Activities

The soil water interface

Level:	Level 7 / Year 12
Curriculum Strands:	Agricultural and Horticultural Science.
Specific Curriculum Links:	**Year 12 Agricultural and Horticultural Science** Achievement Standards: AS90451 – **2.2** Describe physical factors of the environment and techniques used to modify them for plant production. AS90452 – **2.3** Describe how techniques used to modify soil water content optimise primary production. AS90454 – **2.5** Describe manipulations to influence growth and development, and productivity, in livestock or plants. Unit Standards: 9769 Explain the principles of soil properties in a primary production system.
Links to Supporting Material:	**Our Land, Our Future** • Ecosystems Booklet **RuralSource DVDs** • particularly Soils and Fertilisers DVD.

Background information

This activity has been developed as part of the soil water interface unit. Also see Activities and Background information.

Aim: The aim of this activity is to investigate the ways in which soil structure affects the water holding capacity of different types of soil.

Water is the “Jekyll and Hyde” of agricultural and horticultural systems. A shortage of water is the factor most commonly limiting production over the summer periods while an excess of water over the winter and spring can saturate the soil and have a negative effect on production.

Plants need water for a number of important roles. These include:

Photosynthesis – Water is an essential component of the photosynthesis reaction, the means by which plants generate the energy to carry out the biological reactions which allow the plant to grow and reproduce.

Nourishment – Plants depend on water for nutrient uptake from the soil. Water suspends the nutrients in solution bringing them in contact with plant roots for absorption.

Structure – Plants require water as part of their structure. Plants like ryegrass are up to 93% water at certain times of the year. Water is the substance which holds the leaves rigid allowing them to bath in sunshine for photosynthesis.

Soils also need water to maintain their health. The diverse array of micro-flora and fauna which live in the soil help to maintain its fertility and structure, without these a soil would effectively be dead and useless for agricultural and horticultural production.

A surplus of water can stunt plant growth or even cause them to die. Too much water in the soil over long periods can cause the soil biota to die off leaving it in poor health. When stock and machinery also become involved excess water can lead to compaction of the soil resulting in impermeable layers which restrict root growth and water movement through the soil. In the worst case a total breakdown of the soil structure can occur reducing the ability of the soil to host a plant.

Soils vary greatly in their ability to deal with water. Factors such as soil texture and structure affect the drainage characteristics of a soil and its ability to store water in dry times. Sustainable management of this resource is crucial to ensure ongoing productivity.

Glossary

Evapotranspiration

The combined losses of water from evaporation from surface water and transpiration from plant respiration.

Field capacity

The soil water content after the rate of water draining from the soils macropores has decreased.

Hygroscopic water

Water that cannot be removed from a soil by a plant. (Unavailable water)

Infiltration

The rate at which a soil can soak up water.

Macropores

Those pores greater than 0.05mm which are just visible to the naked eye. They transmit water in drainage.

Micropores

Those pores less than 0.05mm wide and are not visible to the naked eye. These pores store water.

Neutron probe

A device emitting neutrons and measuring those which have been slowed down by hitting water to give an estimation of soil water content.

Permanent wilting point

The soil water content when a plant can not extract any further water from it.

Pores

The empty spaces in a soil where water and air are stored and which allow soils to drain water away.

Readily available water-holding capacity (RAWC)

The water in the root zone between field capacity and the stress point.

Stress point

The soil water content when plant growth is retarded through not being able to extract sufficient water.

Tensiometer

Device for measuring soil water potential to give a measure of soil water content. The higher the water potential the drier the soil.

Total available water-holding capacity (TAWC)

The water in the root zone between field capacity and the permanent wilting point.

References

- Agricultural and Horticultural Engineering. Studman, Clifford J, 1990. Butterworths of New Zealand Ltd, Wellington, New Zealand.
- Soil Science. An Introduction to the Properties and Management of New Zealand Soils. McLaren, R.G, Cameron, K.C, 1990. Oxford University Press, Auckland, New Zealand.
- The Drainage of Wetlands. Bowler, D.G, 1980. Hodder & Stoughton, Auckland, New Zealand.

The Soil Water Interface

These activities have been developed as part of the soil water interface unit.

Activities

Brainstorm ideas

What is soil?

- How does water enter an agricultural or horticultural system?
- How is water lost from an agricultural or horticultural system?
- Why is water important in the soil?
- How does soil store water?
- When is water a problem for farmers and growers?
- How can soil moisture be influenced by farmers/growers?

Hands on activities

1. Investigate capillary action

a) Source capillary tubes of different diameters. Label them carefully with their diameter using masking tape tags. Write the diameter on the tape then wrap around the tube to avoid breakages.

b) Place the tubes in a shallow try of water and measure the distance the water travels up the tube above the water level of the outside water in the tray.

c) Plot the distance travelled on the y axis of a graph against the tube diameter on the x axis.

d) What type of relationship exists between the two?

e) Why does the water in the tube rise above the water level in the tray outside?

2. Observe infiltration patterns

Fill either side of a glass viewing box with 2 different soil types, preferably a sandy soil and a clay soil. Create a small well in the top of the soil sample. Pour 100 to 200 ml into each well and observe how the water travels through the soil. (See Figure A1.)

a) Which soil allowed water to travel downwards most quickly? Why is this?

b) Which soil type does the water move laterally in most? Why is this?

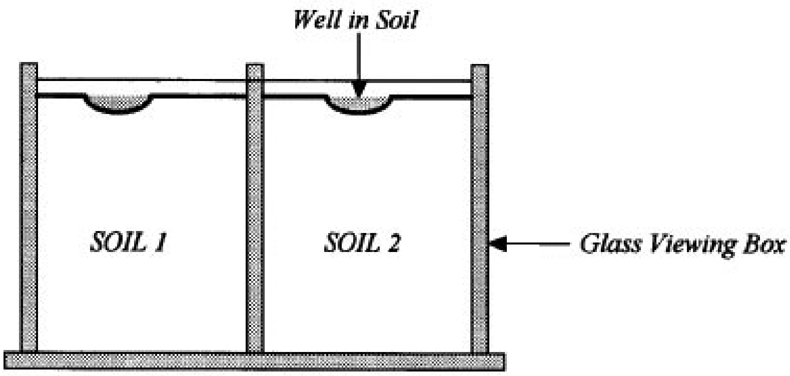

Figure A1: A glass viewing box set up to observe infiltration into two different soil types.

3. Infiltrability and water holding capacity

Materials

- Soil samples of a sandy soil, loam soil and clay soil oven dried to remove all water. These can be brought to class by the students. (You may wish to reduce number of soil textures)
- 3 wide mouth beakers or fruit jars
- 3 garden pots which fit in the mouth of the jars above
- Small pieces of screen for bottom of pots
- Measuring cylinder
- Blu-Tak

Procedure

Record measurements in a table with the following headings.

