In extreme cases, these can form thick impenetrable ironstone or "coffee rock" on which water perches.
- Soil colours are good indicators of the state of soil drainage (see 'Soil colour'). Mottles are spots, blotches or streaks of subdominant colours different from the main soil colour. Poorly drained soils often have rusty coloured mottles in the topsoil which are sometimes not obvious. These would only require subsurface drainage if sensitive high value crops are to be grown. A predominance of grey colours in the subsoil, with or without rusty coloured mottles, indicates a poorly to very poorly drained soil requiring drainage.

DOMINANT SOIL ORDERS OF TASMANIA
using Land System boundaries

The map represents the dominant soil order within land system
boundaries in Tasmania. Soil orders were assigned to land system
components according to the key in the 'Australian Soil Classification'.
The polygon boundaries on this map are land system boundaries
and may not represent actual soil boundaries. This map is reliable
only at the published scale and should not be enlarged.

Dominant Soil Order

Organosol	Kurosol	Ferrosol
Podosol	Sodosol	Dermosol
Vertosol	Chromosol	Kandosol
Hydrosol	Calcarosol	Rudosol
		Tenosol

Burnie
Devonport
Launceston
Hobart

N

0 10 20   40   60   80
Kilometres

DEPARTMENT of
PRIMARY INDUSTRIES,
WATER and ENVIRONMENT
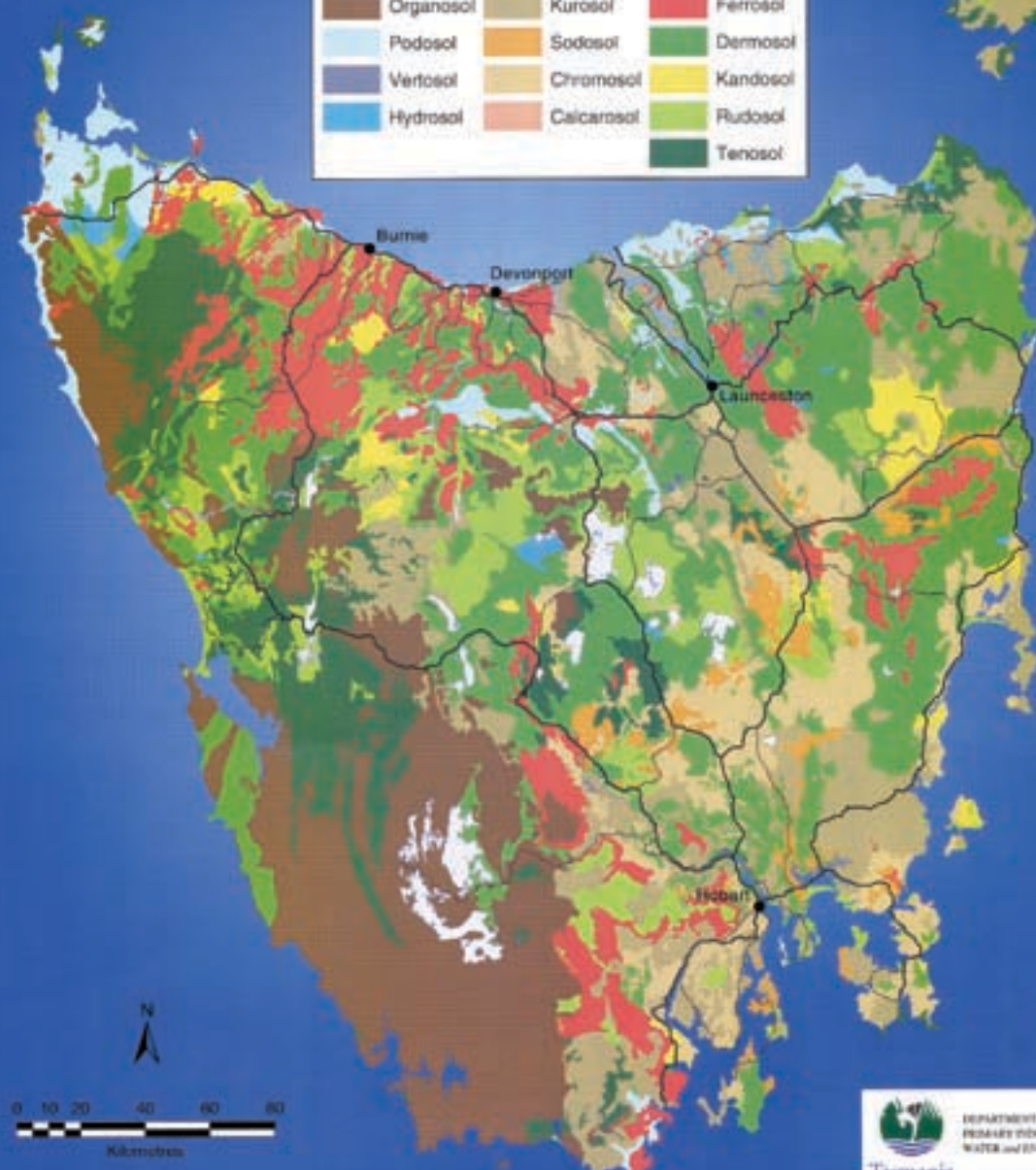
Tasmania

12. Soil orders in Tasmania

"You can't make good soil, you can only buy it" (anonymous)

