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Irrigation of Sugarcane Manual

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▶ Introduction

Introduction

Sugarcane is a plant that originated in wet tropical regions such as Hawaii and Papua New Guinea. Therefore, to achieve maximum productivity, it requires an abundant supply of water from either rainfall or irrigation.

With suitable conditions of adequate temperature and sunlight, cane grows in direct proportion to the amount of water available. For each 100 mm of soil water used by the crop, approximately ten tonnes per hectare of cane is produced.

Irrigation reduces the dependency on rainfall for crop production and improves the reliability of cropping. Removing the dependency on rainfall also allows for better planning and increased flexibility of farming activities.

Ratooning is often more reliable under irrigated conditions and in some cases more ratoons may be grown. With irrigation, growers have more flexibility in deciding when to plant and perform other crop management activities as they are not reliant on rainfall to provide soil moisture.

However, excess water that causes waterlogging will reduce yields so good drainage is often just as important as an adequate supply of crop water. Improving on-farm irrigation and drainage generally leads to an increase in productivity.

This publication is a new edition of the *Irrigation of Sugarcane Manual* originally compiled by Peter McGuire and updated in 1998 by James Holden. Much of the manual is a result of original research conducted by Dr Graham Kingston, Les Chapman, Gary Ham and Ross Ridge.

It contains information useful for cane growers experienced in irrigation and also for those new to irrigation practices. The different sections of the manual cover soil water and the response of sugarcane to irrigation, water quality, irrigation systems, and irrigation of saline and sodic soils.

Above: A channel feed liner irrigator working in the Burdekin region. *Photo courtesy of Steve Attard.*

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▶ Soil water and sugarcane

Soil water and sugarcane

The need for irrigation

The need for irrigation has been recognised in sugarcane for over 100 years. In the Burdekin, Bundaberg and Central regions, groundwater and surface water sources have been used from the late 1890s. There were a number of drought years around that time that proved the importance of a regular water supply.

The irrigated area in Queensland has gradually risen from less than 9000 hectares in 1933 to 192 000 of irrigated sugarcane in 2008–09 (ABS, 2009). Over 40 per cent of the Queensland sugarcane crop is irrigated which accounts for 60 per cent of total cane production.

The requirement for irrigation varies by region **(Table 1)**. Areas with low levels of effective rainfall (e.g. Burdekin) see the greatest response to applied irrigation, while areas with high amounts of effective rainfall are unlikely to benefit economically from irrigation. Within districts the need for irrigation can also vary from season to season.

Full irrigation is a term used to describe the irrigation practice in areas of low effective rainfall. In these areas most of the crop's water requirement will come from irrigation.

Regions with higher levels of effective rainfall and where irrigation is used strategically to stabilise and increase yields are often called supplementary irrigated. Compared with fully irrigated areas, supplementary irrigation supplies a smaller proportion of the crop requirement.

Table 1: Irrigation requirements in sugar regions (from Kingston *et al.* 2000).

Region	Annual crop water use (mm)	Rainfall (mm)	Effective rainfall (mm)	Irrigation requirement (mm)	Level of irrigation
Ord	1960	765	614	1350	Full
Innisfail	1310	3562	1205	100	Nil
Burdekin	1520	1058	600	920	Full
Mackay	1490	1676	870	620	Supplementary
Bundaberg	1360	1106	854	500	Supplementary
Grafton	990	975	782	200	Nil

Crop response to irrigation

Given adequate growing conditions, approximately 100 mm (1 ML/ha) of water (irrigation or rainfall) is needed to produce 10 tonnes of cane per hectare. Very efficient irrigation practices can use the same amount of water to produce up to 15 tonnes of cane per hectare.

Cane grows fastest under conditions of adequate moisture, sunlight and temperature (over 24 °C). Growth measurements of over 40 mm per day have been recorded. As the moisture is removed from the soil by the growing crop, growth rates decline rapidly in response to the moisture stress **(Figures 1 and 2)**.

Crop yield responses to irrigation vary between districts because of climatic conditions. APSIM (Agricultural Production Systems simulator) modelling conducted by Hardie *et al*. (2000) showed the increase in production from irrigation for six sugarcane-growing regions when irrigation water was unlimited **(Table 2)**.

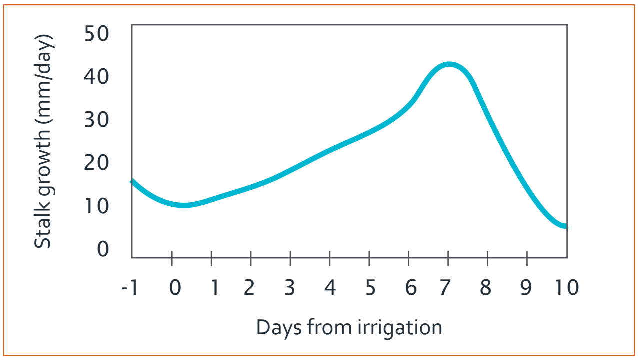


Figure 1: Typical crop growth rates after irrigation of an early plant Q96 crop.

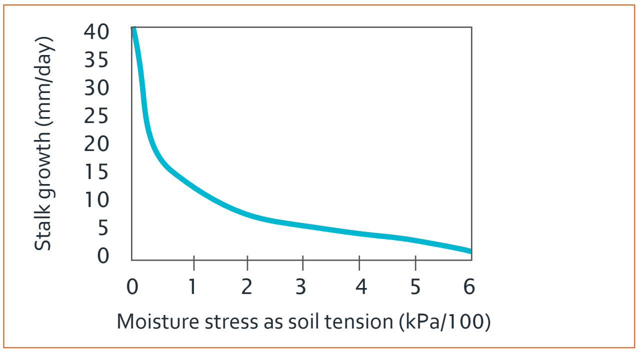


Figure 2: Effect of moisture stress on crop growth rates – Bundaberg Irrigation Trial.

While irrigation for maximum growth produces high cane yields, it reduces Commercial Cane Sugar (CCS) content. Research in Queensland and overseas has shown that supplying approximately 85 per cent of crop water requirements with irrigation gives sugar yields similar to those when the total water requirements are supplied. This occurs because the storage of sugar in the stalk increases when the plant is subjected to some stress.

Total crop water requirements are calculated from reference evapotranspiration (ET_o) (Allen *et al.* 1998). During the peak growth phase the water requirement is 1.25 times the reference evapotranspiration. As the crop matures, the crop factor reduces to 0.7 times the ET_o.

Table 2: Estimated crop yield (365-day crop) under rainfed and unlimited irrigation conditions (from Hardie *et al.* 2000).

Location	Rainfed (tc/ha)	Irrigated yield (tc/ha)	Increase from irrigation (tc/ha)
Bundaberg	62	130	68
Childers	60	120	60
Mackay	84	144	60
Mareeba	29	152	123
Proserpine	73	154	81
Sarina	84	144	60

Soil, water and the crop

Soil is composed of sand, silt and clay. These three particles are of different sizes, with sand being the largest and clay the smallest. The proportion of each particle in a soil determines the soil texture and the size and number of pore spaces in the soil. The size and number of soil pores affect the water-holding capacity of a soil and the ability of crops to extract that water (**Figure 3**).

Very sandy soils have proportionally larger and fewer pores than a heavy clay soil. This means that very sandy soils do not hold as much water as clay soils, but more of the total water in sandy soils is easily available for plant growth. Clay soils have a greater number of pores and hold more water than sandy soils, but the small pore size makes it harder for the crop to extract this water. A loam soil has roughly equal amounts of sand, silt and clay.

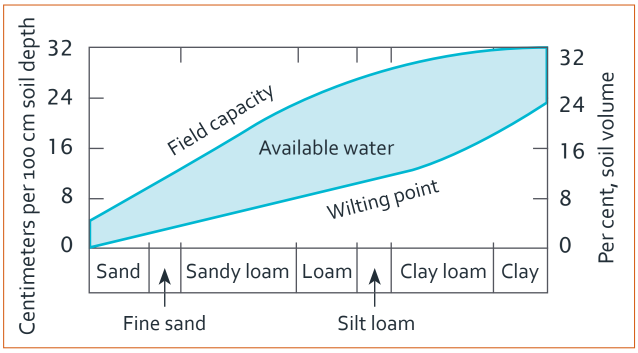


Figure 3: Relationship of soil texture to available water-holding capacity of soils (from Foth 1990).

When water is applied to a soil it fills the pore spaces. The water can be split into two broad types: water available and water unavailable for plant growth (**Figure 4**).

Unavailable water is made up of gravitational water (water that drains away because of gravity) and water that the plant roots cannot physically extract. This water is either held very tightly around soil particles and clumps of particles (soil aggregates) or is below the roots of the crop.