Soil Type	Volume of pot (g)	Wt pot + screen (g)	Wt of pot + soil (g)	Wt of soil (g)	Particle Density (g/cm3)	Start Time	Stop Time	Infiltration Rate (mm/ min)	Wt pot + water (g)	Field Capacity (ml)
Clay										
Loam										
Sand										

1. Take the garden pots and plug the hole in the bottom from the outside of the pot with Blu-Tak. Three quarters fill them with water and mark the water level. Now tip the water from the pots into the measuring cylinder (you may need another beaker) and record the volume in cm3. (Remember 1cm3 = 1 mm3)
2. Take the garden pots, unplug the Blu-Tak and place screen at bottom of pot to stop soil falling out of holes. Weigh the pots and screen and record the weight.
3. Fill the 3 pots with each of the different soil types tapping the soil down with uniform pressure until the soil reaches the mark made at the water level. Weigh and record the weights of the pots filled with oven dried soil. Work out the soil particle density (weight of soil/volume of soil).

4. Place the garden pots in the mouths of the wide mouthed jars/beaker (as in fig. A2)

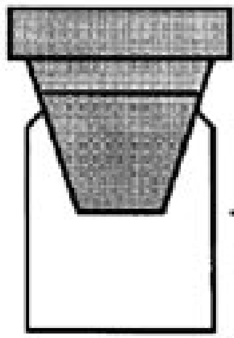

Figure A2: Set up of garden pot and large beaker/jar.

5. Fill the measuring cylinder with water equivalent in volume to the soil in the pots. Note the time. Pour the water from the cylinder into the pot carefully making sure you don't scour the soil surface (You may wish to pour the water onto a spoon placed on the soil surface). Note the time when the last of the water disappears from the soil surface and note the time. Repeat for all soil types. Work out the infiltration rate in ml/min.
6. When the hole in the bottom of the pot stops draining freely and there are only intermittent drips reweigh the pot. Work out the field capacity by finding the difference in weight between now and step 3. (Remember 1g of water = 1ml)

Questions

A. TAWC and irrigation calculations

Using the information supplied in the tables, answer the following questions.

Table 1: TAWC of different soil textures. (Source: Unknown)

Soil Texture	Storage (mm water/100mm soil depth)
Stones & gravel	0
Sand	3
Loamy sand	10
Sandy loam	15
Silt loam	20
Clay loam	18
Clay	16
Peat	25

Table 2:Typical rooting depths of various crops in an unrestricted soil profile. (Source: Unknown)		
←30 cm (Shallow)	70 cm (Medium)	→ 100 cm (Deep)
Potatoes	Maize	Wheat
Strawberries	Peas	Tomatoes
Lettuce	Pasture	Lucerne
Cabbage	Parsnips	Fruit trees

1. A soil consists of 80 cm of peat overlaying gravels. Calculate the TAWC for:
   a) Shallow rooted crops (30 cm) (75 mm)
   b) Medium rooted crops (70 cm) (175 mm)
   c) Deep rooted crops (120 cm) (200 mm)
2. Use the same three rooting depths as in the previous question and calculate the TAWC but this time assume the soil texture is a loamy sand to 80cm overlaying gravel. (30, 70 and 80mm)
3. Calculate the TAWC in a soil with 25 cm of peat overlaying a deep silt loam with a lettuce crop planted. (72.5 mm)
4. Calculate the TAWC of a soil with 65 cm of silt loam overlaying 25 cm of sand which in turn overlays deep gravel. (137.5)
5. During spray irrigation some water does not reach the ground but evaporated into the air. If a pump delivers 60mm to a set of sprinklers and weather conditions cause a 15% spray loss, how many mm actually reach the soil surface? (51mm)
6. On a hot, windy day, 33% of the water from the nozzles of a spray irrigator does not reach the soil surface, how many mm must be pumped to increase the soil moisture level by 24mm? (36mm)
7. If 1mm of rain fell on a paddock how many litres of water would fall on 1m2 of soil.(1 l)
8. How many litres of water would you need to apply to 10ha of soil to increase the soil water by 5mm assuming the system is 100% efficient? (500,000 l)
   a) How many m3 of water is this? (500m3)
   b) How much water would you have to apply, in litres and m3 if the irrigation system was 80% efficient? (400,000 l or 400 m3)
9. If you have a school pool as a reservoir for irrigation and it is 25m long x 8m wide x 1.5m deep and full to the top how many mm of water could you apply to 1ha of land assuming 100% irrigation efficiency? (30mm)
10. If rain is falling at the rate of 4mm/hour on to the farm dairy roof which is 200 m2 how long will it take to fill a tank with a capacity of 10,000 l. (12.5 hrs)

B. Soil moisture balance calculations

Table 3 shows the monthly precipitation and evapotranspiration figures for Agroville.

(You might like to find figures applicable to your area.)

1. Plot these figures on a graph with the month on the x axis.
2. Shade in the areas where there is a moisture deficit and in a different colour shade the areas where the is a moisture surplus.
   – How does this affect plant growth?
   – How can the affects be minimised?
   – What is the total precipitation and evapotranspiration for Agroville in one year?

Table 3: Precipitation & evapotranspiration for Agroville		
	Precipitation (mm)	Potential Evapotranspiration (mm)
January	80	103
February	68	98
March	60	67
April	90	50
May	120	38
June	122	25
July	110	18
August	105	23
September	98	43
October	103	58
November	90	79
December	75	87

Exercises

1. On a graph plot field capacity and infiltration rate against particle density on the x axis.
   a) What general relationship does bulk density have to infiltration rates? and to field capacity?
   b) How does this relate to soil type and texture?
2. Which soil type retained the most water?
   a) Describe why using the terms macropores, total porosity, soil texture
3. Which of the 3 soil types would require the most drainage?
   a) Why is this?
   b) How would drainage benefit the soil and the plants?
4. Which soil requires most irrigation?
   a) Why is this?
5. Explain the difference between field capacity and TAWC
6. Complete a Water Budget

Use local rainfall and evapotranspiration data to complete a water budget for a farm in your area. Do the budget on a weekly basis. Assume on September 20th the soil is at field capacity. Other assumptions which could be useful are:

Field capacity	47 (%,v/v)
Permanent wilting point	24 (%,v/v)
Available water capacity	23 (%,v/v)

a) How much water is required per hectare to maintain field capacity through to autumn rain?
b) If you wished to irrigate 50 ha of pasture and you could only irrigate for 12 hours per day what would be the peak flow rate required by an irrigation gun in litres/minute?
c) Assume the irrigator was only 80% efficient and then how much water should be applied and what would the peak flow rate have to be?

The soil water interface

This has been developed as part of The Soil Water Interface Unit. Also see Introduction, and Activities.

What is soil?