Soil mapping and classification are necessary for rational soil evaluation and planning as well as the good management and conservation of the soil resource. The soil resource is one of the components on which Australian agriculture is dependent but it is a finite resource. The use of soil classification is essential for organising our knowledge so that the properties of soils can be remembered, the relationships between soils can be understood, the properties and behaviour of soils can be predicted, and to be able to correlate this information between different areas. The economic interest in land has been the driver for the collection of soils information in the past but it is important to study the soils in conservation areas if they and their dependent ecosystems are to be properly understood and conserved. Soil map users should be aware that an observed soil in the field might not match the characteristics of the soil indicated by the map. This may be because the observed soil is not the dominant soil in the mapped area, or the mapped area is similar in overall characteristics but contains different proportions of component soils, or because of errors due to the scale of the map. A soil order is the highest level of classification within the Australian Soil Classification and a wide range of soils and soil properties can occur within a single soil order. If more detail is required, the area of interest must be mapped at a scale appropriate for the end use, rather than enlarging the map.

Tasmania contains a diverse range of soils due to variations in climate, landscape and geology with all of the 13 soil orders represented. Rainfall ranges from over 2400 mm per annum on the west coast to less than 500 mm per annum in the south east, topography from alluvial flats to mountain ranges and geology from soft unconsolidated recent sediments to very old and hard metamorphic and volcanic rocks. The soils that have developed in such a diverse landscape include Organosols developed on peat, Ferrosols formed on basalt, Tenosols formed on wind blown sands, and easily degraded Sodosols and Kurosols on sediments and sedimentary rocks. Recognition that parent material is a strong determinant of soil distribution in Tasmania is a recurring theme with several different surveys delineating map units on the basis of geology and soils. The soil types of the State are intimately linked with the State's ecosystem diversity, the visible signs of which are expressed in the complex pattern of both native and exotic vegetation types and the influence of soils on landuse. The uniqueness of this ecosystem diversity is recognized with 40% of the State being protected in the World Heritage Area, national parks and reserves. Clearing for agriculture has occurred mostly on the more versatile soils and gentler slopes and improved access to water has enabled the diversification of land use with an associated increase in the area used for cropping in some areas. The soils with the least versatility of use through poor fertility, poor drainage or climatic restrictions, are well-reserved (e.g. Organosols, Rudosols and Tenosols), due to little competition from other production-based land uses.

Dermosols are the dominant soil order in Tasmania (24%) with a wide geographic occurrence except in the southwest of the State. Organosols are the second most dominant soil order (14.8%) covering large parts of western Tasmania in alpine areas and with mean annual rainfall in excess of 2400 mm. The mapped occurrence of over 985,000 ha of Organosols in Tasmania makes the state the undisputed home of this soil order in Australia. Tasmania has a greater proportion of Ferrosols (8.4%) than the whole of Australia (0.8%) and these soils are some of the most productive in Tasmania with over 25,000 ha used for cropping. The

Cradle Coast Region contains over half of Tasmania's Ferrosols and the combination of good soils and a temperate moist climate makes the Cradle Coast Region the most agriculturally productive in Tasmania. The highly productive Ferrosols, developed on basaltic parent material, are a critical asset for sustainable agriculture and forestry, both in the Region, and in the State.

Dominant soil orders

Descriptions of the individual soil orders are presented below with broad scale maps of distribution and visual appearance given in Figures 34 - 37, and landuses given in Table 17. Calcarosols are the least abundant (0.3%) soil order in Tasmania occurring predominantly on Flinders Island with a small area on the coast in the south. Soils are sandy textured with relatively low organic carbon content and they are strongly alkaline.

Chromosols have a strong texture contrast between A and B horizons which are not strongly acid or sodic. They can have a perched seasonal water table. Chromosols are a relatively minor soil in Tasmania (5.3%) occurring in eastern and southeastern areas. These areas are in the lower rainfall zone receiving less than 800 mm average annual rainfall which gives rise to less leaching than higher rainfall and so higher pHs, which are required for soils to classify as Chromosols. Grazing is the predominant land use (241,000 ha), but considerable areas of Chromosols are mapped as being used for forestry, conservation and cropping. Surface textures are dominated by fine sandy loams and a large proportion of the described Chromosols occur on Tertiary sediments. Surface horizons are moderately to slightly acid and organic carbon contents are greater than for similar Australian soils.

Dermosols have a moderately to strongly structured B horizon and in Tasmania clay content generally increases with depth. They have few persistent limitations to plant growth. Dermosols are the dominant soil order in Tasmania (24%) with a wide geographic occurrence except in the southwest of the State. This dominance is in contrast to the whole of Australia where Dermosols cover only 1.6% of the land surface. The brown suborder is dominant and red is subdominant which is the reverse of the rest of Australia. This is likely to be a result of Tasmania having a relatively cooler and wetter climate than mainland Australia, i.e. less oxidizing, which gives rise to more of the iron in the soils being in the form of goethite, which has a more yellow hue than the redder haematite.

Native vegetation covers most of these soils (1,300,000 ha) with large areas used for conservation or production forestry and they are the most widely used soil order for pasture grazing and horticulture which is likely due to these soils having few persistent limitations to plant growth. Dermosols occur on a wide range of parent materials including sedimentary and volcanic rocks and sediments, which indicates that parent material is not the dominant soil forming factor for this soil order but rather the Tasmanian climate which is cool temperate with relatively high rainfall. Surface textures are predominantly clay loams and surface horizons are moderately to slightly acid with mean organic carbon contents ranging considerably on different parent materials from 3.7% on Tertiary sediments to 6.5% on dolerite.