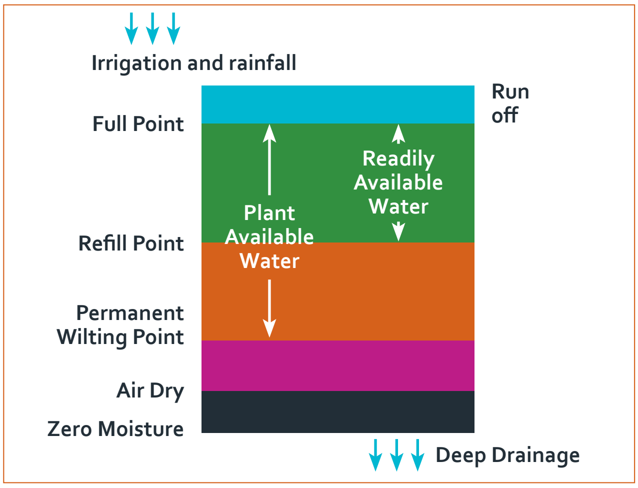
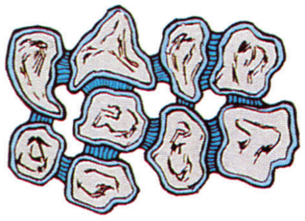


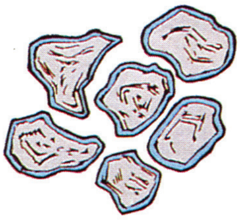
Figure 4: Different types of soil water.

Plant Available Water (PAW) is the water that plants can extract from the soil. When all the PAW has gone, the soil is said to be at Permanent Wilting Point (PWP) (**Figure 5**). Within PAW is Readily Available Water (RAW). This is water that plants can easily extract. Irrigation scheduling should aim to replace the RAW.

In sandy soils, approximately 80 per cent of PAW is readily available. In clay soils, because more of the water is held in small pores, plants have more difficulty extracting the water. Therefore only 45–50 per cent of the PAW is RAW. However, the RAW of clay soils is still approximately twice that of sandy soils **(Table 3)**.



Field capacity occurs when some soil pores are filled with water.



Wilting point is reached when water between the soil pores is depleted.

Figure 5: Soils at field capacity and PWP.

Table 3: Typical RAW for a range of soil types (NCEA, undated), sugarcane experiences stress at -100 kPa (Inman-Bamber, 2002).

RAW (mm water per m soil) between field capacity and different stress levels					
Soil texture	**Crop stress level**				
	-20 kPa	**-40 Kpa**	**-60 Kpa**	**-100 Kpa**	**-200 Kpa**
Sandy	30	35	35	40	45
Loamy sand	45	50	55	60	65
Sandy loam	45	60	65	70	85
Loam	45	65	75	85	105
Sandy clay loam	40	60	70	80	100
Clay loam	30	55	65	80	105
Light clay	27	46	57	70	90
Medium clay	24	43	55	65	83
Heavy clay	21	40	53	60	81

Rooting depth

The effective rooting depth (or effective root zone) is the depth of soil containing most of the roots which actively extract water. In irrigated deep soils (e.g. a clay loam) the effective rooting depth of sugarcane may vary from 0.9 to 1.2 metres. Under rainfed conditions, the effective rooting depth may extend to 1.8 metres.

In a deep, well-drained soil, some sugarcane roots may extend to a depth of over 4 metres. However, such deep roots supply only a small proportion of the water needs of the plant and are not considered to be a part of the effective rooting depth.

In sodic duplex soils (generally a loamy topsoil over a sodic clay subsoil), the effective root zone is usually restricted to little more than the depth of topsoil.

This restriction in the rooting depth is caused by sodium in the soil, which also produces a weak soil structure. Therefore sodic soils have poor water-holding capacities. The amount of RAW that these soils store depends on the depth of the sodic layer and the percentage of sodium in the profile.

Compaction layers or shallow watertables can also restrict the effective rooting depth.

The distribution of roots in the soil is affected by irrigation practices. As shown in **Figure 6**, the more frequent the irrigation, the shallower the roots. With trickle irrigation, most of the roots will be close to the emitter, and are generally confined to the wetted area.

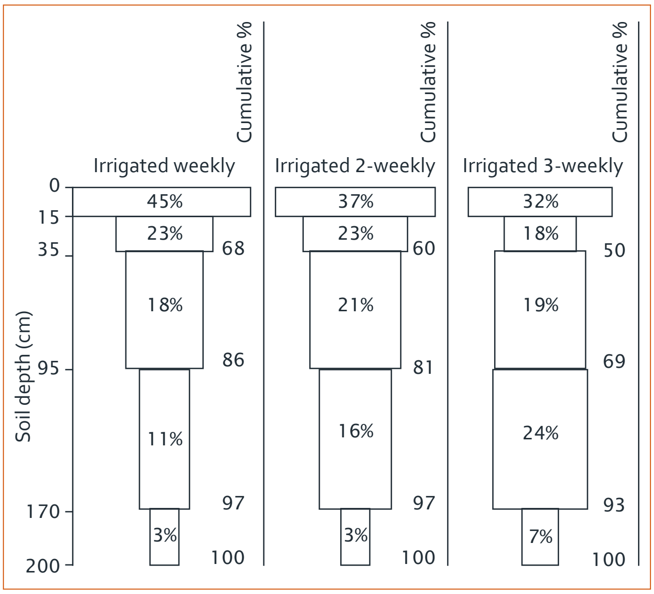


Figure 6: Root distribution by weight in successive strata of soil (after Baran *et al.*)

Practical implications

The less RAW a soil holds, the more frequently it needs to be irrigated. For maximum productivity, an irrigation scheduling tool needs to be used. Irrigating by visual crop stress causes yield loss.

Variations in the water-holding capacities of soils can cause management difficulties. Where possible, irrigation runs should only include soils with similar water-holding capacities to ensure all parts of the run will be ready for irrigation and cultivation at the same time.

Block design should aim to have minimal mixing of soil types along the row.

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Irrigation water quality

Water quality and its effect on crop growth

Irrigation water contains many types of salts. Some harm crop growth while others have beneficial effects. For example, sodium and bicarbonate salts in the water can damage soil structure while calcium salts can improve it.

Over time, soils will take on the chemical properties of the irrigation water used on them. Thus, without proper leaching, saline soils will result from the use of saline water. Water with a high sodicity hazard will produce sodic soils.

To decide whether irrigation water is suitable for long-term use, a prediction must be made on the state of the soil when it eventually comes into equilibrium with the irrigation water. Water quality and the amount of leaching are the two most important factors to consider in making this prediction.

The four components of water quality are:

- Salinity
- Sodicity hazard-comprised of sodium adsorption ratio (SAR) and residual alkali (RA)
- The presence of toxic ions
- The presence of materials that may clog or corrode irrigation systems.

Salinity

Salinity is the *total quantity of dissolved salts* (TDS) in the water. TDS concentration is best estimated by measuring the *electrical conductivity* (EC) of the water, and is often expressed as EC units. The greater the concentration of salts, the higher the electrical conductivity of the water.

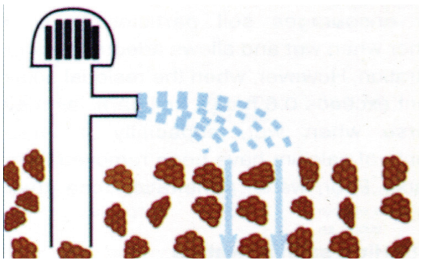
Using water with a high EC causes a build-up of salts in the root zone. The rate at which these salts accumulate is affected by the soil type and amount of leaching. Soils with low levels of internal drainage will accumulate salts more quickly than those that drain freely. Salinity in the soil induces water stress within the plant which causes wilting, scorching of the leaves and restrictions to growth (Calcino, 1994).

The effect of high salinity water on the crop foliage also needs to be considered if overhead irrigation systems are used. When saline irrigation water evaporates from the leaf surface the salts are deposited on the leaf surface and can cause leaf scorching or death.

Conversely, irrigating with water of very low salinity can create problems with water penetration, particularly on light-textured soils (see **Figure 1**).

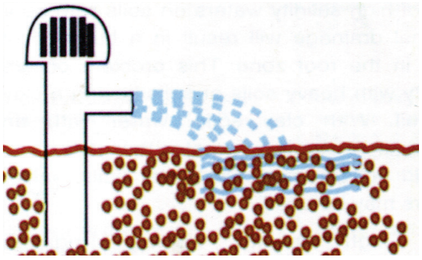
The standard EC unit is decisiemens per metre (dS/m). However, conductivity meters commonly read in millisiemens per centimetre (mS/cm) or microsiemens per centimetre (µS/cm). TDS is also often expressed as milligrams per litre (mg/L) or the outdated unit of grains per gallon (gpg). Use the following equations to convert between different EC measurements:

EC (dS/m) = EC (mS/cm)
EC (dS/m) = EC (µS/cm) ÷ 1000
TDS (mg/L) = 640 x EC (dS/m) (approximate)
TDS (mg/L) = 14.3 x TDS (gpg)



Good soil structure

Good quality irrigation water contains enough soluble salts to prevent soil crumbs breaking up when wet. This permits water to soak through the soil easily.



Poor soil structure

Low salinity waters can cause soil crumbs to break up and form a slurry when wet. This slurry seals the soil surface and makes adequate water penetration impossible.

Figure 1: Effect of water quality on soil penetration and dispersion.

Sodicity hazard

The sodium adsorption ratio (SAR) of water is a prediction of how that water will affect the sodicity of the soil.

Over time, the sodicity or exchangeable sodium percentage (ESP) of the soil will approximate the SAR of the irrigation water. Because sodic soils disperse, they are difficult to cultivate and irrigate and have poor infiltration and drainage properties. Irrigation water with a high SAR value has a more harmful effect on a light-textured soil than on a heavy clay soil. The risk of soil dispersion is greater with low salinity waters. **Table 1** indicates the risk of soil dispersion using irrigation water with different SAR and EC levels.

