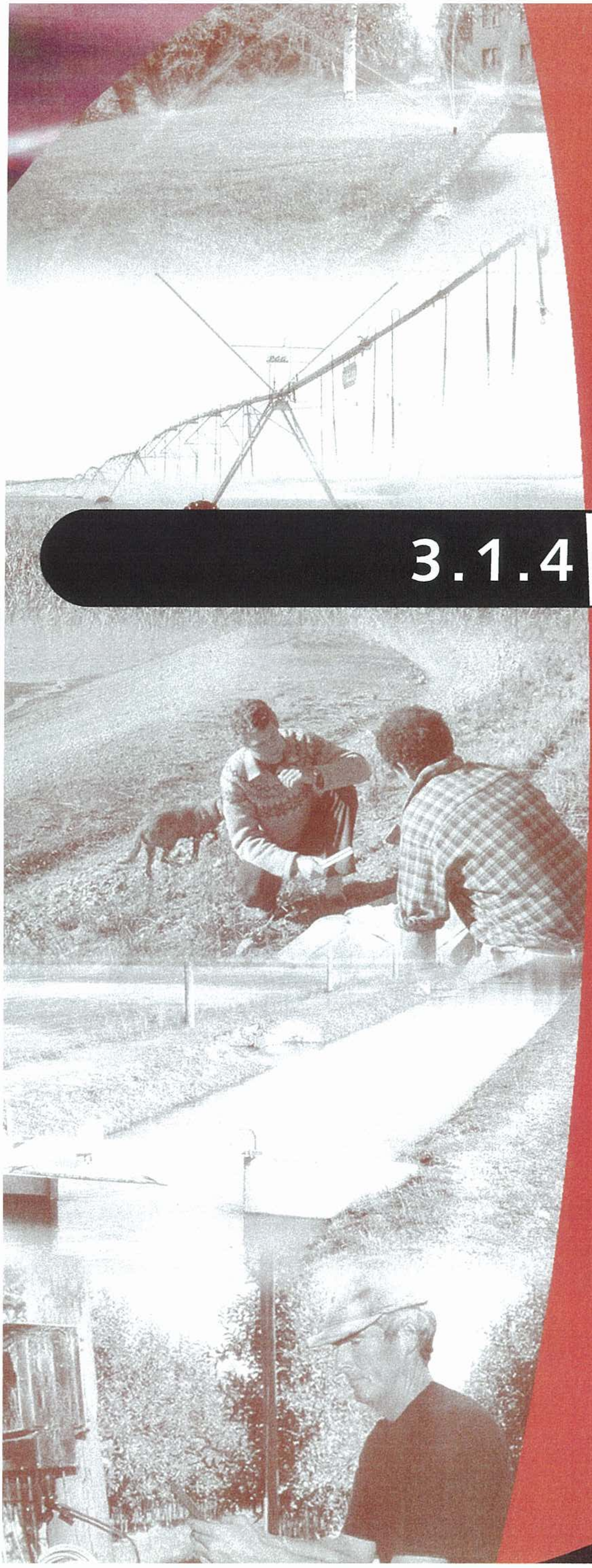


3.1.4 SOIL-WATER FACTS

How much water can the soil hold for plant growth?

There are two aspects to this:

- The soil water holding capacity.
- The maximum available soil water.

The water holding capacity is principally a physical characteristic of the soil. It varies between horizons in a soil profile.

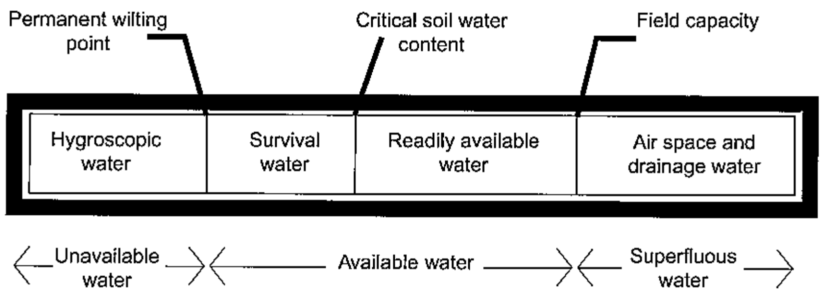
The maximum available soil water in a soil profile depends on the depth of the root zone and the thickness and water holding capacity of each soil horizon within the root zone.