Soil is a complex mixture of solid, liquid and gas phases and the components of the soil may be represented as:

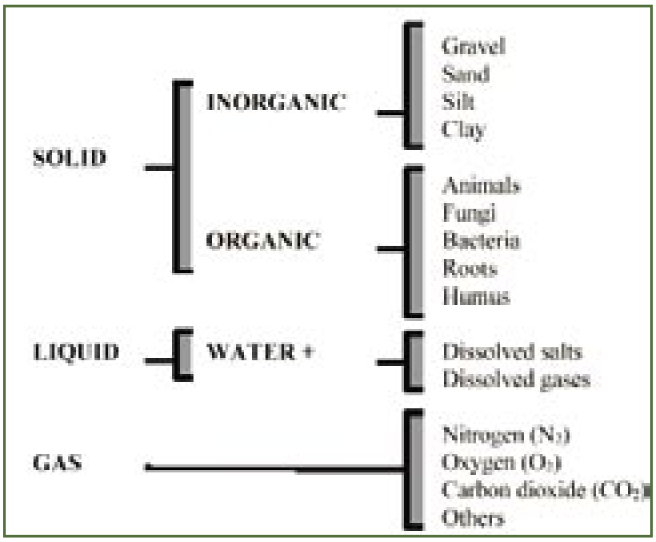

Figure 1: The components of soil

The following figure illustrates the way in which these differing components join together to form what we know as soil. The illustration depicts a single aggregate or "lump" of soil. Within the aggregate is contained all of the components listed above. The ratio of these components determines the texture and structure of the soil, which in turn affects the range of uses it can be put to.

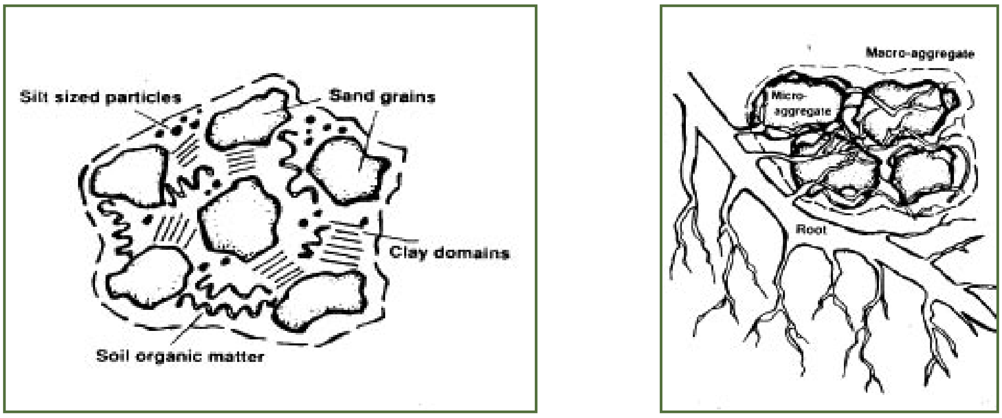

Figure 2: Inside a soil aggregate. On the left is a micro-aggregate. The diagram on the right shows how micro-aggregates are bound together into macro-aggregates. (Source: McLaren & Cameron)

Soils are generally described in terms of their structure, texture and colour. However this only scratches the surface and at a more detailed level a soil can also be described in terms of its density, porosity, water holding capacity and management characteristics.

Density and porosity

Think about a core of soil. It has a volume or takes up a space and it also has a mass or weight. Not all of this mass or volume is taken up with solid soil particles, some of it is taken up by air and water. This is represented in Figure 3 below. The air and the water are contained in soil pores. Pores are small tunnels and fissures in the soil structure which allow water, gas and nutrient to interact with the root system of a plant. Pores are divided into macropores and micropores. Micro pores are extremely small and fine and cannot be seen with the naked eye. Macropores are larger and are those pores over 0.05mm.

The solid, liquid and gas phases are all mixed up together in a very complex manner. However the volume and mass of solid particles in a given soil remains fairly static with the amount of air and water varying depending on soil moisture content.

The number of pores in the soil as well as the parent material of the soil affect the density of the soil. A very dense soil is very hard to penetrate meaning roots have a hard time breaking through the soil. It is also usually very wet and needs intensive drainage. On the other hand a light soil (one with a low density) is generally free draining and has trouble holding water in its structure and is prone to erosion by water or wind.

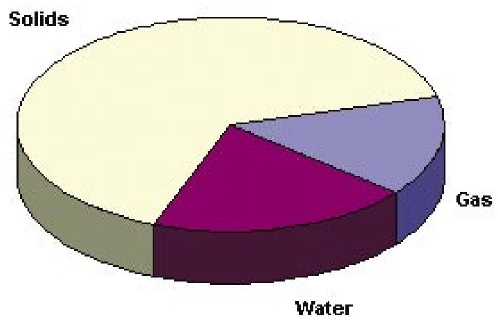

Figure 3: Soil contains a complex mix of gas, water and solid particles.

Soil Water

The importance of soil water

A shortage of water is the most common factor limiting summer pasture production in NZ. Irrigation is an important input in many horticultural systems and increasingly in agricultural systems, especially in dryland areas such as Northland, Canterbury and Otago. Poor internal drainage, and excess water in winter and spring are also problems in many soils. Soils vary widely in their ability to store and transmit water, and this needs to be taken into account in their management. Also the design and management of irrigation and drainage systems depends on an understanding of soil water.

The hydrological cycle

Water enters an agricultural or horticultural system as either precipitation (rain, hail, snow or dew) or irrigation (stored precipitation). Water is absorbed by the soil up to point when all the pores of the soil are full. At this point it has reached its storage capacity. After this further precipitation will result in surface ponding and run-off will occur and water will flow to waterways. Run-off will also occur when infiltrability (rate at which rainfall or irrigation can be absorbed) of the soil is low and the rate of precipitation exceeds infiltrability.

Water which is absorbed and has not left the system through drainage or run-off is lost through a combination of evaporation from surface stored water and the soil surface and transpiration (evaporation of water from plant leaves). Together these processes are known as evapotranspiration.

The process of water entering and leaving a system is known as the Hydrological Cycle and it is represented below. Also refer to page 11 of the Ecosystems booklet in the Our Land, Our Future for senior secondary schools.