Residual alkali (RA) or free alkali is another property of water that influences ESP of the soil. RA represents the amount of sodium bicarbonate and sodium carbonate in the water. These salts remove calcium and magnesium from the soil and replace them with sodium, thereby increasing ESP of the soil.

Toxic ions

Excessive amounts of chlorine, sodium, boron, lithium and other elements may be toxic to some crops. Such toxicity is rarely a problem with sugarcane.

Potential clogging or corrosive materials

The presence of iron, clay, or calcium carbonate can cause blockages and shorten the effective life of trickle or spray irrigation systems.

The most important characteristic influencing corrosion rate is pH. Acidic waters with a high proportion of chloride ions are the most corrosive, and turbine pumps are highly susceptible to corrosion.

Table 1: Soil dispersion risk for irrigation water with different EC and SAR levels.

EC, SAR and soil dispersion risk					
SAR	**EC (dS/m)**				
	0–0.3	**0.3–0.9**	**0.9–1.8**	**1.8–2.8**	**Above 2.8**
1–10	High	Medium	Low	Low	Low
10–18	High	High	Medium	Low-medium	Low
18–26	High	High	High	Medium	Low
Above 26	High	High	High	High	Low

Water quality types

Irrigation water is classified into seven quality types depending on electrical conductivity and residual alkali content.

Type 1: Low salinity waters

Electrical conductivity: 0–0.6 dS/m

Residual alkali: 0–0.2 milliequivalents per litre (meq/L)

When some light-textured soils (e.g. sandy or silty loams) are irrigated with low salinity water, the soil particles disperse and form a slurry which prevents adequate water penetration (**Figure 1**).

Corrective measures: mix with higher salinity water or treat the soil with gypsum or lime, depending on soil pH.

Type 2: Low salinity waters with residual alkali

Electrical conductivity: 0–0.6 dS/m

Residual alkali: 0.2–2.4 meq/L

The presence of residual alkali in this type of water aggravates the penetration problem on light-textured soils.

Type 1 and 2 waters are similar in their effect on water penetration and require the same remedial measures.

Corrective measures: as for Type 1 water.

Type 3: Average salinity waters

Electrical conductivity: 0.6–1.5 dS/m

Residual alkali: 0–0.6 meq/L

Average salinity waters can be used on all soil types. They do not cause water penetration problems or result in excessive build-up of soluble salts if leaching occurs.

Corrective measures: none required.

Type 4: Average salinity waters with residual alkali

Electrical conductivity: 0.6–1.5 dS/m

Residual alkali: 0.6–2.4 meq/L

A moderate amount of soluble salts in the water encourages soil particles to bind together when wet and allows adequate water penetration. However, when the residual alkali content exceeds 0.6 meq/L, soil particles may disperse when wet, especially if large amounts of calcium have been removed from the soil. Poor water penetration can then result.

Corrective measures: on light soils, treat as for Type 1.

Type 5: High salinity waters

Electrical conductivity: 1.5–2.2 dS/m

Residual alkali: 0–2.4 meq/L

Use of high salinity waters on soils with poor internal drainage will result in a build-up of salts in the root zone. This problem occurs mostly with heavy soils or soils with a clay subsoil. With clay soils, water with an electrical conductivity greater than 1.5 dS/m should not be used. On lighter soils, saltier waters may be used.

Corrective measures: With high salinity waters, irrigation management is important. Slow, heavy irrigations aimed at leaching salt from the crop root zone must be carried out (**Figure 2**). Light irrigations will result in a rapid build-up of salt. Deep ripping the soil may improve leaching to below the root zone.

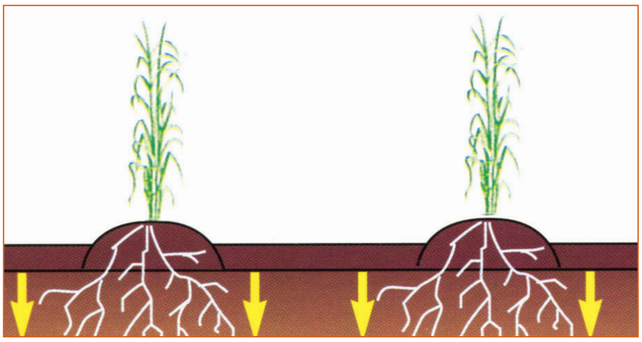


Figure 2: Slow, heavy irrigation leaches salt below the root zone.

Type 6: Very high salinity waters

Electrical conductivity: 2.2–3.2 dS/m

Residual alkali: 0–2.4 meq/L

Very high salinity waters can be used only on free-draining sandy soils without causing a serious build-up of salt. Water with a conductivity greater than 3.0 dS/m should be used only in extreme circumstances.

Corrective measures: where Type 6 waters are used, more frequent, heavy irrigations are necessary to leach excess salts from the root zone. Where a build-up of salts is evident, the soil should not be allowed to completely dry out. Drying concentrates salt in the soil solution. During irrigation with these waters, soils should be wet to a depth of at least one metre.

Type 7: Waters unsuitable for irrigation

Electrical conductivity: greater than 3.2 dS/m or

Residual alkali: greater than 2.4 meq/L

Such water is not suitable for routine irrigation of sugarcane due to the extreme levels of salt or residual alkali.

Table 2: Summary of water quality types.

Water	Quality	Corrective measures
Type 3 EC 0.6–1.5 dS/m RA 0–0.6 meq/L	Good	None required
Type 4 EC: 0.6–1.5 dS/m RA: 0.6–2.4 meq/L	Good to fair	Light soils may need to be treated as for Type 1 or 2
Type 5 EC: 1.5–2.2 dS/m RA: 0–2.4 meq/L	Fair to poor	Ensure irrigation is heavy enough to prevent salt accumulation in the soil, deep rip
Type 1 EC: 0–0.6 dS/m RA: 0–0.2 meq/L	Poor on light soils	Irrigation waters may be mixed or treat the soil with gypsum or burnt lime
Type 2 EC: 0–0.6 dS/m RA: 0.2–2.4 meq/L	Poor on light soils	As for Type 1
Type 6 EC: 2.2–3.2 dS/m RA: 0–2.4 meq/L	Very poor	Use on sandy soils only, wet soil to a depth of at least one metre
Type 7 EC: greater than 3.2 dS/m or RA: greater than 2.4 meq/L	Extremely poor	**Do not use**

Symptoms of water quality problems

Poor water penetration

Cane affected by poor water penetration typically shows poor growth and lack of stool except at the bottom end of cane fields where water lies in the rows.

The problem does not appear while the cane is being cultivated as this roughens the soil and opens cracks and airspaces that slow the flow of water and enable good water penetration.

When blocks with poor water penetration are furrow irrigated, the water runs through very quickly, even when small irrigation outlets are used. Excessive run-off occurs when overhead irrigation is used on blocks such as these. Also, water in the soil does not soak to the top of the hill formed in the cane row.

Digging in the water furrow following irrigation will show that only the top 80 mm to 120 mm of soil has been wetted.

Sugarcane in blocks with poor water penetration may show symptoms of water stress as soon as one or two days after irrigation. Also, crops in these blocks are slow to ratoon. Poor water penetration is a symptom of the irrigation water having too low a level of EC or too high a level of SAR or RA for the particular soil.

Water stress symptoms in wet soil: salinity

Symptoms of water stress, such as a poor yellowish crop with brown leaf tips and margins, show when saline water is used for irrigation. Although the soil may be wet, the plant cannot take up sufficient water. The symptoms may be particularly noticeable at the bottom end of cane fields if the water lies there.

Improving water penetration

Where the water penetration problem is not severe, it may be overcome by changing the irrigation technique. More severe problems will require either a change in the quality of the irrigation water or application of a suitable soil ameliorant.

Irrigation technique

Water penetration can be greatly improved by forming small hills and making a broad flat interspace. Take care that irrigation water does not simply follow the tractor wheel mark. Lower inflow rates and larger watering sets will also improve soakage. Trickle irrigation may also be of benefit in soils with poor water penetration.

Slope

Too much slope on a block will reduce the intake of water. Where water penetration is poor, the slope should not exceed 0.125 per cent.

Trash blanket

Where green cane harvesting is practised, using a trash blanket will improve water penetration. Trash slows the flow of water down the drill and allows more time for the water to infiltrate into the soil. Increased irrigation times up to 25 per cent have been observed. As the trash breaks down, the soil structure at the soil surface is improved which aids water infiltration. However, this effect may be of limited value if soil dispersion still occurs below the surface.

In young ratoon crops, a trash blanket acts as a mulch to reduce evaporative losses from the soil. Measurements show that up to 40 mm additional soil moisture can be conserved by a trash blanket.

Other organic material

Mill mud, rice hulls, or other organic material will improve water penetration when incorporated into the soil. However, the effects are only temporary and usually last no more than two seasons.

Soil ameliorants

Water penetration can be greatly improved by applying a soluble form of calcium. Gypsum applied at 10 tonnes per hectare is the most suitable product. Good results have also been obtained with earth lime in soils with a pH of 7 or less. The solubility (expressed as electrical conductivity) of various calcium-containing products is shown in **Table 3**. The more soluble (i.e. the higher the EC) the product, the greater the effect it will have.

The best result is obtained from these products when they are applied before planting and can be incorporated into the hill. Applications to ratoon cane do not allow adequate incorporation of the product into the hill in the cane row where it is most needed. Depending on the severity of the problem and the rate applied, these products should be effective for three to five years.

Table 3: Typical solubility of various calcium products (saturated solution).