Water Holding Capacity (WHC)

The WHC of a soil horizon is the maximum amount of water that can be held in the soil that is available for plant growth. The soil texture (type of soil) and the crop type determine the WHC. It is the water bank for plant growth. Withdrawing water without a deposit (rainfall or irrigation) will lead to overdraft or conditions where water limits potential plant growth. Ultimately if there are no deposits then bankruptcy or plant death occurs.

For practical purposes, the water holding capacity is defined as:

- WHC equals the amount of water in the soil between Field Capacity and Permanent Wilting Point.
- WHC is usually expressed as mm of water / m depth of soil, or as volumetric water content, V%.



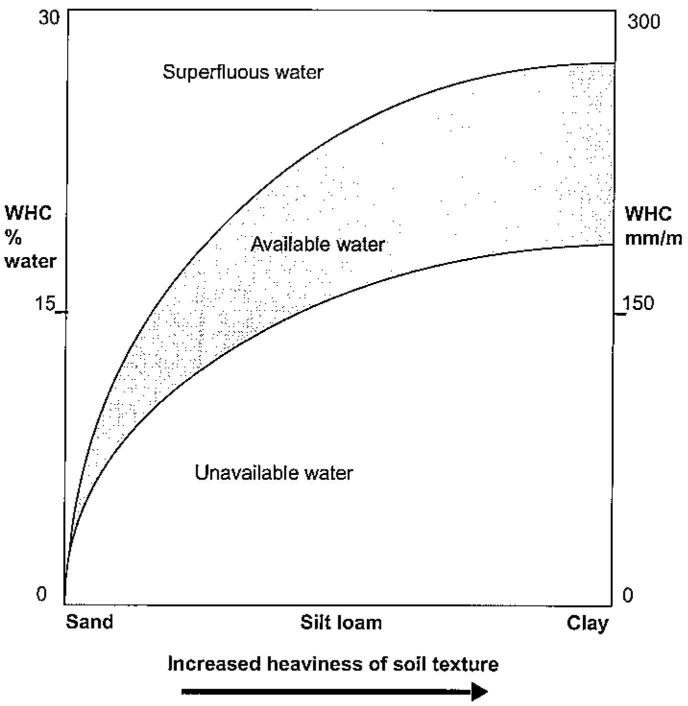
Field Capacity – may also be referred to as Full Point.

- The soil water content of well-drained soils becomes a relatively "definite" value after drainage from an initially saturated profile has become negligible.
- It is normally reached 1-3 days after a very large rainfall or irrigation events.
- At Field Capacity the macro pores of the soil are filled with air and water fills the micro pores as a film on the soil particles.
- While drainage will continue after Field Capacity is reached, the rate is very low and is due to capillary forces and not gravitational forces associated with initial drainage.
- Field Capacity is expressed as volumetric soil water V% or mm depth of water per mm of soil depth.
- Exceeding Field Capacity begins to saturate the soil and reduces the proportion of air in the soil. For some crops growth will be impaired.

Permanent Wilting Point

- The soil water content when the crop will die is referred to as the Permanent Wilting Point.
- As the soil dries out the supply of water to plants is insufficient to maintain turgor and wilting occurs.
  - At first, daytime wilting will be followed by renewed turgor at night when the supply of water exceeds the reduced transpiration requirement of the plant.
  - Eventually the supply of water cannot maintain even night time demand and the plant will become permanently wilted.
  - If water is not added the plant will die.
  - For practical purposes, Permanent Wilting Point is defined to be the soil water content equivalent to a soil tension of 15 bar (1500 cba).
- Permanent Wilting Point is expressed as V% or mm depth of water per mm of soil depth.

The relationship between soil type (texture) and the components of soil water is further illustrated in the following diagram.