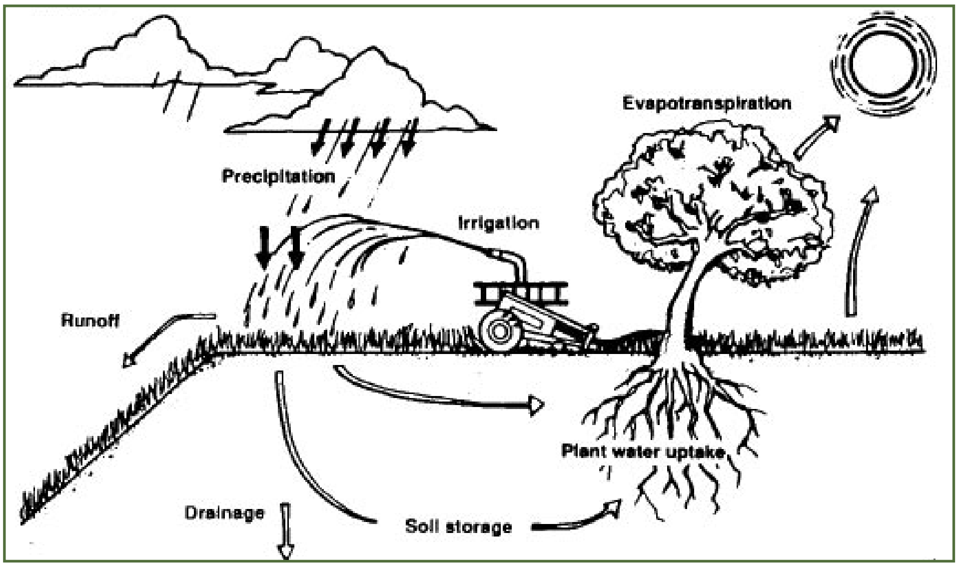

Figure 4: The hydrologic cycle in agricultural systems. (Source: McLaren & Cameron)

Water storage

Water is of a polar nature (it has a positive and negative alignment) and as a result water molecules attract one another as well as other surfaces such as glass or clay particles in the soil. The attraction of water particles to each other is called cohesion while attraction to other surfaces is adhesion. These forces are important as they allow the soil to store water against the pull of gravity which would otherwise drain all water from the soil profile.

Water storage is also dependant on capillarity. The effects of capillarity are demonstrated when a narrow (capillary) tube is dipped into a water bath. The water will be drawn up into the tube above the level of the free water due to the adhesive attraction of the water for the surface of the glass tube and the cohesive attraction of water molecules for each other. This explains why water can be held in the soil profile against the force of gravity. This is demonstrated in Figure 5.

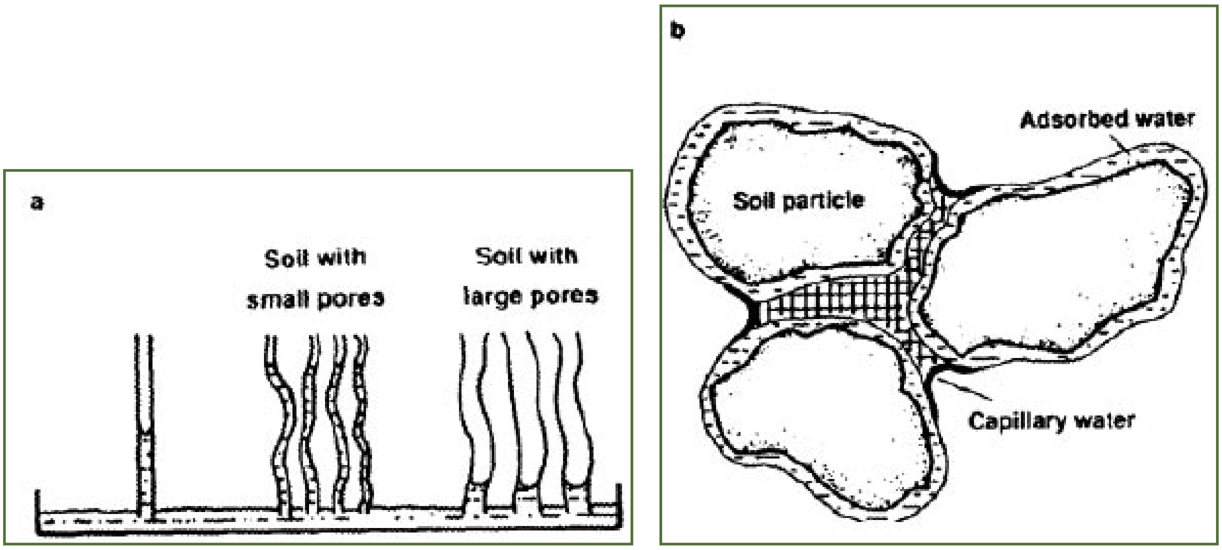

Figure 5: Water is held in soil pores and on the surface of soil particles. a) shows the effects of capillarity. b) shows adsorbed water on the surface of the soil particle and capillary water stored between the particles. (Source: McLaren & Cameron)

The distribution of pore size is also important. In a situation where a soil is saturated the macropores can store water but in an unsaturated soil these drain quickly and are empty. Water is more strongly held in soils with more small pores than one with predominantly large pores. As a guide the finer the soil particles the greater the number of micropores in the soil. For example sandy soils have coarse particles with a high ratio of macropores and only hold 3mm moisture per 100mm depth. Compare this with a silty loam with fine particles which can hold 20mm/100mm depth.

Infiltration

Infiltration is the rate at which water passes into the soil. This is also affected by the ratio of macro to micropores. The more macropores a soil has the easier it is for water to soak into it and drain away. Soils with coarse particles like sand or gravel or nutty or block soil structures have a high proportion of macropores and as a result have high infiltration rates. Soils such as clays have a high proportion of micropores and therefore have low infiltration rates. Figure 6 below illustrates different infiltration rates based on soil structure and texture.

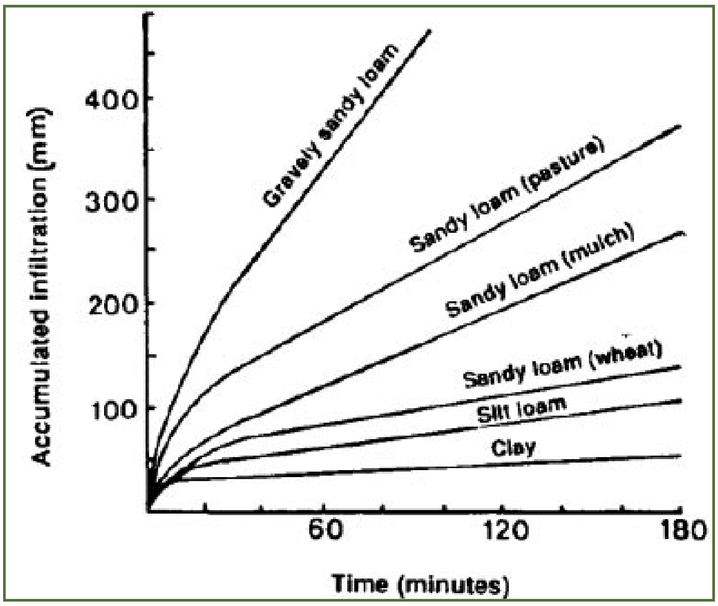

Figure 6: Typical infiltration curves for different soil textures. (Source: McLaren & Cameron)

Field capacity (FC)

What happens in a soil profile after the root-zone has been wet to near saturation by excess rain or irrigation? When infiltration ceases gravity is still pulling the water downwards so drainage commences with the largest pores draining first. This water draining from the soil is sometimes referred to as "gravity water". After a day or so, once the macropores have emptied, drainage becomes much slower as the micropores hold the water more tightly. The soil is now at field capacity.