Product	Electrical conductivity (dS/m)	Calcium concentration (meq/L)
Byproduct gypsum	2.3	30
Natural gypsum	2.2	29
Earth lime *	0.3	2

** Earth lime is more soluble in acidic soils and less soluble in alkaline soils.*

Improving water quality

If penetration problems are caused by low salinity water, mixing it with water from a 'salty' bore will often produce better quality irrigation water. In most circumstances this involves mixing open water with a moderately saline underground water supply. Recycled tail-water may also improve the quality of low salinity open water.

Management of saline waters

All irrigation waters add salt to the soil. For example, 800 mm of water with an EC of 1.0 dS/m will add over 5 tonnes of salt per hectare. Without adequate leaching, this salt will accumulate in the soil profile. Ideally each application of water should leach away the salt left by the previous irrigation. To achieve this, water in excess of the crop's needs must be applied. This excess is known as the leaching requirement. The higher the EC of the water, the greater the leaching requirement to remove salts from the root zone.

The amount of water applied for leaching will also affect the quality of the resulting drainage water. The less water available for leaching, the more saline the drainage water becomes.

The leaching requirements for different irrigation and drainage water qualities are shown in **Table 4**. In most situations, rainfall can be relied on to provide adequate leaching.

Deep drainage will cause groundwater to rise. If the groundwater is not too salty, it may be used for irrigation, and this will slow or prevent its rise. If groundwater rises to within 2 m of the soil surface, cane growth will be adversely affected. Sub-surface drainage and disposal of the drainage water is then necessary.

Table 4: Irrigation leaching requirements.

Quality of irrigation water dS/m	Tonnes of salt added per ha per 10 ML of water applied	Leaching requirement (ignoring rainfall) as per cent of irrigation to produce drainage water quality of:		
		5 dS/m	10 dS/m	15 dS/m
0.1	0.6	2	1	0.7
0.2	1.2	4	2	1
0.4	2.5	8	4	3
0.8	5.0	16	8	5
1.6	10.0	32	16	11
3.2	20.0	64	32	21

Irrigation water as a source of fertiliser

All irrigation waters contain some potassium, sulfur and traces of zinc. Under full irrigation, sufficient quantities of these elements may be applied to meet the needs of a crop.

With full irrigation the amount of potassium and sulfur supplied by irrigation water should be taken into account when deciding on a fertiliser program.

Nitrogen

Some groundwater supplies, particularly in areas of the Burdekin, can supply large amounts of nitrogen for crop use (**Figure 3**). Because the levels of nitrogen in these supplies can fluctuate within (**Figure 4**) and between seasons, an annual water test is recommended. Groundwater used for human or stock water should also be tested regularly as high nitrate levels can affect health. The World Health Organization (2011) has set a limit of approximately 10 mg/L nitrate nitrogen (50 mg/L nitrate) as the maximum safe level for human consumption.

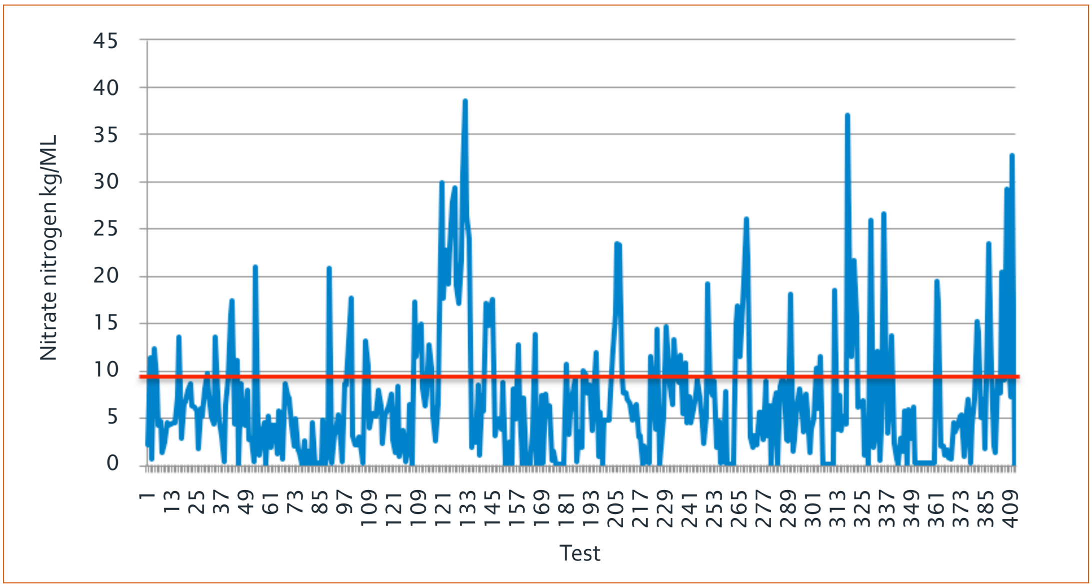


Figure 3: Nitrate nitrogen levels (kg/ML) in Burdekin water samples tested by BSES between 1999 and 2005. Maximum safe level for human consumption is marked in red.

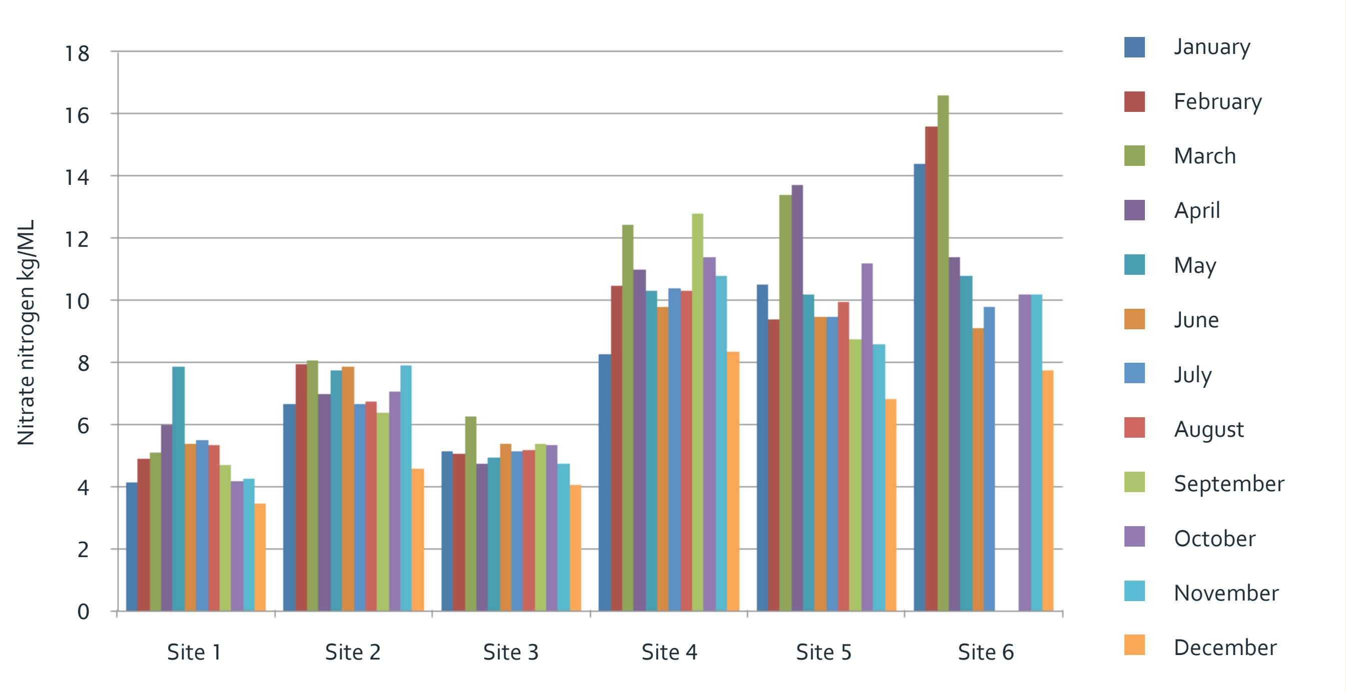


Figure 4: Range in nitrate nitrogen levels at six Burdekin sites tested by BSES during 2010.

Potassium

In the Burdekin, water quality testing has shown that a 'typical' irrigation water will supply between 3 and 5 kg of potassium per megalitre **(Table 5)**. Applications of excess potassium to a cane crop increase the ash content of raw sugar produced and reduce its quality.

Table 5: Potassium in Burdekin irrigation water (kg potassium per ML).

EC (dS/m)	Average potassium content (kg/ML)	Minimum contained in 80% of waters (kg/ML)
0–0.4	3.1	1.7
0.41–1.2	5.2	2.3
1.21–1.6	7.2	3.0
1.61–2.0	9.8	3.7
2.01–2.3	11.5	4.3
> 2.3	14.3	5.3

Sulfur

Sulfur levels in river and other open water sources are up to 2 kg of sulfur per megalitre. Even under full irrigation, these sulfur levels will meet no more than half the sulfur requirement of the crop. Bore water generally contains higher levels of sulfur. Levels above 4 kg sulfur per megalitre are common. Under full irrigation such levels are more than enough to meet the sulfur requirements of the crop.

Zinc

Irrigation water also contains traces of zinc. In the Burdekin district, one-third of the waters analysed supplied sufficient zinc to meet the requirements of the crop. Zinc levels in these waters ranged from 0.002 kg to 0.08 kg per megalitre.