Ferrosols are characterised by high free iron oxide content and are strongly structured. The iron oxides, together with smaller amounts of free aluminium oxides and relatively high organic matter contents, give Ferrosols their strongly developed structure. Ferrosols are a significant soil order (8.4%) occurring throughout Tasmania with just over half of them occurring in the Cradle Coast Region. Tasmania has a greater proportion of Ferrosols than the whole of Australia where they cover 0.8% of the land surface. Red and brown

suborders are described (Table 3) with red soils occurring at lower altitudes (warmer) and under less rainfall than brown soils. Pasture grazing and forestry are the predominant land uses but these soils are some of the most productive in Tasmania with over 25,000 ha used for cropping. The more intensive land uses practiced on Ferrosols are characterized by a considerable degree of soil disturbance and they are subject to stresses resulting from farm operations and being left without a protective vegetative cover for prolonged periods. The resulting soil loss by accelerated erosion, structural deterioration and declining organic matter levels associated with intensive management represent the major challenges for long term management of Ferrosols. Most of the described profiles occur on basalt with a mean topsoil depth of 21 cm and surface horizons are moderately acid but subsoils can be strongly acid. Ferrosols contain considerable amounts of organic carbon (6.5%) with soils on dolerite having a mean of 9.0% carbon in surface horizons which is likely to be due to their occurrence at higher altitudes and annual rainfall in excess of 1400 mm.

Hydrosols are seasonally or permanently wet with the greater part of the profile being saturated for 2 to 3 or more months in most years. Wetness can be caused by being in a low part of the landscape such as on a flat swampland, or by low soil permeability. Hydrosols are mapped as occupying 3.7% of Tasmania and they are relatively evenly spread across the State. However, many Hydrosol occurrences are small in area and hence are not mappable, e.g. wet drainage depressions, low lying coastal plains and seepage areas on lower slopes. Consequently the total area is probably an underestimate and previously they have been under reported in Tasmania. Mottled Hydrosols dominate (redoxic) and whole coloured soils (oxyaquic) are also strongly represented. Pasture grazing is the predominant landuse with significant areas used for forestry or under conservation. Artificial drainage has been installed on many areas of these soils to overcome the limitation of waterlogging and this has made these areas more agriculturally productive, but in some instances can lead to significant loss of applied nutrients to waterways. Surface textures are predominantly clay loams to medium clays and A1 horizons have mean thicknesses of 21 cm but variability is high. Surface horizons are moderately to strongly acid but variability is high, particularly in profiles developed on Quaternary alluvium. Mean organic carbon contents in surface horizons range from 2.4% on Tertiary sediments to 5.0% on Quaternary alluvium.

Kandosols lack a clear or abrupt textural B horizon, are not calcareous throughout and the clay content of the weakly structured B2 horizon exceeds 15%. Kandosols are mapped as occupying 3.9% of Tasmania and they are relatively evenly spread across the State. Conservation and production forestry are the predominant landuses (104,000 ha and 76,000 ha respectively) with 67,000 ha used for grazing. Surface textures are predominantly clay loams and A1 horizons have mean thicknesses of 20 cm. Surface horizons are moderately acid and mean organic carbon contents in surface horizons range from a low 1.0% on Quaternary alluvium to 4.2% on Tertiary sediments.

Kurosols have a clear or abrupt textural B horizon, the upper part of which is strongly acid. Many of these soils have a strongly bleached A2 horizon and the B2 horizon is commonly mottled. Kurosols are a significant soil order (9.8%) occurring mainly in the east of Tasmania. Grazing is the predominant landuse, both on modified pastures and natural vegetation but there are significant areas used for conservation and forestry. Kurosols are the second most extensively used soil order for cropping in Tasmania (15,000 ha) behind Ferrosols (26,000 ha) but several studies have found soil degradation associated with cropping on texture-contrast soils in Tasmania. Surface textures are predominantly sandy loams and clay loams with A1 horizons having mean thicknesses of 19-20 cm. Surface horizons are strongly acid and mean organic carbon contents in surface horizons are 4.6% for the profiles described.

Traditionally, agricultural use of Sododols in Tasmania has been for pasture production but they are being used increasingly for cropping. Associated with increasing cropping intensity has been the use of irrigation which is now normal practice for many of the crops grown. The major challenges for farmers who crop these soils in Tasmania's Midlands are to maintain organic matter levels, minimise the amount of tillage, avoid mixing of the less stable A_2 horizon with the A_1 horizon, and promote surface drainage. Cultivation for crop sowing and harvesting, particularly potato harvesting, is often carried out when soil moisture content is greater than ideal which results in soil structure problems such as compaction and hard setting.

Organosols are dominated by organic material and have long been known as peats. They characteristically occur in wet landscapes under high rainfall and so are subject to waterlogging. Many of the Organosols in Tasmania are shallow, ranging from 0.2 to 0.4 m in thickness, and overlie a range of substrates from massive quartzite to gravels. Organosols cover large parts of western Tasmania occurring in alpine areas and with mean annual rainfall in excess of 2400 mm. They are the second most dominant soil order in Tasmania (14.8%) and Tasmania has the largest area of Organosols of any Australian state (985,000 ha), most of which are protected in the World Heritage Area and reserves. The factors that promote peat formation in the west and southwest of Tasmania include the high rainfall, low evaporation and high relative humidity the region experiences. These conditions provide the anaerobic, acidic environment in which peat develops through the accumulation of organic matter. The dominant land use is conservation (88%). Organosols in the south west and central highlands of Tasmania are subject to degradation by sheet erosion and fire. Erosion is usually initiated in areas of poor land management with areas corresponding to regions that have been burnt. Fires arise from lightning strikes, hazard reduction burns or arson and they remove the vegetation allowing the high rainfall and strong winds to intensify the erosion. The degradation of the Organosols by fire and erosion is serious because the rate of formation is so slow.