Field capacity is commonly defined as "The amount of water held in soil after excess water has drained away and the rate of downward movement has materially decreased". This usually takes place within 2 or 3 days after rain or irrigation in free draining soils.

Permanent wilting point (PWP)

Not all the soil water stored in the root-zone can be extracted by plants. Some of it is too strongly bound to the solid particles of the soil. This is called hygroscopic water. The soil water content at which 'plants have extracted all the water they can from a soil' is called the permanent wilting point. This varies depending on soil type and porosity.

Stress point (SP)

Long before the soil in the root zone has dried out to the permanent wilting point, plant growth is severely retarded due to water stress. Plant leaves are subjected to a certain evaporative water demand by the prevailing climatic conditions (mainly the solar radiation and air temperature.) If plants are to remain turgid, with their stomata open to allow CO_2 to be absorbed for photosynthesis, the roots must be able to extract water from the soil at a rate sufficient to match the evaporative demand.

The supply to the roots depends on the water potential gradient between the roots and the soil where the water is being extracted from, and also the permeability of the soil the water is moving through to get to the roots. Thus as the soil dries out, sooner or later the supply of water to the roots can no longer match the demand from the leaves, so the plant closes its stomata and is under stress.

A definition of the stress point is, 'the soil water content in the root zone at which plant growth starts to be significantly affected by water stress.'

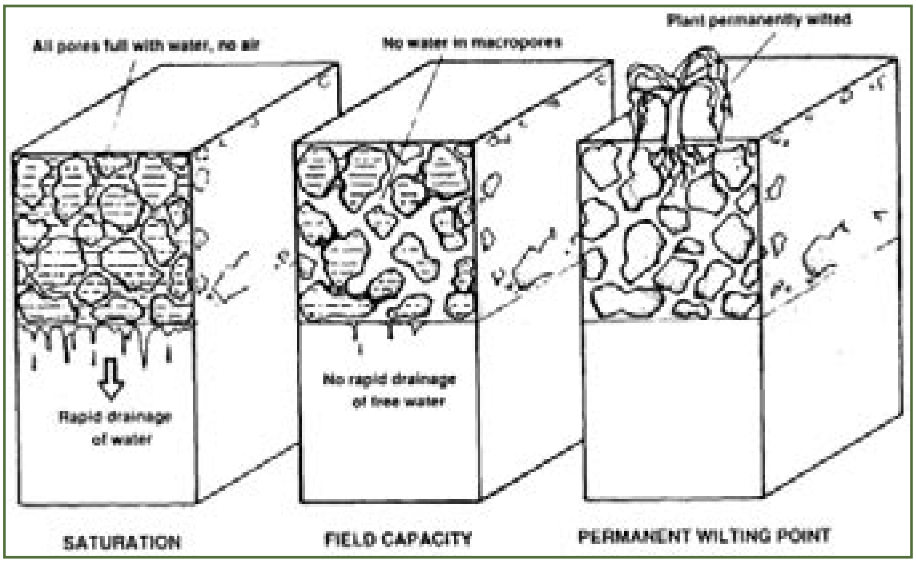

Figure 7: Representation of soils at saturation, stress point and permanent wilting point.
(Source McLaren & Cameron)

Total available water-holding capacity (TAWC)

This is defined as "the water held in the root-zone between field capacity and permanent wilting point". That is ALL the water which the plant can withdraw from the soil. Once the plant is drawing water from below the stress point its growth is hampered. This is influenced by soil structure and texture.

The TAWC of a soil is dependant on the crop or pasture being grown as rooting depth varies between species. Plants can not draw water from below their rooting depth so water held below this depth is not considered. Increased rooting depth allows plants to forage deeper into the soil profile for water. The density of the roots is also important as the more dense a root system is the more likely it is to come in contact with soil water and nutrients stored in the soils micropores. In general when a soil is planted within a deep and dense rooting crop it will have a greater TAWC than it would if a shallow rooting crop were planted.

Readily available water-holding capacity (RAWC)

If plant growth rather than survival is of interest, or if irrigation is available, it is 'the water held in the root-zone between field capacity and the stress point' that is of interest. This may be called the readily available water-holding capacity and as a rough estimate is roughly half the TAWC.

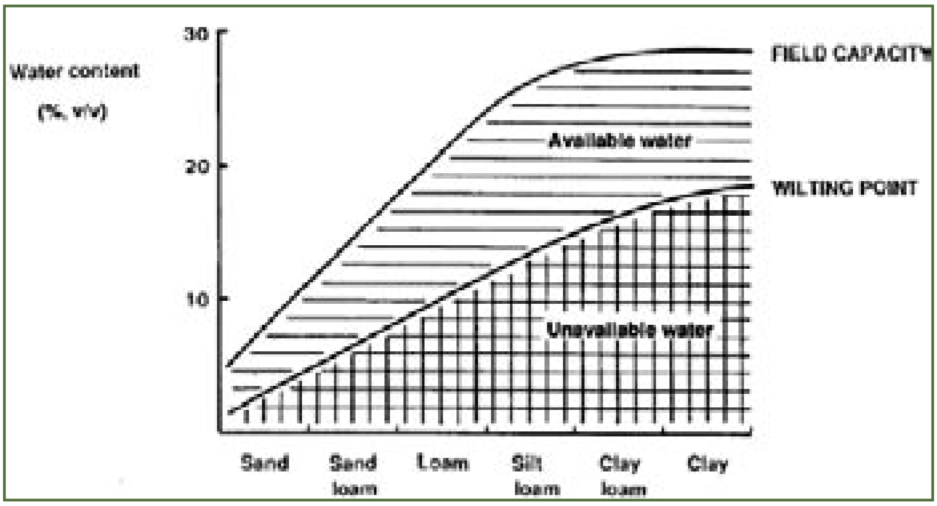

Figure 8: Relationship between soil texture, field capacity, permanent wilting point, RAWC and TAWC.
(Source: McLaren & Cameron)

The importance of RAWC and TAWC

Rainfall is irregular, but evaporation goes on virtually continuously. It is the available water stored in the soil that provides plants with their water between rainfall events.

The following table gives the TAWC for a number of different soil textures per 100mm soil depth. For example a peat soil with a 400mm root zone has a TAWC of 100mm. Assuming the RAWC is approximately half of this it is equal to 50mm.

Figure 9: TAWC of different soil textures. (Source: Unknown)

Soil Texture	Storage (mm water/100mm soil depth)
Stones & gravel	0
Sand	3
Loamy sand	10
Sandy loam	15
Silt loam	20
Clay loam	18
Clay	16
Peat	25

Consider a soil with two horizons as in Figure 10 below, forget about the plant growing in it for the moment and imagine the plant roots were as deep as the soil. The first horizon is 300mm deep and is a sandy loam. Referring to Figure 9 we know the TAWC of a sandy loam is 15mm of water per 100mm of soil depth. That means the TAWC of this horizon is 45 mm.