The table below is a guide to the WHC of different soil textures:

Soil Texture	WHC (mm/m)
Clay loam	175-190
Silt Loam, no stones or gravel	155-165
Silt Loam, approx. 30% gravel by volume	110-120
Sandy Loam	65-110
Sand	45-55

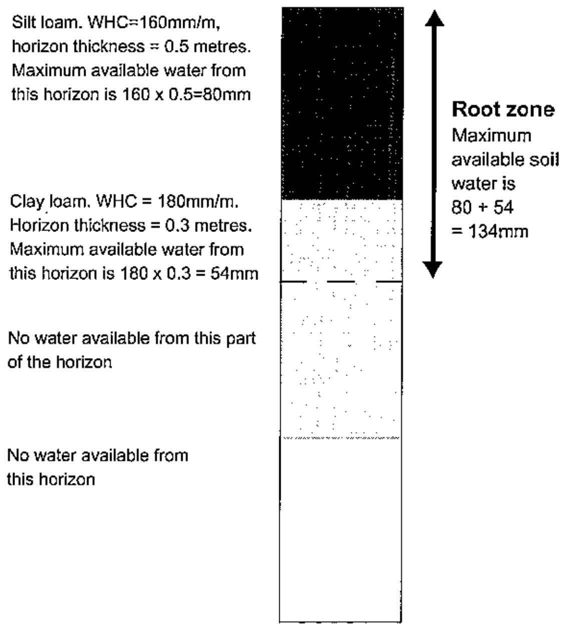
Maximum available soil water

The maximum available soil water is the volume or depth of water available to a crop when all soil horizons within the crop's root zone are at their full point, or field capacity. It is a measure of the root zone's capacity to store water for crop growth, and is therefore a key factor in irrigation management.

To determine the maximum available soil water in the root zone you must know the:

- Soil type
- Depth of the crop root zone, for that specific soil type
- Thickness and WHC of each soil horizon within the root zone.

The following diagram illustrates how to determine the Maximum Available Soil Water in the crop root zone.



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How far can the soil dry out?

This is the question every irrigating farmer wants the answer to. The answer determines when to irrigate and how much water to apply.

The amount of water plants can take out of the soil depends on:

- The crop.
- The soil type and the maximum available soil water in the crop's root zone.
- The growth stage of the crop.

Is all of the available soil water useful?

Not all of the available soil water is useful for maintaining crop growth at its potential rate.

If the potential growth rate is to be maintained and top yields are to be achieved, then:

- Only a portion of the maximum available soil water can be used before the potential growth and yield is detrimentally affected.
- This portion of the maximum available soil water is termed the **critical deficit**, or readily available soil water.
- Once the critical deficit is reached, the readily available soil water is exhausted and the rest of the available water is more difficult for the plant to access. Crop water use continues, and the available soil water reduces, but at a steadily decreasing rate.

Critical Deficit

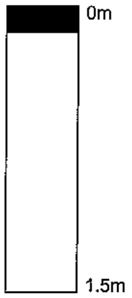
- Irrigation should be applied before the critical deficit is reached.
- Each crop has a different critical deficit.
- In general, critical deficit is about 50-70% of the maximum available soil water within the crop root zone.
- The yield loss when critical deficit is exceeded is 1-3% for each 10 mm of potential soil water deficit below the critical deficit.
- The potential soil water deficit accumulates at the potential crop water use rate after the critical deficit is reached. For example
  - In December, crop water use could be as high as 6 mm/day, so if irrigation is 4 days after the critical deficit is reached, the potential deficit would be 24mm. This would mean a reduction of about 7% of the potential yield (6 mm/day x 4 days / 10mm x 3%)
- Exceeding the critical deficit results in **irreversible yield loss.**
- Exceeding the critical deficit is more costly in crops with high yield potential:
  - Using the example above, 7% of a 12 t/ha wheat crop is 0.8 t/ha, but for a 7 t/ha crop it is only 0.5 t/ha.
- Critical deficit is also affected by soil type, planting date and growth stage.

How much water can be used before critical deficit is reached?