Podosols have B horizons dominated by the accumulation of compounds of organic matter and aluminum with or without iron. They are usually sand textured and have a bleached A2 horizon, often of considerable thickness, with a hard pan beneath. Podosols cover 4% of Tasmania and they occur predominantly in the north of the State. Many Podosols occur in the coastal zone on Quaternary deposits of quartz sand, both dunes and low lying sand plains but Tasmania has many profiles described as being formed on acid rocks such as sandstone, quartzite and conglomerate. The predominant landuse of Podosols is grazing, particularly modified pastures, for which drainage is required but there are also considerable areas under conservation. A horizons are relatively thick with Podosols having the greatest mean depth (48 cm) to the B2 horizon of any order. Surface horizons are moderately to strongly acid and have relatively high organic carbon contents for sand textured materials, probably because of long periods of saturation which result in accumulation rather than oxidation of organic matter.

Rudosols have not been greatly affected by pedological processes and so have little or no pedologic organisation, apart from minimal development of an A1 horizon. Rudosols are a significant soil order (10.2%) occurring throughout Tasmania. Many of the mapped Rudosols are in coastal areas with these young soils formed on sand dunes. Upland areas such as the Central Plateau and Ben Lomond, with rock to the surface and only minor soil development between boulders and in crevices, result in most of the Rudosols being gravelly or stoney. Much of the land use for Rudosols is conservation or production forestry (405,000 ha combined).

Sodosols have a clear or abrupt textural B horizon, the upper 0.2 m of which has an equivalent sodium percentage (ESP) of 6 or greater and is not strongly acid. A seasonal perched water table, with a bleached A2 horizon, is common due to clay textured B horizons with low permeability. Sodosols are a minor soil order (1.4%) occurring mainly in the southeast of Tasmania. These areas are in the lower rainfall zone receiving less than 800 mm average annual rainfall which gives rise to long term accumulation of salt from rainfall. Tasmania is known as having a wet climate and in general this applies, but there are areas in the southeast that have less than 500 mm mean annual rainfall, which results in net soil water deficits and the build up of salt in the soil. Grazing is the predominant landuse, both on modified pastures and natural vegetation, and significant areas are used for cropping but soil degradation associated with cropping on Sodosols has been reported. Surface horizons are generally moderately acid with organic carbon contents being the lowest (mean 2.9%) for any of the duplex soil orders.

Tenosols have only weak soil development with weakly expressed B horizons but strongly developed A horizons are included. Tenosols cover large parts of western and northwest Tasmania, often occurring in association with Organosols and Rudosols at higher elevations. They are the third most dominant soil order in Tasmania (12.1%) and the dominant land use is conservation (481,000 ha) with production forestry and grazing being lesser uses. Recorded profile descriptions are weighted towards those on dunes with loamy sand textures and near neutral pHs dominant in surface horizons.

Vertosols are shrink-swell soils with 35% or more clay by field texture throughout the profile. They are known to crack to considerable depth in summer and have self-mulching A horizons. Vertosols are a minor soil order in Tasmania (1.8%) and they occur much less frequently than on mainland Australia. The dominant landuse is grazing and considerable areas are used for cropping which has been found to degrade soil physical properties and result in reduced soil carbon contents. Vertosols occur on a wide range of parent materials with surface horizons being moderately to slightly acid.