The second horizon is 500mm deep and is a sand. Referring to Figure 9 again the TAWC of a sand soil is 3mm/100mm. That means the TAWC of the horizon is 15mm

The TAWC of the whole soil to a depth of 800mm is therefore the sum of the TAWC of the two horizons. In this example the TAWC of the whole soil is 60mm. The same methodology is applied to work out the TAWC of a soil with any number of horizons.

Now remember the plant in the example below. The TAWC of the soil varies depending on the rooting depth of the crop grown in it. In this example the crop has an effective rooting depth of 600mm. Water held in the soil below the root zone is unavailable to the plant. Therefore the TAWC is the sum of the TAWC of the A horizon and part of the B horizon. The roots only extend 300mm into the B horizon so the TAWC of the B horizon is equivalent to 9mm within the root zone. The total TAWC is 54mm for the soil planted in this crop.

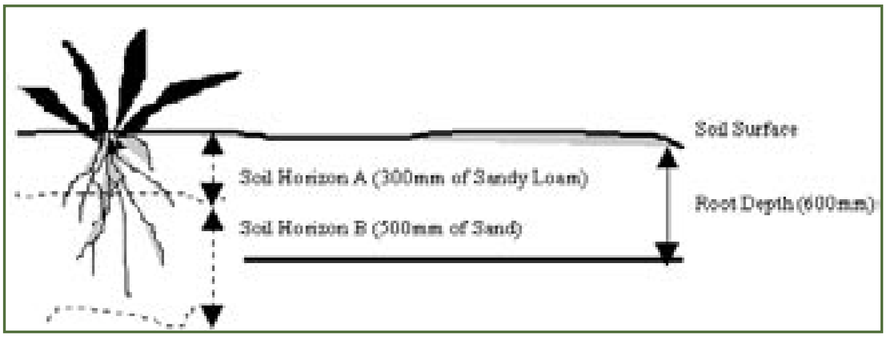

Figure 10: Plant with root extending into two horizons with differing TAWC

In their calculation of 'drought days' the NZ Meteorological Service assumes an average NZ soil growing an average NZ crop or pasture can store 75 mm of readily available water (18mm/100mm TAWC to 83cm depth) when fully rewet to field capacity. Drought days are assumed to occur once the 75 mm has been used up. As a typical summer evaporation rate is 5 mm/day, an average soil can only store water for about 15 days use in summer.

Summary of soil water holding capacity

Soil water dynamics can be thought of as comparable to a sponge. When a sponge is saturated by soaking it in water when it is lifted out of the water any excess water will drip off it. This is equivalent to drainage from the macropores in the soil. Once the sponge has stopped dripping it is at field capacity.

When the sponge is squeezed it is easy to get the first half of the water out. This first squeeze is equivalent to draining the sponge to the stress point and the water is removed like the RAWC. Squeezing the second half of the sponge out is much harder. This is like draining the sponge to permanent wilting point. The total water squeezed out of the sponge from when it stopped dripping is the TAWC. But no matter how hard the sponge is squeezed there is no way to get all the water out of it. The water left is the equivalent to the hygroscopic water found in soil.

This sponge analogy is similar to how plant roots find getting moisture from the soil. From field capacity to the stress point it is easy to get the water. From the stress point to the permanent wilting point plants find it much harder to draw water from the soil and their growth is stunted. Below the permanent wilting point no further water can be removed and the plant dies.

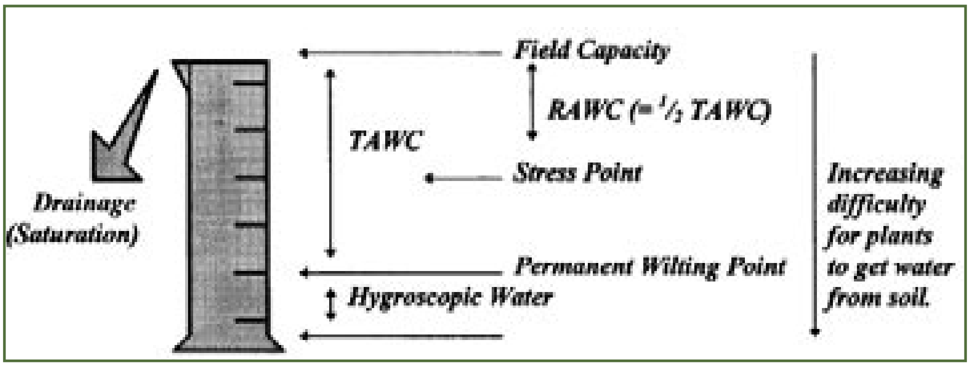

Figure 11: Representation of soil water holding characteristics and terms

Managing soil water

Water is a necessary part of agricultural and horticultural production systems, however at certain times of the year it is out of balance with the requirements of the system. A shortage of water is the factor most commonly limiting production over the summer periods while an excess of water over the winter and spring can also have a negative effect on production. These problems can be managed through the use of drainage to remove surplus water or irrigation to supplement unpredictable summer rainfall.

Drainage

In most areas of New Zealand rainfall is concentrated over the winter months when air and soil temperatures are low. This means evapotranspiration is at its lowest, leading to a surplus of water inputs over water usage and saturation of the soil profile. This surplus water must be removed in order to maximise productivity and then if natural drainage cannot do this it can be assisted through the use of surface and subsoil drainage techniques.

The drainage characteristics of a soil are dependent on soil structure and texture. As mentioned previously a coarse soil with a large proportion of macropores will drain freely whereas a fine soil with a higher percentage of micropores will be comparatively heavy with poor drainage.

Other impediments to drainage also occur. Surface caps can be created through cultivating the soil too finely which with a bit of rain can bake into a hard crust which then prevents further infiltration. Impermeable pans can be created through plough shear as a result of using a blunt plough or ploughing when the soil is too wet. Some soils have natural pans of clay or other minerals which have the same effect. The diagram below in Figure 12 contrasts good and poor soil structure. The poor structured soil will also have poor drainage characteristics.