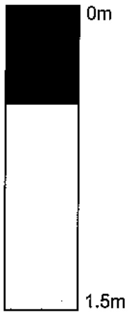
- Critical deficit is large for deep-rooted crops on deep soils, but small for shallow rooted crops on shallow soils.
- For practical purposes, the critical deficit is always the same proportion of the maximum available soil water within the crop root zone.
- Typical values for the critical deficit for a silt loam soil as a proportion of the maximum available soil water are:

Ryegrass pasture	30-35%
Winter Wheat	60-70%
Spring Barley	60-65%
Peas	35-45%
Potatoes	30-45%
Lucerne	70-75%
Onions	30-60%
Pipfruit	55-65%
Grapes	70-80%

- Soil type (texture) will influence the depth of the root zone and therefore the amount or size of the critical deficit. Some typical guidelines for critical deficits are given in the following table:



Shallow soils	
Ryegrass pasture	20-25mm
Peas	20-25mm
Barley	25-30mm
Spring wheat	30-40mm
Pipfruit	25-35mm
Winter wheat	35-40mm
Lucerne	40-50mm
Grapes	30-45mm



Medium soils	
Ryegrass pasture	20-30mm
Peas	20-30mm
Barley	35-40mm
Spring wheat	35-40mm
Pipfruit	40-45mm
Winter wheat	45-50mm
Lucerne	60-65mm
Grapes	60-80mm

Deep soils	
Ryegrass pasture	35-45mm
Peas	35-40mm
Barley	55-60mm
Spring wheat	60-65mm
Winter wheat	75-80mm
Lucerne	90-110mm
Grapes	110-160mm

- Growth stage must also be considered when determining how far you let the soil dry out. During early growth stages, the plant roots will not have reached the potential depths of a mature crop. In the absence of rainfall, or when sown into dry seedbeds, these crops will come under water stress before the critical deficit that is given above is reached. This is particularly applicable to spring sown crops.

Key requirements

To determine the critical deficit for a given crop and soil type combination, the following information is required:

- Crop root depth (remember to allow for crop growth stage – particularly with annual crops).
- Critical deficit as a proportion of the maximum available soil water.
- Water holding capacity and thickness of each soil horizon – to enable estimation of the maximum available soil water in the root zone.

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How much water should be applied?

In the absence of irrigation season rainfall, ideal irrigation management practice would be to wait until the critical deficit is reached and then apply enough water to return the soil water in the crop root zone to field capacity. In practice this is not always practical or desirable. The amount of irrigation applied must always be tempered by:

- The prevailing climatic conditions.
- The risks associated with returning the soil profile to field capacity.
- The need to return soil water to field capacity.
- The requirement that some crops have for "wet" soil water conditions. Optimum yield from other crops may require deliberate stressing by delaying irrigation.

Returning to field capacity

- For many crops on most soil types, during the first half to two-thirds of the growing season, returning the soil water content to field capacity must be the target. If not, the critical deficit will be reached again quickly, before the crop can be irrigated again, and irreversible yield loss sustained.
- On shallow soils this must be the target for almost all crops and all the growing season. With little or no available soil water reserve in the sub-soil, irrigation must supply all the water requirement(s) of the crop. If this practice is not adopted, the critical deficit will be reached very quickly and irreversible yield loss will occur.
- There is no benefit applying more water than the amount required to return the soil water content to field capacity. Excess water is lost to deep drainage and there is no increase in the time to the next irrigation.
- Good irrigation practice will match the irrigation application depth to the difference between field capacity and the current soil water content.
- Good irrigation management requires varying the application depth to match need, not irrigating according to convenience.

Prevailing climatic conditions

- The prevailing climatic conditions should always be considered. The cheapest water application is rainfall, so if rain is likely within two or three days of irrigation don't return the soil water content to field capacity. Allow some capacity to store rainfall.
- During cool wet growing seasons, the risk of applying less than the critical deficit is less than in hot dry seasons. Crop water use is lower, rainfall is more reliable and return periods are longer.

Risk of returning to field capacity

- The crop type and soil type should be considered when deciding how much to apply.
- Some crops are susceptible to yield loss if the soil water is above field capacity for any length of time; e.g. peas, beans, seed clover and potatoes.
- On deep or heavy soils it is safe to apply less than the critical deficit, but be prepared to return to irrigate the crop sooner. The rotation length will be shorter.
- Applying more than the critical deficit, particularly on medium to deep soils during cool seasons, may create conditions that encourage disease in some susceptible crops; e.g. mildew in onions, blight in potatoes, fusarium in wheat.
- For all the above circumstances the weather forecast should be considered. If rain is forecast, delay irrigating crops that are susceptible to over-watering, be flexible and irrigate less susceptible crops.