Acid sulfate soils

In some areas of Tasmania the soil parent materials have been saturated by tidal sea water during their deposition and formation. The sea water brings soluble sulfate anions into the soil profile. Anaerobic bacteria use the sulfate as an electron acceptor and release sulfide (S^{2-}) which combines with ferrous iron to precipitate as black iron sulfide. A little hydrochloric acid (HCl) dropped on this black pigment quickly produces a rotten egg odor of hydrogen sulfide (H_2S) gas. Soils that release H_2S gas are called sulfidic soils. With time, iron sulfide alters to pyrite (FeS_2) and imparts a metallic bluish color. If sulfidic soils are drained and aerated, they quickly become very acid (pH 2.0 to 3.5), and a distinctive pale yellow pigment of jarosite forms. This is the mark of an acid sulfate soil that is quite corrosive and grows few plants. When the water table rises in these soils and drainage occurs, the drainage water can be extremely acidic and can result in fish kills in nearby rivers and estuaries.
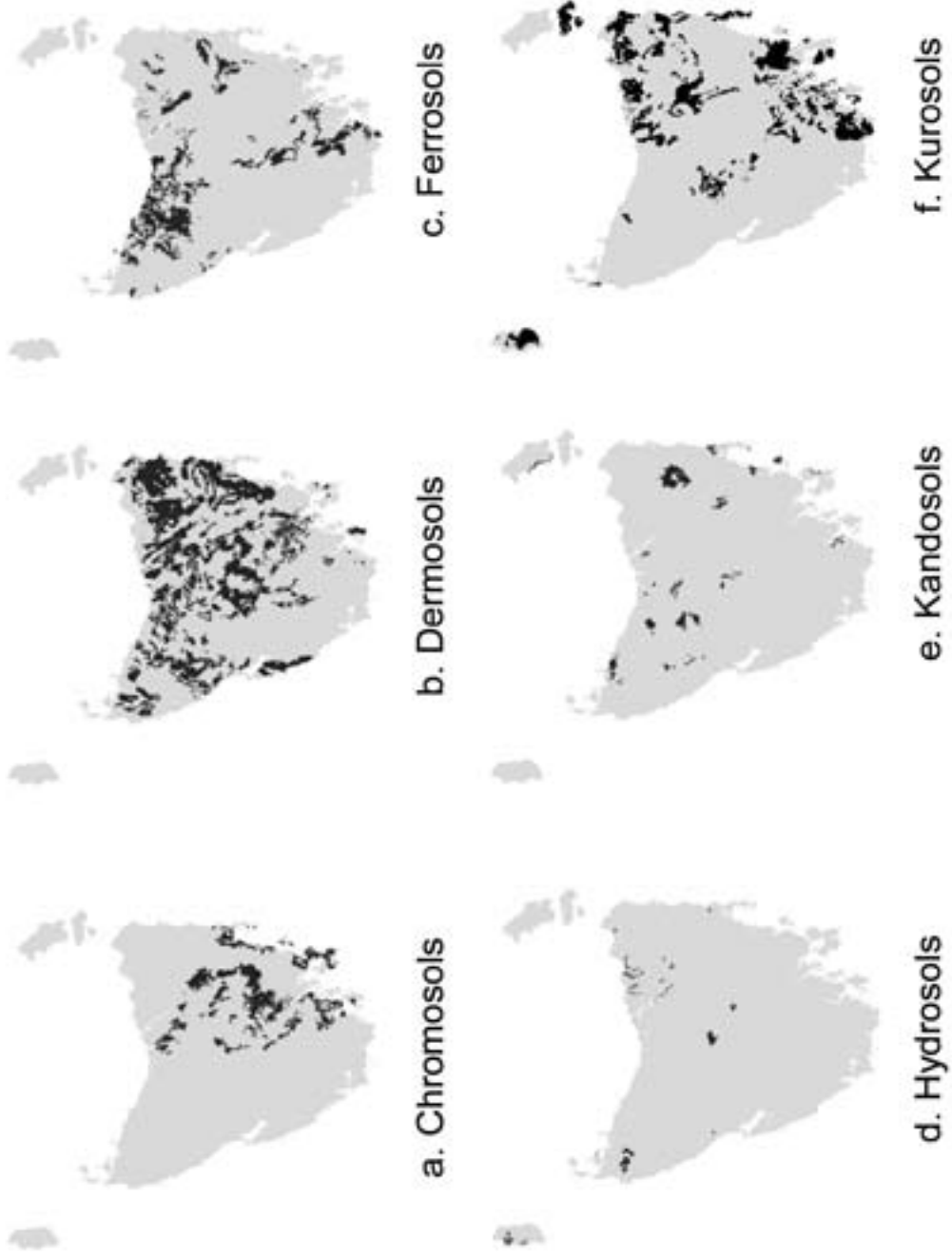
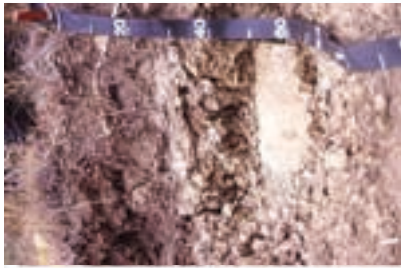**Figure 34. Distribution of dominant soil orders in Tasmania (Chromosols, Dermosols, Ferrosols, Hydrosols, Kandosols, Kurosols).**

a. Chromosols

b. Dermosols

c. Ferrosols

d. Hydrosols

e. Kandosols

f. Kurosols

Figure 35. Profiles of the Tasmanian soil orders (Chromosols, Dermosols, Ferrosols, Hydrosols, Kandosols and Kurosols).

a. Chromosol

b. Dermosol

c. Ferrosol
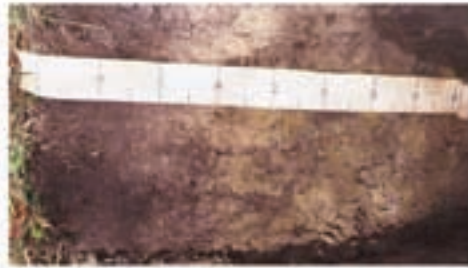
d. Hydrosol

e. Kandosol

f. Kurosol

Figure 36. Distribution of dominant soil orders in Tasmania (Organosols, Podosols, Rudosols, Sodosols, Tenosols, Vertosols).
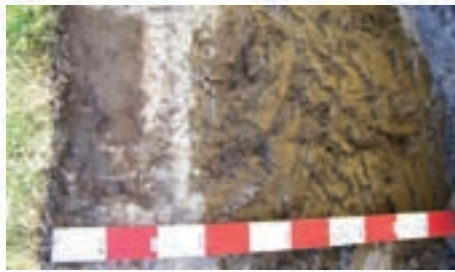
a. Organosols

b. Podosols

c. Rudosols

d. Sodosols

e. Tenosols

f. Vertosols

Figure 37. Profiles of the Tasmanian soil orders (Organosols, Podosols, Rudosols, Sodosols, Tenosols and Vertosols).

a. Organosol

b. Podosol

c. Rudosol

d. Sodosol

e. Tenosol

f. Vertosol

Table 17. Areas of soil orders within major landuse categories in Tasmania.