Water analysis

Water analysis is the best way of determining the suitability of a water source for irrigation. It can be obtained through commercial laboratories.

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Saline and sodic soils

Saline and sodic soils

Saline soils

Saline soils are those in which the concentration of soluble salts in soil water is sufficient to restrict plant growth. These salts can be a combination of calcium, magnesium, sodium or potassium ions in association with chloride, sulfate, carbonate or bicarbonate ions. Sodium chloride (table salt) is the most common salt in problem areas of the sugar belt.

Why are soils saline?

Soils with natural or primary salinity have developed in old marine areas or on rocks that release salts upon weathering. Secondary or induced salinity is a more important issue for the future of new and existing cropping areas.

Secondary salinity is caused by the rise of saline or non-saline groundwater tables into the crop root zone. Capillary action and evaporation then cause the concentration of salt near the soil surface. Watertable rise is caused by an increase in deep drainage below the crop root zone. Deep drainage increases when deep-rooted forest trees are replaced by more shallow-rooted cultivated plants. The watertable rises faster in irrigated areas because of deep drainage of the irrigation water.

As well as these local management effects on the watertable, changes in water movement in the district can cause a watertable rise that results in secondary salting. Secondary salinity is more severe when subsoils contain a store of salt, or where groundwaters are saline and under pressure.

Where does salinity occur?

Salting of soils has occurred in the ancient irrigated areas on the Tigris and Euphrates rivers in the Middle East. It is currently occurring in the Murray-Darling Basin and in irrigation areas throughout the world.

Soil salinity will develop where a source of salt or shallow groundwater is available, where annual rainfall is less than approximately 1200 mm, and where evaporation exceeds rainfall for much of the year. In higher rainfall zones, soil and groundwater systems are subjected to more leaching and less evaporation, thus salts concentrate less.

In most cane-growing districts, primary salting affects soils in small areas which adjoin tidal areas. Secondary salinity occurs in the Burdekin, Bundaberg, Isis, Maryborough and Mareeba-Dimbulah irrigation areas.

How does salinity affect plant growth?

As soil salinity increases, soil moisture becomes less available to plant roots because plants rely largely on osmotic forces to move water from soil into roots. In other words, in a non-saline soil, the higher sugar and nutrient level (solutes) in root tissue tends to absorb fresh soil water.

As soil water becomes more saline, the difference in osmotic pressure between roots and soils decreases or may even reverse. Less water is then able to enter roots.

Salinity therefore induces water stress over and above that caused by normal drying of the soil. This stress is shown in saline areas by premature wilting and scorching of leaves, restrictions in growth and, in severe cases, plant death.

Ratoon cane is more susceptible to yield loss from salinity than plant cane because induced moisture stress affects the development of ratoon shoots and reduces growth of individual stalks. Kingston (1993) and Nelson and Ham (2000) found yield losses of 16 per cent and 14 per cent respectively for every one unit increase in the electrical conductivity of the saturated extract.

Sugarcane is regarded as a relatively salt-sensitive plant, but there are varietal differences in salt tolerance.

Sugar produced from sugarcane grown on saline soils has a high ash content. The ash affects recovery of raw sugar in mills and adds to the cost of refining sugar. Ash content rises with salinity because the plant absorbs more minerals from the soil, especially potassium, in an attempt to balance the higher salinity of soil water.

Measurement of soil salinity

Soil salinity is measured in the laboratory by measuring the electrical conductivity (EC) of a water extract. The extract may be 1:5 soil:water extract ($EC_{1:5}$) or a saturated extract (EC_e). Test results can be converted from one to the other if the texture or clay content of the soil is known **(Table 1)**. Electromagnetic Induction Meters can be used to measure soil salinity in the field (**Figure 1**).

Table 1: Approximate conversion factors between electrical conductivity of a 1:5 soil:water extract ($EC_{1:5}$) and a saturated extract (EC_e).

Texture	Clay content (%)	To convert $EC_{1.5}$ to ECe multiply by
Sand, loamy sand, clayey sand	< 10	22.7
Sandy loam, fine sandy loam, light sandy clay loam	10–20	13.8
Loam, fine sandy loam, silt loam, sandy clay loam	20–30	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay	30–45	8.6
Medium clay	45–55	7.5
Heavy clay	> 55	5.8

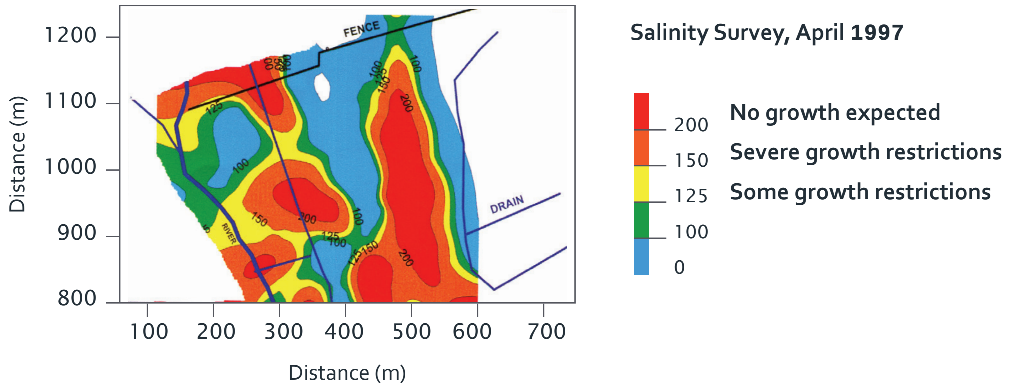


Figure 1: Salinity survey compiled from readings taken with EM38 equipment.

Management of saline soils

Management of soil salinity is important to ensure long-term production on land being developed where salinity is a potential problem. As well, the area of irrigated cane is increasing. Technology and expertise is now available to recognise areas where salinity is likely to prevent sustainable economic production and cause land degradation. Avoiding development of these areas for cropping should be the first step in future management of salinity.

In existing saline areas, or where only a slight potential hazard is predicted, all management efforts should be directed towards leaching salt from the root zone while minimising the amount of deep drainage that contributes to watertable rise. There is no single input that will achieve this objective. The most important factor is an efficient irrigation program that supplies only crop requirements plus a small amount of water to allow for leaching. Irrigation scheduling is the best way to achieve this. In most cropped areas, some form of sub-surface drainage or groundwater pumping will be required to prevent the rise of watertables into the root zone.

Bare fallows in the wet season should be avoided to assist with deep drainage control. Where surface and sub-surface drainage have been improved, trash retention will reduce evaporation from the soil surface.

Cane varieties have a wide range of salinity tolerance characteristics. Vigorous varieties tend to be the most tolerant of saline conditions. The choice of a tolerant variety will reduce the impact of salinity but this should be regarded only as a measure to buy time for more permanent management inputs to take effect.

The high cost of sub-surface drainage will prevent its use in non-cropped saline areas. Reclamation of these areas will rely on improved drainage on upslope cropped land and/or partial revegetation of non-cropped areas with suitable trees.

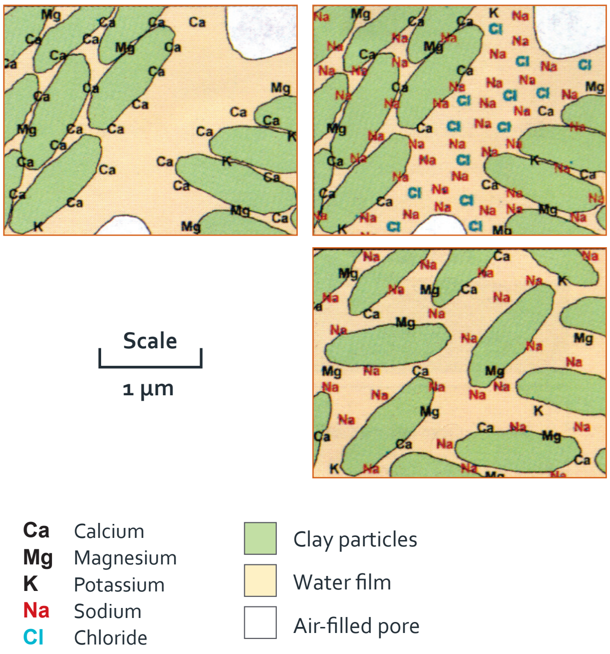
Research in Western Australia has shown that tree planting alone is unlikely to lower watertables and control salinity unless 35 to 45 per cent of the affected landscape is revegetated.

Some growers have used gypsum in an attempt to manage soil salinity in cane fields. Experience has shown that gypsum generally causes greater crop losses in the shorter term because as gypsum dissolves it adds to the salt load in the soil. Thus, gypsum cannot make a useful short-term contribution to improved soil structure and drainage if the seepage or shallow watertable is not controlled. A saline area should be drained, and then gypsum may be needed if the soil is sodic.

Sodic soils

Sodic soils occur when sodium represents more than 6 per cent of the elements attached to clay particles. Sodic soils may or may not be saline. Saline soils are usually also sodic.

Sodicity affects soil structure and therefore water infiltration and water-holding ability. The effect of salinity and sodicity on clay aggregations and soil structure is shown in **Figure 2**.



Top left: Non-saline, non-sodic soil. Clay is aggregated. Air-filled pores.

Top right: Saline sodic soil. Clay is aggregated. Air-filled pores. High salt content.

Bottom right: Non-saline sodic soil. Clay is dispersed. No air-filled pores.