Need to return to field capacity

- As the growing season progresses always consider if it is necessary to apply enough water to return the soil water to field capacity.
- Balance the crop requirement for water to finish the growing cycle against that required to return the soil to field capacity. For example;
  - Wheat takes about 35-45 days from flowering to end of grain fill. If irrigation is needed and it is 30 days after flowering then the water required is equivalent to between 5 and 15 days of crop water use. This is typically 25 to 60 mm of water.
- The harvest date for process crops such as peas, beans and sweetcorn are known, and a similar estimate of water requirement and the need to irrigate can be made.
- On medium or deep soils consider how much soil water reserve is still available, it may be possible to finish the crop without irrigation.

Need for "wet" soil water conditions

- Consider whether the crop will benefit from returning the soil water to field capacity. Some do not.
  - For example pipfruit and wine grapes do not benefit from irrigation that returns soil water content to field capacity. Doing so encourages vegetative growth and not the development of fruit quality.
- Apply only enough water to "eliminate" pending water stress conditions and match it to the system return time.

Remember that no irrigation system is 100% efficient. The estimates described above are net amounts to the soil. Allow for the inefficiency of your irrigation system to estimate the gross application depth.

System capacity considerations

In many circumstances, especially on shallow soils, the irrigation system is not physically capable of applying sufficient water to eliminate the critical soil water deficit as frequently as required.

In these cases a decision needs to be made about which crops to drop from the irrigation rotation, or to upgrade the irrigation system.

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What should the return interval be?

The return interval is the time period (number of days) between successive irrigation applications on the same irrigator run, orchard block, or group of borders. Either the irrigation system or the characteristics of the soil-crop system determine the irrigation return interval. These will be referred to as the supply return interval and the demand return interval. If optimum crop growth and yield are to be achieved, the supply return interval must be shorter than, or equal to, the demand return interval.

The supply return interval

Assuming all fields in the irrigated area are irrigated in the same sequence, the supply return interval can be calculated by the following equation.

$$\text{Supply return interval (days)} = \frac{\text{Critical deficit (mm)} \times 10}{\text{Water allocation (l/s/ha)} \times \text{Efficiency} \times 86.4}$$

If, for example, the critical deficit is 30mm, the water allocation is 0.4 l/s/ha and the irrigation efficiency is 60% the supply return interval will be approximately 14 days.

Demand return interval for ryegrass pasture

The demand return interval will vary throughout the season, in response to the changing evapotranspiration rate and root zone depth.

The shortest demand return interval is equal to the critical deficit for pasture on the particular soil type, divided by the expected crop water use.

For example, on shallow stony soils with a critical deficit of 30mm during December when crop water use is about 5mm/day, the demand return interval should be 6 days.

On deep soils with a critical deficit of 45mm, and with crop water use of 5mm/day, the demand return interval is 9 days.

Irrigation must begin early enough to complete a full round of irrigation before the critical deficit is reached.

Demand return interval for crops

The demand return interval will vary throughout the season, in response to the changing evapotranspiration rate and root zone depth.

The return interval for crops is more complex than for pasture. The mix of crops, the different critical deficits, the growth stages of the crops and the irrigator move distance between crops on the farm must all be considered.

The pressure time for crops will be in November and December when all crops could require irrigation. Each crop should be considered in the same way as the pasture example above to identify the crop that has the shortest demand return interval. If the supply return interval is less than the shortest demand return interval all crops can be irrigated before any critical deficits are reached.

Do not stick blindly to a fixed rotation length and application depth. Monitor the trends in available soil water levels field by field, and your ability to irrigate to maintain levels above the critical deficit. Think about the implications of these trends for crop yield and what you can do to achieve the best possible outcome across the whole farm – not just for the prize crop.

The consequences of a wrong decision on crop yield are much too severe – there is no room for error.

Return Interval when the critical deficit is not fully replaced

Where crops are grown that do not require the critical deficit to be fully replaced, irrigation systems normally have the capacity to irrigate the entire area in 24 hours.

Establish a target soil moisture deficit with a range of +/- 5mm. If, for example, the target is a deficit of 50mm, the target range is 45 – 55mm. Apply sufficient irrigation to keep the soil moisture within this range. The soil moisture range divided by the current or projected crop water use will determine the irrigation frequency (return interval).