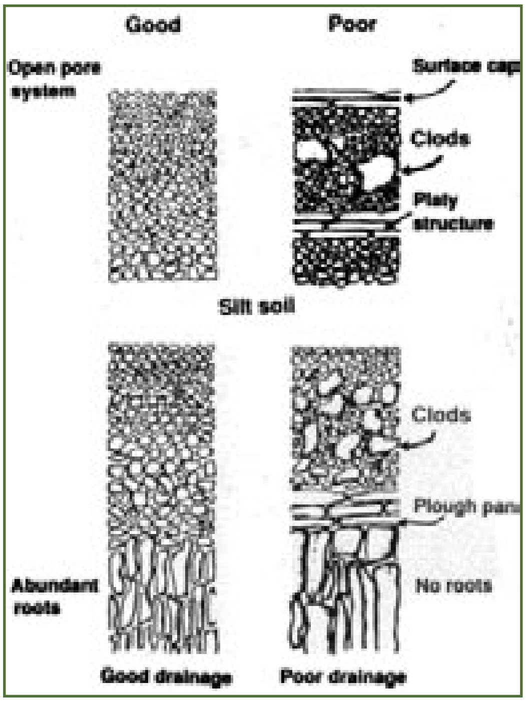

Figure 12: Contrasting good and poor soil structures in a clay and silt soul and the effect on drainage. (Source: McLaren & Cameron)

The reason soils are drained is to maximise plant growth. The following article, adapted from “The Drainage of Wet Soils” by D G Bowler (1980), explains the effects waterlogging has on plants and soil.

The effects of waterlogging

Soil aeration is essential for plant roots and it depends upon soil particle size, their arrangement and the degree of saturation, or soil moisture content. If the larger pores are free of water (ie soil is below field capacity) aeration of the soil can proceed normally. However, when the soil becomes saturated, the rate of aeration is reduced. This results in increased levels of carbon dioxide (CO_2) due to continued respiration of soil organisms and decomposition. In saturated soils this CO_2 can not be removed or replaced by fresh air.

In soils where drainage is a problem, annual crops will be stunted and distinctly yellow in colour; if excess water remains for some time, the plants will die and be replaced with water tolerant weeds. These conditions are primarily the result of root damage caused by a reduced oxygen supply and accumulations of carbon dioxide.

A lowered oxygen content in the soil and an increase in carbon dioxide affects different crops to varying degrees. Spring grown crops are especially vulnerable, particularly wheat.

Excessive soil moisture also reduces the uptake of plant nutrients. Restricted root growth limits the volume of soil from which the plant may draw nutrients. Plants grown in soil that has been maintained near saturation contain less crude protein, potassium, magnesium and chloride. All these elements are required for animal production and lowered levels result in lost production, eg. Less milk, meat or wool.

Poor aeration in the soil and a high moisture content can also affect the occurrence and severity of some plant diseases particularly in horticultural crops, for example fusarium root rot in brassicas such as cabbages or cauliflower or in flowers such as roses or carnations.

Water logged soils are cooler than free draining soils and also take longer to re-warm. The effect that good drainage has on the warming up of soils in the early spring and the consequent growth responses in pasture and spring sown crops is one of its greatest advantages.

Soil temperature affects the rate of absorption of mineral nutrients and water by plants, germination, emergence of seedlings and the dormancy period. Low soil temperatures also restrict root development and depresses the activity of soil organisms so that the rate of production of nitrogen available for plant growth is lowered.

Water logging also impacts on the physical condition of the soil when it is subjected to traffic such as stock or farm machinery. The soil can become compacted, reducing it's ability to drain and the ability of plant roots to penetrate the soil. In the worst case the soil can be mashed to a point where the top soil has no structure left. This means it is almost useless and will grow very little until it is renovated through cultivation. Even with renovation it will be years until such a soil is back to top production.

The following techniques are those most commonly employed in New Zealand to remove excess water. They can be divided into two major categories; surface and subsurface drainage.

Surface drainage

Surface drainage systems involve forming soil into shallow beds or deeper drains that can remove excess rainfall. They are used mainly on flat to gently sloping land. The slope of the drain must not be too shallow or else water can't be cleared adequately. A slope that is too steep will result in undesirable scouring of the soil or erosion.

Shallow open ditches

This type of drainage can be installed using a range of soil moving machinery and are often constructed to drain localised low areas where waterlogging has been occurring. Ditches need to have gently sloping walls to be stable (1:6 to 1:10) and a gradient of 1:500 along the ditch, i.e. 1 metre drop per 500 metres of length. The following are examples of shallow open ditches:

Graded banks

These can be formed on slopes up to about 150 . They are formed by carving out shallow v-shaped drains. The cut soil forms the downhill side of the channel. The graded banks follow the contour at 30-50 metre intervals and pick up surface water runoff and therefore reduce erosion. Installation is cheap and easy with respect to other drainage methods.

Graded furrows

These are also shallow drains formed on slopes up to about 100. They are suited to rough surfaces where simple and cheap equipment is available. A single mouldboard plough cuts a furrow (soil strip) that can be turned downhill and the furrow is compacted by the tractor wheels to make it more erosion-resistant.

Spinner ditches

There are also specialised tractor-mounted spinner ditchers available that have high speed rotation blades that cut and throw soil away from the drain therefore disposal of removed soil is not a problem. This action is similar to a rotary cultivator but working across (perpendicular to) the direction of travel.

Bedding or humps and hollows

This involves preparing the land so that there are alternating humps and hollows 10-30 metres apart. This can be achieved using the mouldboard plough and grading the topsoil using a blade or grader. The system is suited to soils that have low water permeability and therefore subsurface drainage is not possible.

Diversion terrace: These can be used on hill country where interception of water runoff is required to prevent waterlogging of flatter areas. The channel is formed by a bulldozer and needs to slope towards the inside bank so that soil subsidence and stock trampling on the outside edge does not reduce the effectiveness of draining. The channel also needs to slope downhill at about 1.50 gradient.

Grassing of the above ditches can assist with soil stability, and grazing stock can keep the ditches in good order.

Deep open ditches

Also known as deep-V drains this type of ditch is usually an outfall for smaller drains and subsurface pipe and/or mole systems. Their disadvantages include:

- Loss of productive land
- They require maintenance to keep them working effectively. Maintenance involves removal of weeds and soil either by using herbicides, mowing, re-digging, or grazing by livestock. In the case of re-digging, getting rid of waste soil can be a problem
- They are dangerous to stock, people and machines and should be fenced to reduce this risk
- They hinder access to workers and machinery, therefore bridges or culverts are needed.

Subsurface drainage

Subsurface drainage systems have none of the disadvantages mentioned for surface drains; there is no loss of land, maintenance requirements are comparatively low, there is no safety risk to animals, people and machines and access for workers and machines is unrestricted.

Subsurface drainage can be achieved by using field tiles, plastic pipes (Nova-Flo), mole ploughing and subsoiling systems.

Field tiles

Field tile systems use clay pipes (tubes) that have been fired to produce a brittle long-lasting drainage pipe. Tile pipes are laid into a trench and back filled with shingle to allow water to gather at the pipe. Water then enters the pipes primarily through the gaps between the ends of the pipes, even when they are pushed hard up against one another.

Plastic pipes are a cheaper and more easily handled alternative to field drains. They have corrugated walls to give strength to the pipe. It is treated in the same manner as field tiles and when laid in a trench and water enters the pipe through slots in the walls.

Both tile and plastic systems are expensive to install, either in terms of the large amount of labour needed with simple machinery, or alternately due to using expensive automated machines requiring low labour input. If the systems are installed correctly they are long lasting. However, repairs to subsurface systems, if needed, are expensive.