Soil order	Major land use category*								
	Conservation	Production forestry	Plantation forestry	Grazing natural vegetation	Grazing modified pasture-dryland	Grazing modified pasture-irrigated	Cropping	Perennial horticulture	Urban/ Disturbed
Calcarosol	359	0	42	6424	10907	181	146	19	47
Chromosol	32553	55799	8262	131365	110017	390	2527	487	7340
Dermosol	516941	518197	54220	264497	219801	8830	9131	1700	19243
Ferrosol	83406	148890	93621	55866	125935	12240	25711	349	7728
Hydrosol	55053	42793	11141	39098	79635	6969	3168	1099	6377
Kandosol	104012	75764	9050	25032	39774	2031	1273	256	2603
Kurosol	159044	107311	19242	129122	183610	4321	14943	1571	14741
Organosol	872180	70944	988	28999	10536	25	39	0	2152
Podosol	63680	15206	4818	65089	104497	6632	1542	1167	5830
Rudosol	277167	127538	10704	128956	112453	592	2578	897	13139
Sodosol	4957	3640	639	20070	73136	11	4115	327	1395
Tenosol	480918	110461	2514	108181	88571	1358	3401	712	5696
Vertosol	7528	7693	555	33972	57337	136	8504	388	2050
Total	**2657798**	**1284235**	**215798**	**1036672**	**1216210**	**43715**	**77080**	**8972**	**88342**

* Derived from Bureau of Rural Sciences landuse classification (2003)

Chapter 13 - Soil rejuvenation

"We haven't inherited this land from our ancestors;
rather we have borrowed it from our children" (Kenyan proverb)

The use of machinery in modern agriculture is probably the activity with the most potential to cause soil degradation. Tillage and traffic at inappropriate soil water contents can destroy soil structure and result in compaction. Soil physical properties, such as structure, are notoriously difficult to amend compared to chemical properties. Consequently it is much more advantageous to prevent soil physical degradation rather than to try and ameliorate it. This discussion will concentrate on the physical and biological aspects of soil rejuvenation as the addition of fertilisers invariably aids in the productivity of soils, except in the case of some native plants that are adapted to soils with a low fertility status. On some soils improvement in productivity can be gained through improved drainage which reduces the risk of physical degradation under intensive use.

Soil health can be considered to be the capacity of the soil for self renewal but improving soil condition under current farming systems depends on the following factors:
- Inherent resistance of soils to change (buffering);
- Type of impacts resulting from current practices;
- Land use trends;
- Inherent rejuvenation ability of different soils;
- Opportunity for recovery.

Inherent resistance of soils to change (buffering)
The amount of clay in the topsoil plus the type of clay dominating the mineral fraction are the main determinants of a soil's buffering ability. Soils with clay loam textures in the topsoil are more susceptible to damage from physical impacts (tillage and compaction) which result in clod formation, hard pans and overall compaction. The clay types of most relevance to buffering are the hydrated iron and aluminium oxides that predominate in Ferrosols. These clays have strong inter-particle bonding that give rise to relatively stable micro-aggregates. Another important property influencing a soil's buffering ability is the organic matter content (measured as organic carbon). The greater the organic matter content, the greater is a soil's ability to resist degradation. The level of organic matter in a soil has been shown to determine the microbial activity which plays a role in re-aggregating soil by physically binding particles together. Inherent organic matter content is largely determined by climate and clay content. In general, the cooler and wetter the climate, the greater the organic matter content and a direct relationship also applies to clay content.

Sandy loam to sand textured topsoils in lower rainfall areas (less than 800 mm/year) are the soils (Chromosols, Kurosols, Sodosols, Tenosols) with the least clay and organic matter contents, making them the most susceptible to physical damage. The clay loam textured Ferrosols on the north coast of Tasmania with greater than 1000 mm annual rainfall are the most resistant to change (Figure 38).

The addition of fertilisers aids in productivity of all soils for modern agriculture, however, there are instances when the addition of fertilisers could be detrimental to productivity e.g. native plants. On some soils improvements in productivity can be gained through improved drainage which reduces the risk of physical degradation under intensive use.
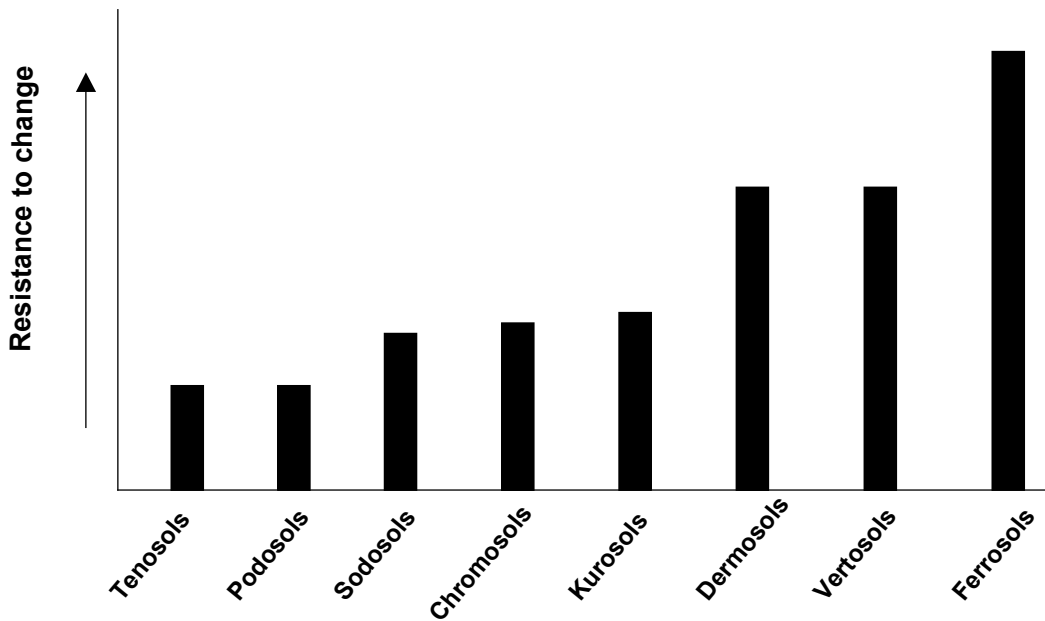
Figure 38. Relative levels of resistance to change – by soil order.