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How fast can water be applied to the soil?

With sprinkler irrigation systems, water should ideally be applied to the soil at a rate no faster than the soil can absorb the water. In other words, the average application rate of the water should not exceed the average infiltration rate of the soil.

Definition of average application rate

This is the rate that the irrigation system applies water to the soil. It should not be confused with the depth of water applied. It is usually measured in mm/h, although on many systems watering time may be less than an hour.

Definition of average infiltration rate of soils

This is the rate at which water can soak into the soil without causing any significant ponding on the surface. It is measured in mm/h.

How do you know if there is a problem?

The visual indication of an application rate problem is significant ponding of water on the soil surface. In serious cases, water may run off the field, particularly when irrigating slopes. Ponding of water on the surface causes the water to move off the higher spots in a field into the low spots in the field. The low spots then end up with too much water and the high spots with too little. Ponding on the surface also causes water to run down cracks and wormholes in the soil, resulting in uneven watering.

In terms of yield, the problem usually becomes apparent in hot dry conditions, when dry spots or low yield areas appear on the high spots in a paddock; suppressed yield and loss of nutrients are possible in the low spots due to overwatering. Using a spade to dig into the soil soon after irrigating can often show lack of water penetration on high spots and excessive watering on low spots.

The application rate of the system can be calculated and compared with infiltration rates for the soil on your property, to confirm an application rate problem. This calculation is also used in the system design stage. The method is described below.

How to calculate application rate

Application rate is calculated by dividing the total depth of water applied by the time in hours taken to apply the water. For fixed sprinkler systems, the total watering time is used. For travelling irrigator systems, the time is related to the wetted footprint of the irrigation system, not the total run time for the shift. The watering time can be measured by marking a point in the field and measuring the time from when that point first starts to get watered to the time when watering stops at that point.

Alternatively, you can calculate the watering time by measuring the wetted footprint of the irrigator, which is the distance that is being wetted at any time in the direction of the irrigator, and dividing by the speed of the irrigator.

For example, if an irrigator is covering 600 metres in 23 hours,

$$\text{Irrigator speed} = \frac{600\text{ m}}{23\text{ h}} = 26.1\text{ m/h}$$

If the wetted footprint is 30 metres wide, then,

$$\text{Watering time} = \frac{30\text{ m}}{26.1\text{ m/h}} = 1.15\text{ h (1 hour \& 9 minutes)}$$

If 50 mm of water is applied over this time,

$$\text{Average application rate} = \frac{50\text{ m}}{1.15\text{ m/h}} = 43.5\text{ mm/h}$$

How to determine infiltration rate

Infiltration rate is usually obtained from published information for various soil types. It varies according to crop cover, soil structure, soil compaction, surface sealing, amount of moisture in the soil, and slope. For this reason, the curves should be used as a guide only.

An important point is that infiltration rates are usually highest just after watering begins and drop off as the soil becomes wet. Generally, the longer the watering time, the lower the average infiltration rate of the soil. The implication is that applying a small amount of water can take advantage of the higher initial rates.

What you can do to improve soil infiltration rates

- Avoid procedures that compact the soil or destroy soil structure.
- Improve soil structure by growing pasture in a rotation.
- Add organic matter.
- Add gypsum or soil conditioners where salinity and surface sealing are a problem.
- Rip soil pans.
- Cultivate on the contour.
- Leave soil surface rough rather than rolled down.
- Don't let soil get dry and hard (keep it damp).
- Keep a good ground cover if possible.

What you can do to reduce water application rates

This is generally achieved by increasing the wetted footprint of systems and applying less water over a longer watering time. Although application rates of irrigation systems tend to be fixed according to the type of system and the design parameters, it is possible in some cases to reduce a system's application rates by:

- Reducing operating pressure. This has the effect of reducing the depth of water applied over a given time.
- Reducing nozzle sizes.
- Changing the type of sprinkler to increase the wetted footprint.
- Changing the type of irrigation system to one with lower application rates.
- Applying smaller amounts of water more often.

These measures are usually a trade-off with other issues, such as applying the correct depth of water, uniformity of applications, wind effects and operational limitations.

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