Figure 2: Salinity and sodicity influence aggregation of clay particles at the microscopic scale.

Where do sodic soils occur?

Sodic soils have usually formed where soils with high concentrations of sodium salts were leached over time, removing the salt, but leaving a high proportion of sodium attached to the clay. The original source of salt in naturally sodic soils was from parent materials with high sodium contents, previous inundation by sea water, or salt spray from the sea in areas close to the coast.

Sodic soils have also formed under the influence of irrigation water with a high sodicity hazard. The higher the electrical conductivity (EC), sodium adsorption ratio (SAR) and residual alkali (RA) concentration of the irrigation water, the greater its sodicity hazard. If low salinity water is subsequently used to leach the soil, a high proportion of sodium remains attached to the clay.

Sodic soils occur in most cane-growing districts **(Table 2)**. In the Burdekin Haughton Water Supply Scheme Area (BHWSS), Mackay, Proserpine and the Mareeba-Dimbulah Irrigation Area (MDIA), soil mapping by the Queensland Government has identified sodic soils, and the maps and accompanying soil descriptions are useful tools.

Table 2: Approximate areas (per cent) of sodic soils in cane-growing regions (Ham, 2005).

Region	Area (per cent) of sodic soil
Southern	10
Mackay	24
Proserpine	15
Burdekin	15
Mareeba	10

Characteristics of sodic soils

The most common forms of sodic soils have hard-setting, fine, sandy loam to clay loam topsoils over medium to heavy clay subsoils of poor structure and drainage. These types of soils are commonly referred to as sodic duplex soils in the BHWSS and MDIA, and solodics or soloths in the Southern and Central districts.

Not all sodic soils have this type of profile, and other soils, such as alluvial loams or deep clays, may also be sodic.

Sodic layers that occur deeper than 600 mm in the profile generally do not restrict cane growth, but do reduce drainage through the soil profile.

Sodic soils may be any colour. They tend to be boggy when wet, and sodic topsoils turn to blocks or dust when cultivated.

Sodic soils support very little timber and grass, even in the virgin state. In the Burdekin area, virgin sodic soils are usually associated with a stand of beefwood *Grevillia striata* and/or Rhodes grass *Chloris* spp. Only Rhodes and couch *Cynodon* spp. grasses flourish in sodic patches in cultivated areas.

Virgin sodic soils in the Bundaberg/Maryborough area support a mixed community of stunted *Eucalyptus* spp., a marked proportion of tea tree/broad leaved paperbark *Melaleuca quinquenervia*, swamp mahogany/swamp box *Lophostemon suaveolens* and poverty grass *Eremochloa bimaculata*.

Measurement of sodicity

Sodicity is measured in laboratory soil analyses. It is calculated as the ratio of sodium to all elements with positive charge on the clay (calcium, magnesium, sodium, potassium and aluminium). This ratio is called the exchangeable sodium percentage (ESP). A soil is generally regarded as sodic when the ESP is greater than 6 per cent (less on light textured soils).

How does sodicity reduce yield?

Trial work in the Burdekin (Nelson and Ham, 1998) showed that cane yield decreased by 2.4 t/ha for every one per cent increase in subsoil ESP. Earlier work in Mackay (Spalding, 1993) had demonstrated a loss of 1.5 t/ha for each one per cent increase in ESP. The difference in yield loss was attributed to the Burdekin having a higher yield potential of 179 t/ha at ESP 0, compared to Mackay with 100 t/ha (**Figure 3**). The work by Spalding in Mackay on a strongly sodic soil showed that a 20 per cent yield loss had occurred up to ESP = 15; yield was halved at ESP = 33; and cane growth had failed completely by ESP = 66. This result was backed up by the later work in the Burdekin.

Large amounts of sodium attached to clay, in the absence of high concentrations of soluble salts, are not directly toxic to the cane plant. Instead, the effect is through deterioration of soil structure. High levels of ESP coupled with low EC cause clay particles to disperse when the soil is wet.

Clay dispersion results in sealing and crusting in surface soils, and dense subsoil clays which resist penetration by roots and water. Even if water does penetrate the surface it is held strongly in the very small pores formed in the dispersed soil. It is difficult for roots to withdraw this water.

The end result of sodicity is similar to that of salinity – water stress. Both water infiltration and Plant Available Water (PAW) storage in the soil are reduced. When a sodic soil is wet, the clay is dispersed and has a very low load-bearing capacity. When dry, sodic soils set very hard. They are poorly structured and when cultivated with a ripper tine, the soil breaks into large, hard clods.

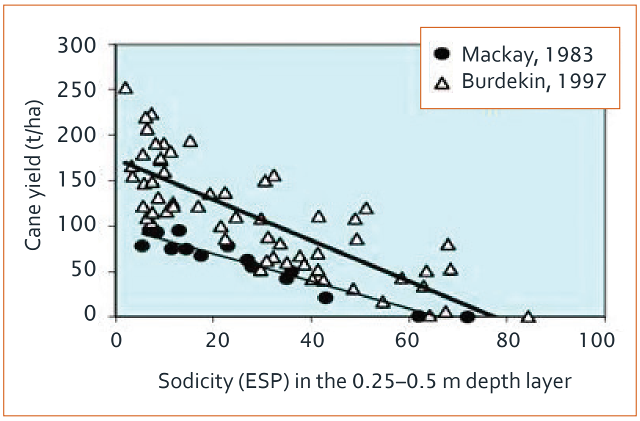


Figure 3: Relationship between cane yield and sodicity (ESP) in the 0.25–0.5 m depth layer at Mackay and Burdekin (Ham, 2005).

Management of sodic soils

The main goal in managing sodic soils is to reduce the degree of sodicity. However, it is difficult and rarely economical to make soils completely non-sodic, so other management practices also have an important role.

To reduce the degree of sodicity, a calcium source must be added and leached through the soil. As it leaches, the calcium replaces exchangeable sodium, and the sodium is leached down the profile. The greater the extent of replacement of sodium by calcium, and the deeper the sodium is leached, the better the results. Leaching is particularly important when the soil is also saline. If a high watertable is present, it must be lowered by sub-surface drainage or groundwater pumping to avoid the addition of sodium to the soil from the groundwater.

The best and most economical source of calcium is usually gypsum (calcium sulfate). Gypsum is soluble enough to be effective in replacing sodium, but not so soluble that it creates a salinity problem in its own right unless the soil is already saline. Lime is much less soluble than gypsum, especially at high soil pH. Lime may be an effective ameliorant in acid sodic soils, but not in soils with pH greater than 7. On sodic soils, gypsum normally has a positive cost-benefit ratio at rates of approximately 10 t/ha per crop cycle. Particularly bad patches can be marked out and treated with higher rates. Lower rates should be applied to saline sodic soils, as the gypsum adds to the salt in the soil. At a rate of 1 t/ha, gypsum supplies the sulfur needs of the crop for approximately five years.

Ripping has a very short-term effect in sodic soils because the cultivated soil collapses when wet. Ripping should be accompanied by high rates of gypsum application.

Mill mud and ash added at high rates also improve production on sodic soils. In some cases it is economic to remove sodic soil to headlands or roads and replace it with non-sodic soil.

Retention of trash (incorporated or left as a blanket) improves the permeability and water-holding capacity of sodic soils. A trash blanket:

- Slows the rate of flow along furrows, thereby increasing infiltration
- Reduces losses by evaporation and thereby increases the amount of water available for plant uptake and leaching
- Holds plant available water itself.

The behaviour of sodic soils also depends on the quality of irrigation water and the way it is applied. Irrigation water should be analysed to determine its sodicity hazard. Clay dispersion and associated problems may be prevented by irrigating with slightly saline water. The optimum level of salinity (around 0.8 dS/m) can sometimes be achieved by blending water from different sources.

Infiltration of water into sodic soils can be improved by having low slopes and wide, flat furrows. Otherwise, sodic soils should be irrigated more frequently than non-sodic soils. A trial by Gary Ham (2005) found substantial yield increases were possible when irrigation intervals were reduced from nine to 14 days (the standard grower practice) to six to seven days. This effect was more evident in ratoons than plant cane (**Figure 4**).

More vigorous varieties are generally the best performers on sodic soils.

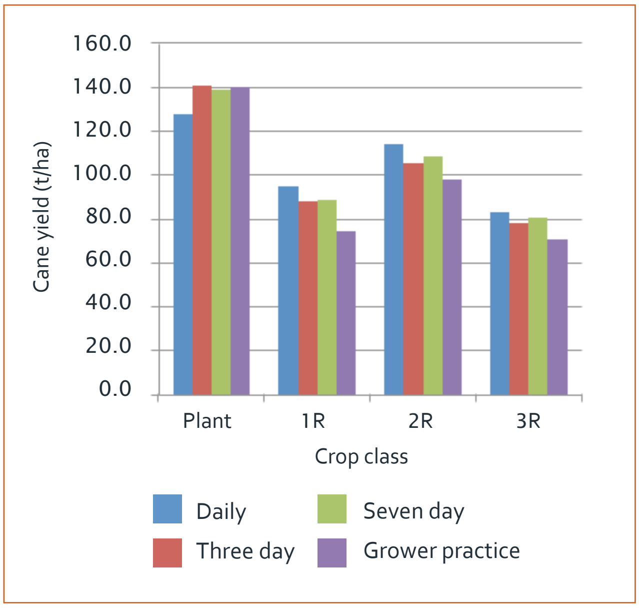


Figure 4: Crop yields in response to irrigation frequency (Ham, 2005).