The gradient of an installed pipe drain (plastic or clay) needs to be steep enough to be self-cleaning but not so steep as to cause water to force its way out of pipes and scour the surrounding soil. Recommended gradients are in the range of 1:100 (gentle) to 1:30 (steeper) depending on pipe diameter and soil conditions. The gradient has to be not only accurate, but also unaffected by ground contour changes, otherwise water will pool or lie in low parts of the pipeline, resulting in silt settling and blocking the drain.

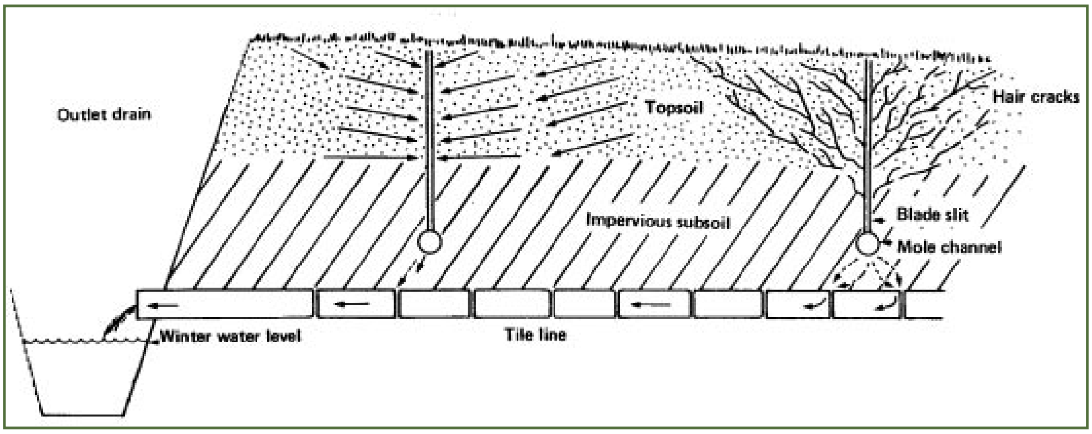

Figure 13: Shows a mole and tile drain in situ.

The water moves into the cracks generated by the mole plough and down into the tile line. The out-fall must be positioned above the winter water level in the drain. Also refer to Figure 16 to see the end on profile of a tile drain showing the permeable gravel back fill over the tile to allow easy access to the tile & prevent silting. (Source: AgLink FPP379)

Mole drains

The mole plough is often used in conjunction with field tiles or plastic pipe. It is a long vertical blade with a torpedo like plug at the bottom of the blade. As it is drawn through the soil the plug forms a circular channel, known as a mole drain, which water will run down. At the same time the blade and the plug gently lift and crack the soil profile above the plug helping to channel water into the mole drains.

Mole drains are usually pulled perpendicular to field tile through the back fill of gravel in the trenches. This allows an efficient transfer of water from the mole drains to field drains. Alternatively they can be pulled into open drains.

Mole drains really only work or are of any permanence in soils with a moderate clay content which will "bake" into a mole tunnel. They need to be pulled when the soil is not too dry and not too wet so the mole plough will not smear the soil surface but so it will form a tunnel without collapsing. It also requires time to "bake" and harden to reduce scouring during use. For this reason mole drains are usually pulled in spring to allow the tunnel to bake and harden over summer. This means the mole is at its maximum strength by the time it is need the following winter. Mole drains which have been well installed in the right soil type can last up to 10 years.

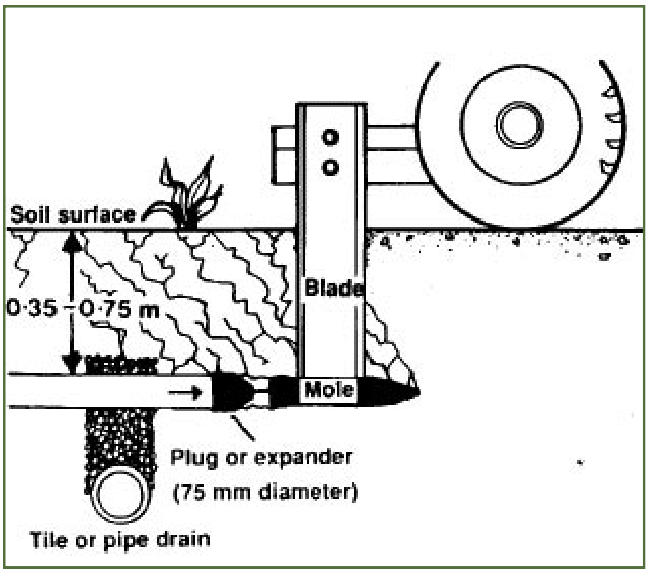

Figure 14: Installation of a mole drain being pulled through the backfill in a tile drain.

This allows easy interchange of water from the mole to the tile drain. Also note the design of the mole plough and the shattering effect it has on the soil above it. (Source: McLaren & Cameron)

Subsoiling

A subsoiler is like an inverted T under the soil. The cross bar has a wing shape which lifts and shatters the earth above it providing channels for drainage and root growth.

This is not strictly a form of drainage but it does in the process help drainage through breaking up any existing pans. A pan is an impermeable soil horizon which makes drainage difficult. This means the top soil can absorb much less rain than normal making the soil susceptible to damage for longer periods and water logging plants resulting in lower production. Generally plant roots cannot penetrate the pan meaning they have a shallower rooting system and are more prone to drought due to the soils lower TAWC.

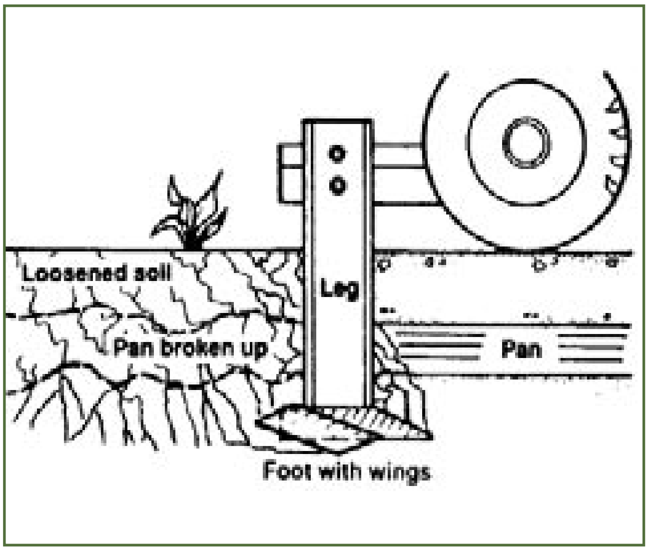

Figure 15: Subsoiler design and its effect on the soil. (Source: McLaren & Cameron)

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Resources for agriculture and horticulture education

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