Types of impacts resulting from current practices

The major impacts on soils resulting from agricultural land use are erosion, soil structure degradation, and organic matter decline. Erosion occurs if the soil surface is bare (i.e. no protective cover) at times of heavy rainfall. Erosion also occurs when land use results in channeling water flow that increases the water's energy causing scouring. Cropping is the land use that gives rise to the longest time interval when the soil is left bare. Soils are left bare to allow for conservation of water, weathering down of soil clods, germination of weeds, and preparation of seedbeds by tillage. Most crops grown in Tasmania are sown in the winter/spring period, which means that tillage is required prior to this time. This time coincides with the period of maximum rainfall, particularly in northern areas.

Soil structure degradation can result from excessive loadings on the soil, either by machinery or animals, particularly when soils are wet and they have their least bearing strength. Compaction is the consequence of this excessive loading and can be identified by a soil's over firmness when dug or cultivated, the presence of clods, or the presence of pans or layers restricting root growth and water movement. Tillage can also degrade structure because the many fungal hyphae that bind soil particles together into aggregates are destroyed and are unable to reform if tillage is frequent. Excessive tillage can result in the production of fine soil aggregates (0.2 – 2 mm) or primary particles of sand that are more susceptible to compaction than irregularly shaped coarser (2 – 10 mm) aggregates. The finer soil particles are also more susceptible to erosion.

The mixing of soils by deep tillage, or deeper tillage than is appropriate for the soil type, can bring poorer quality soil nearer to the surface. This is a particular problem in Tasmania's sodic soils in which the clay dominated by sodium occurs beneath the topsoil. Left in it's natural layers, these sodic clays result in little soil degradation. However, deep tillage that mixes this subsoil clay with topsoil results in dispersive topsoils that are structurally

unstable and tend to form surface crusts that inhibit seedling emergence. Once these soils have been mixed, they are difficult to manage and rehabilitate. Mixing of the sandy textured bleached A2 horizon with the topsoil in duplex soils (e.g. Kurosols & Sodosols), can reduce the topsoil's aggregate stability and make it more susceptible to erosion and crusting. This degradation is also difficult to remediate.

Organic matter decline results from organic inputs being less than outputs (removal by oxidation). Every soil type/land use combination has a different equilibrium level (inputs vs outputs) of soil organic matter. Cropping with it's seasons of no growth, fallow or bare soil, returns less organic matter to the soil than perennial plants. Tillage aerates the soil, giving rise to greater levels of oxidation and so organic matter reduction. In lower rainfall areas (< 800 mm/year) irrigation can result in increased biological breakdown of organic matter and so reduced soil organic matter levels.

Land use trends
Different land uses result in different levels of soil impacts (Figure 39) and a different equilibrium within soil properties. If soil management is undertaken with currently known best practices, then it is likely that the equilibrium can be maintained. Best practice soil management can be summarised in a number of principles:
• Protect the soil from erosion.
• Avoid tillage, traffic or high stocking rates when soils are wet.
• Use the minimum amount of tillage.
• Use direct-drill technology where possible.
• Grow green manure crops as often as possible.
• Include a pasture phase in cropping rotations.

The timing of soil operations can often separate good soil managers from poor soil managers. This relates particularly to soil water content because at high water contents, soils are more susceptible to physical damage.
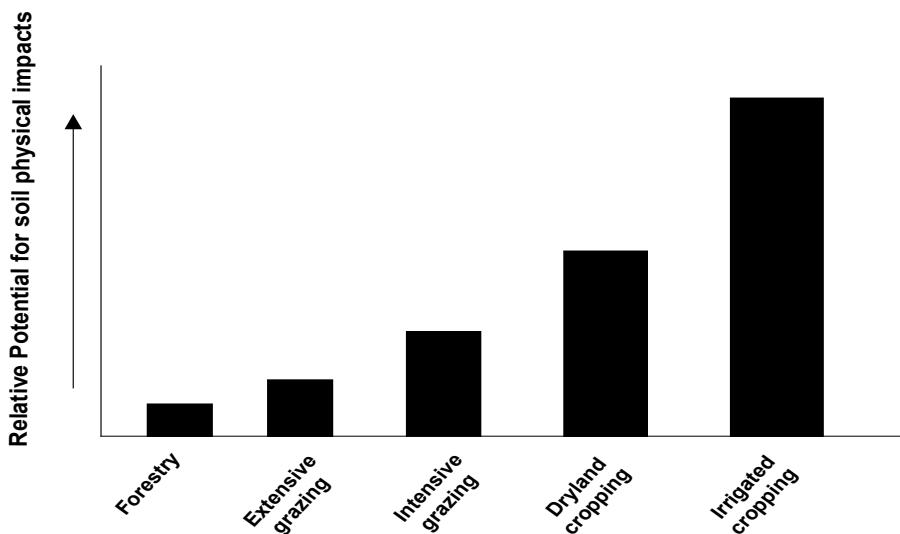

Figure 39. Relative levels of potential for physical soil impacts resulting from different agricultural land uses.