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Irrigation systems

Selection of a suitable irrigation system depends on many factors. These include the availability and cost of water, water quality, soil type and field slope. The availability, cost and labour requirements of equipment and the expertise needed to operate it must also be considered.

Furrow irrigation

Furrow irrigation is the most widely used irrigation system for sugarcane in Queensland. It has low equipment costs and is simple to operate. It is suitable for land with up to three per cent slope although greater slopes have been used. However, application efficiency with furrow irrigation is very variable, ranging from 30 per cent to 90 per cent. The Watercheck project, conducted by BSES, showed that the efficiency of furrow irrigation can be improved significantly through increased management.

At the top end of a field, water is introduced to the furrows from open channels, a gated pipe or plastic fluming. The irrigation is stopped when the water reaches the bottom end of the field. In some situations the irrigation may be allowed to continue to allow more water to infiltrate into the soil. Run-off water is removed via tail drains or collected in on-farm storages for recycling.

End banking, a technique which produces no tail water, is sometimes used on land with little slope. To carry this out, the lower 40 m to 80 m of the field is graded to minimal or zero slope and a bank is formed at the end of the furrows. Water is held by this bank of soil and then has time to enter the soil. The system is also used widely where poor water penetration is a problem and where availability is limited.

In conventionally planted young plant cane, the cane drill can be used as the water furrow. When cane is planted into dry soil, light irrigation can be used to encourage germination. To achieve light irrigation, the bottom of the drill is compacted with a heavy press wheel. For post-planting irrigation over the row, no more than 60 mm of soil cover over the cane sett is generally used. On heavy soils with waterlogging problems, less than 20 mm of soil cover should be used.

Post-planting irrigation is particularly useful when planting into cloddy soils. Irrigation water disperses the soil clods and removes air spaces from around the cane sett and ensures good contact with setts.

When the plant crop is between three and six months old, a hill measuring 150 mm to 250 mm high is formed in the cane row (hilling up) and furrows are formed between the rows. From this point, the cane will be watered down the furrow. Soil in the hill will settle to make a final hill height of 100 mm to 200 mm.

Where cane is planted into preformed beds, irrigation is always down the furrow. For this reason good water penetration and soakage is needed to ensure that water reaches the sett. Controlled traffic systems with wide beds and single rows can present problems with germination and crop growth if there is poor soakage into the hills.

Above: Furrow irrigation.

Slope and furrow length

Furrow irrigation systems are rarely designed with slopes greater than three per cent. Slopes of less than one per cent are most often used. For example, in the Burdekin district, most growers prefer slopes between 0.06 per cent and 0.3 per cent. In practice, the natural fall of the land and the cost of earthworks determine the final slope. Design specifications for furrow irrigation developed by the United States Soil Conservation Service are shown in **Table 1**.

Table 1: Optimum furrow slope and cross slope.

Furrow slope %	Maximum cross slope
0.05 to 0.15	Twice the furrow slope
0.15 to 0.3	Not greater than 0.3%
More than 0.3	Not greater than the furrow slope

Attention to cross slope is most important on sandy soils and cracking clay soils where water can easily 'break through' the hilled rows. On cracking clay soils, cracks may extend from one furrow to the next and allow water movement across the furrows.

On less permeable soils where the hilled rows can contain water within the furrows more effectively, steeper cross slopes are sometimes used. Where the furrow grade is 0.1 per cent or less, cross slopes more than three times the furrow grade may be used.

Varying slopes can be used down the length of the furrow to reduce the cost of earthworks. Steeper slopes at the top end of the furrows will reduce the problem of excessive water intake by the soil near the irrigation outlets. Where water penetrates poorly, slopes as low as 0.06 per cent are often used to provide a greater length of time for water to enter the soil.

Row lengths vary from less than 25 m to over 1000 m. Preferred row lengths in the Burdekin district are between 400 m and 800 m, although in the Burdekin Haughton Water Supply Scheme area (BHWSS – formerly Burdekin River Irrigation Area) they commonly exceed 1000 m. Furrow lengths in other centres such as Bundaberg are usually 200 m to 400 m.

Low water-use efficiencies and excessive deep percolation losses may result from the use of very long furrows (see **Chapter 5**). In general, as furrow length increases the slope should be increased. Waterlogging problems are likely where long rows and low slopes are used.

Furrow shape and flow rates

Where water penetration is a problem, wide flat interspaces and small hills provide a greater surface area and help to improve penetration. For irrigation of more permeable soil, steeper slopes (greater than 0.5 per cent) and shorter row lengths (100 m to 300 m) are recommended.

To minimise deep percolation losses, large hills in the cane row (up to 300 mm) and V-shaped furrows are used. The higher hill allows a greater volume of water to flow faster in the furrow. The V-shaped furrow reduces the soil surface area in contact with the water and the compaction caused when the V-furrow is formed also helps to reduce drainage losses.

Above: Large hills and narrow interspaces limit water penetration (permeable soils).

Above: Small hills and broad interspaces maximise water intake (less permeable soils).

V-shaped furrows can be achieved with the use of modified hill-up boards. In one pass, the hill for the row and the correct furrow shape can be made. Variable boards are available for farms with a variety of soils and slopes.

Varying the flow rate down each furrow can also alter water penetration and the total volume used. Hard-setting and other low permeability soils (e.g. sodic soils) will need a very low flow rate whereas some soils may need high flow rates (2.5–3.0 L/s per row). This flow rate again will be dependent on slope, infiltration and length of run.

Infiltration

Water infiltrates the fastest into dry soil. For example, on a moderately permeable soil an initial infiltration rate of 200 mm per hour may drop to a steady 8 mm per hour.

Without corrective measures, some alluvial soils in the Burdekin district and gleyed podzolic (grey forest) soils in the Bundaberg district will allow less than 50 mm of water to infiltrate in six hours. After the initial wetting, infiltration rates may drop to less than 2 mm per hour. The factors causing such poor penetration are water with low salinity, a high sodicity hazard, or low calcium and low clay content in the soil.

Furrow irrigation causes a sorting of soil particles into a compact layer, which reduces water penetration. This layer can be broken up by cultivation until the crop is at the 'out-of-hand' stage of growth.

Labour requirements

Labour requirements are reduced by using long irrigation runs and by ensuring that water in all furrows reaches the end of the field at about the same time. Two other ways are correct land levelling and use of a timer switch for pump shutdown.

On a well-designed farm, with tail-water recycling, one person can readily manage 400 ha of full-time irrigation. If other farm labour requirements are to be carried out, one person should be able to manage over 150 ha of sugarcane.

Picking up and relaying the irrigation pipe or fluming with each cultivation or fertilising operation is the greatest labour requirement associated with furrow irrigation. Use of a green cane trash blanket or other reduced cultivation technique avoids this work.

Irrigating a trash blanket

Furrow irrigation is possible where green cane trash blanketing is practised. During the irrigation of young cane, water passes under the trash without disturbing it. The trash blanket reduces evaporation from the soil compared to a burnt cane system, particularly during the early stages of the crop. This normally allows a saving of two irrigations, so irrigation schedules should be modified to ensure that the crop is not watered excessively.

Also, the trash blanket slows the rate of water movement along the furrows and provides longer irrigation times. This is most beneficial where poor water infiltration is a problem. If it's not a problem, irrigation inflow rates should be increased to minimise the risk of waterlogging.

On heavier clay soils that are prone to waterlogging, other management practices may need to be investigated. Splitting the trash with a coulter or raking trash from alternate rows and then watering down the raked row are other practices that have been implemented in conjunction with increased inflow rates to assist with irrigation.

Where excessive infiltration occurs on heavy soils with conventional cultivation, trash blanketing may still be an option. Because the soil has not been cultivated, total water infiltration may not increase.

With trash blanketing, correct furrow slope, cross fall and hill size in the cane row become more critical because trash slows the flow of water and results in deeper water in the furrow. Furrow shape may need to be adjusted for green cane trash blanketing. This change must occur in the plant crop.

Where cross slope exceeds the furrow slope, hill size in the row may have to be increased to contain the water within the furrows. This is most important at the top end of the field.

For trash blanketing on a furrow slope of less than 0.1 per cent, cross slope should be close to zero. Where there is no cross slope, furrow irrigation has been used successfully on clay soils with a slope of 0.06 per cent.

Where cross slope is high, avoid damage to the hills from harvesting equipment. This is critical near the water outlets where haul-out vehicles will be turning. Provide wide headlands so that drivers do not need to turn in the field. If cost allows, use a greater slope just below the water outlets.

Surge irrigation

Surge or pulse irrigation is used to provide more uniform soil wetting down the length of the furrow. With surge irrigation, two sets of furrows are watered intermittently.

Water is automatically switched from one set to the other at increasing frequencies using a butterfly valve or ball valve controlled by a programmed timer.

At the end of each irrigation pulse, the soil has time to consolidate, and sediment in the water is allowed to settle. This reduces the infiltration rate for the next irrigation pulse, which then advances more rapidly over the previously wetted soil. Surge irrigation reduces high water intake at the top end of the field, a common problem with furrow irrigation.

Alternate furrow irrigation

With alternate furrow irrigation, water is applied to every other furrow. The benefits of alternate furrow irrigation are not well understood, but it is thought that water savings may be possible with this technique.