Current land use trends are for greater intensification of use and the more intensive the land use, the greater is the likelihood for soil damage. Farmers have greater expectations of their soils to produce due to financial pressures and tighter gross margins. In lower rainfall areas there is continued growth of the area under irrigation used for cropping. These areas are dominated by duplex soils with sandy textured topsoils. These soils are vulnerable to damage and so greater management skill is required to prevent damage. However, the more these soils are cropped, the more likely it is that timing of operations will be compromised due to constraints of the weather, finances and contractual obligations.

Inherent rejuvenation ability of different soils
If a soil has suffered severe structure degradation, it is going to take many years to rejuvenate it. Anecdotal evidence suggests that this recovery period can be 10–20 years. If intensive use is still required to maintain farmer income, this period would be even longer. Recovery of soil organic matter levels has been found to take a similar time. Consequently, prevention of degradation must be seen as preferable to rejuvenation.

Soils with clays that shrink and swell (smectites) have a natural mechanism for structure rejuvenation. This attribute is most notable in the black cracking clay soils (Vertosols). Under a regime of dryland cropping with direct drilling of crops, Vertosols in Tasmania can be maintained in good physical condition. However, under irrigated cropping where soil structure degradation is more severe, this natural repair mechanism is insufficient to maintain these soils in good physical condition. Soils with other clay types (illites, kaolin) have less natural potential for structure rejuvenation and so will require other mechanisms and more time to rejuvenate.

Topsoil structure is dependent on biological processes for its full development. If physical mechanisms for rejuvenation of structure are not inherently present in a soil, then we must rely on biological processes to rejuvenate degraded structure. This means the growing of root systems to create pores and channels that are left behind when the roots die and production of organic compounds (eg humus) that stabilise soil aggregates against physical damage. Alternatively, earthworms are able to rejuvenate structure by combining primary soil particles of sand, silt and clay into aggregates that are stabilised with mucous gels and infused with the microfauna that inhabit worms' intestines.

Rejuvenation of the structure of sodic soils requires addition of gypsum to provide calcium to replace sodium that is attached to clay particles. Applying gypsum at rates of 2.5–10 t/ha can alleviate structural problems caused by dispersion, but follow up soil testing and reapplication may be required every 2-3 years.

Opportunity for recovery
Locally the best known mechanism to rejuvenate degraded soil is to grow a vigorous grass pasture. The longer a farmer can leave a soil under pasture the better. In Tasmania's climate with a summer dry period, the benefit is enhanced by growing pasture under irrigation in order to ensure high levels of organic matter production. Pasture is probably more effective than cereal crops because grasses have a greater proportion of their biomass as roots. Grass roots are very fibrous creating a multitude of holes, splitting clods into aggregates and binding soil particles together. Pastures also encourage a higher level of fungal hyphae that bind soil into aggregates. Longer periods under pasture allow for regrowth of fungal hyphae that can extend up to 20 cm from a plant into surrounding soil whereas short rotations of growing grass as a green manure crop may not allow for regrowth of optimum

levels of fungal hyphae. Growing pasture also encourages proliferation of earth worms as regular cultivation is physically disrupting.

Pasture farming enterprises generally have a lower gross margin than cropping and so including pasture in a cropping rotation results in an apparent short term opportunity cost to the farmer. This is particularly apparent if a traditional rotation of 50% of the time the soil is cropped and 50% it is under pasture. Costs become even greater if the pasture is irrigated to maintain vigour over dry summer months. If an intense cropping rotation is practiced, the incorporation of as many green manure crops as possible may maintain organic matter levels and allow for some re-aggregation. There is a cost to growing green manure crops and there are associated issues of timing the spraying off, incorporation of residues, and tillage for seedbed preparation. Soil compaction experienced under full time livestock farming can be remedied by maintaining a vigorous pasture, perhaps some surface tillage, and minimising stock grazing on the soils when wet.

Conclusion
The opportunity to improve soil condition exists but is limited under current farming systems. The main constraint is that natural repair or enhancement processes take time. This recovery time needs to be without continuing the degrading impacts associated with many farming practices such as tillage, traffic and bare fallows. Time is needed for the natural processes to work, whether these be physical (shrink/swell, frost heave) or biological (organic matter growth, earth worms or growth of fungal hyphae). Crop yields have been shown to be reduced when soils are degraded but there is a cycle operating in which farmers require greater returns from their soil assets forcing more intense use or tighter rotations. This allows less time for soil rejuvenation but results in more degradation and ultimately lower crop yields and lower gross margins. The best currently known way to rejuvenate soils used for agriculture is to grow a vigorous grass pasture. This provides large amounts of organic matter and is far cheaper than importing organic material from off-farm sources.

Further reading

"When we stick our hands in the soil, we affirm our connection to that which sustains us"
(Bela Johnson)

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