On self-mulching clay soils, there are no advantages with alternate furrow irrigation because of the large amount of lateral water movement. On soils with less sideways movement of irrigation water, there may be some water savings with alternate furrow irrigation. However, more frequent irrigation schedules would be necessary because less of the soil is wetted at each irrigation.

Costs

Capital costs will vary according to terrain and the source of irrigation water. A detailed costing should be sought before commencing any works.

Overhead irrigation

Overhead irrigation systems include low-pressure systems, such as pivots and lateral moves, and high-pressure water cannons. Correctly set up irrigators can be used on many soil types and provide uniform water distribution under most conditions. Water application efficiencies over 75 per cent can be obtained with good management.

With overhead irrigation systems, it is important to choose the correct pipe size for main and sub-main lines. Larger pipes will cost more initially but will lower pumping costs through reduced friction losses.

When making this decision, estimate the expected annual water requirements, then determine the savings in operating costs with larger diameter pipes. Compare this saving with the extra capital cost of larger pipe.

As a guide for smaller spray irrigation systems, a pressure loss of one to two metres per 100 m of pipe should be allowed.

High pressure systems

Water cannons/Travelling guns

Water cannons (also known as travelling guns) operate at high pressures (up to 600 kPa) and require the provision of regularly spaced tow paths. Because tow path spacing is fixed, uneven water distribution occurs if changing wind conditions prevent overlap of water application. Also, tow paths reduce the area available for crop production.

Application rates published for most travelling gun irrigators range from 5 mm to 13 mm per hour (mm/h) over 87.5 per cent of the wetted diameter in full circle application. Field tests carried out by the Water Resources Commission in light winds showed that precipitation on 70 per cent of the wetted areas was reasonably uniform. Application rates varied from 15 to 26 mm/h with an average of 16 mm/h for full circle operation. On a 300° arc (normal operation) the average was 17 mm/h.

However, prevailing winds parallel to the tow path reduced the effectively watered area and increased application rates to 20 to 34 mm/h. Such application rates exceed infiltration rates of soils with a fine texture and/or a tendency to seal. Run-off is likely where application exceeds 15 mm/h.

Excessive winds cause major changes to application rates. **Figure 1** shows that a crosswind caused 80 mm average on one side of the tow path and 40 mm on the other.

Water cannons with a capacity over 40 litres per second (L/s) are available. Such machines are capable of irrigating 5.9 ha on a 600 m run. Typical irrigation runs are 200 m to 400 m long.

Above: Water cannon.

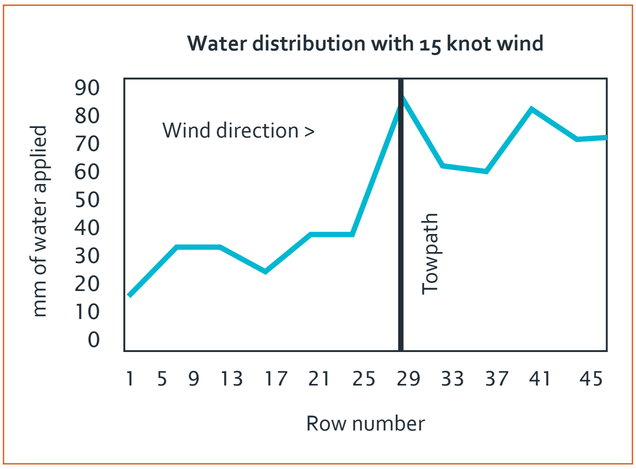


Figure 1: Impact of wind on uniformity of water distribution.

Drive mechanisms

Water cannons are driven hydraulically using either a turbine, piston or bellows drive. Piston and bellows drives discharge the water used in the drive mechanism.

While turbine drives do not 'waste' water by discharging it, they do produce more head loss as water passes through the turbine.

Tow paths

The spacing and direction of tow paths should take into account prevailing winds. Jensen (in NCEA, 2006) recommends the following lane spacings.

Table 2: Recommended lane spacing distances for different wind speeds.

Wind speed (m/s)	Lane spacing (% of wetted diameter)
0	80
< 2.2 (8 km/h)	70
2.2–4.4	60
> 4.4 (16 km/h)	50

Typically, tow paths in sugarcane are spaced 80 m to 90 m apart. They should be oriented, where possible, across rather than parallel to prevailing winds.

Tow paths should not be used as drains. Keeping them dry around the water cannon during irrigation will lessen tracking problems.

Operation

Soft hose water cannons

The machine is towed to a hydrant halfway along the length of the tow path. After connecting the hose, the irrigator is towed to the end of the field and the hose allowed to unwind. At the end of the field, the machine is turned to face back towards the hydrant and the cable is pulled out to the other end of the field.

The irrigator then travels the length of the tow path pulling the hose behind it. On reaching the other end the hose is emptied of water and wound onto the reel. The machine is then moved to the next tow path. To avoid tracking problems, maintain the tow path in good condition.

On heavy soils, the hose may ‘bulldoze’ soil as it is pulled along. Eventually, the hose may become ‘bogged’ and stop the irrigator. Hard hose water cannons don’t have this problem.

The flexible hose is prone to damage when dragged over sharp objects such as stones. The normal life expectancy of these hoses is 10 years.

Hard hose water cannons

With hard hose water cannons, the hose-winding mechanism remains on the headland and only the water gun or carriage travels the tow path. The hose is used to pull the carriage towards the reel. As the hose is pulled in a straight line instead of being dragged in a loop, it is less prone to damage, particularly on stony ground. However, a longer hard hose may be required because run length is limited to the length of hose.

At the end of each irrigation run the hose is already wound onto the reel. This makes shifting hard hose machines easier than the soft hose machines, and growers who have used both types say that shift times can be cut by 25 to 50 per cent. As soft hose machines are capable of run lengths of twice their hose length, this time saving will be realised only where the block length does not exceed the hard hose length. The most common hard hose lengths are 300 m and 320 m but lengths up to 400 m are available. Hard hose irrigators are particularly useful on short runs when only part of the hose needs to be extended.

Hard hose water cannons cost more to buy than soft hose cannons. Operating costs are also increased because higher operating pressure is needed to overcome head loss due to friction in the hard hose.

Application rates can be varied by:

- changing pressure
- changing the nozzle size
- changing speed.

Water cannons operate best on straight runs. For operation in contoured fields, a series of pegs is used to guide the tow cable. Because the hose can be laid along a curved headland the hard hose system is easier to use than the soft hose system where the farm has been contoured.

Capacity permitting, irrigation is best carried out at night to take advantage of still conditions and cheaper electricity. For continuous operation, run times should be 11 hours, 23 hours or 47 hours. Allowing one hour shifting, this provides for two runs per day, one run per day or one run every two days respectively. The Economic Evaluation of Irrigation practices report (Sinclair Knight Merz, 1996) revealed that it was more profitable to irrigate at night only on the low water-holding capacity soils.

Costs

Machinery and installation costs will vary according to farm size, shape and topography, plus the expected irrigation requirements. The high pressure required at the nozzle (around 500 kPa) raises operating costs.

In drier districts or seasons, one irrigator may not be sufficient during peak demand.

Table 3: Typical application rates (mm) for water winch and hard hose guns.

Nozzle diameter (mm)	Pressure at sprinkler (m of head)	Flow rate (L/s)	Travel speed	
			40 m/h	20 m/h
41	50	40	38	76
	60	44	39	78
38	50	35	34	68
	60	39	36	72
36	50	30	31	62
	60	34	32	64
33	50	26	28	56
	60	29	29	58
30	50	22	25	50
	60	25	26	52

Hand-shift sprinklers

Hand-shift sprinklers are used mostly for strategic irrigation of young plant and young ratoon cane. They are particularly useful where water supplies are limited.

Quick-coupled aluminium pipe is available in 50, 75, 100 and 125 mm diameters. Standard pipe lengths are 7.5 m and 9.0 m.

The main disadvantage of a portable sprinkler is the high labour requirement, which makes their use in tall crops in Australia impractical. Where sprinkler risers are mounted in the pipe, each sprinkler set will irrigate 12 to 14 rows. This requires frequent shifting of irrigation pipe.

The use of flexible hoses attached to the sprinkler allows the sprinklers to be shifted three times before moving the pipe. Maximum application rate should take account of the intake capacity of the soil and the potential for soil erosion.

Spacing

For winds up to 10 km per hour, sprinkler spacing along the pipe should be half the wetted diameter. The distance between the spray lines should be no more than 60 per cent of the wetted diameter. If winds over 10 km per hour are common, spacings at right angles to the wind should be reduced to 30 to 40 per cent of wetted diameter.

Operation

Operating pressures at the nozzle range from 200 kPa to 500 kPa. Both double jet and single jet impact sprinklers are available. Single jet nozzles perform better under windy conditions and are most commonly used.

Sprinklers should be operated at the higher end of their operating range (300 to 400 kPa) to allow the best break-up of the water stream. At low pressures, the stream will not break up, resulting in soil splash and poorer water infiltration.

A nozzle pressure of 400 kPa will give a spray diameter up to 39 m depending on the nozzle orifice and its height.

Sprinklers should be operated across the slope or slightly downhill because running the spray line uphill has poor water distribution.

Table 4: Maximum application rates for sprinkler systems (from Benemi and Olfen, 1983).

Maximum allowable sprinkling rate (mm/h)								
Description of soil and profile conditions	0–5% slope		5–8% slope		8–12% slope		over 12% slope	
	With cover	Bare	With cover	Bare	With cover	Bare	With cover	Bare
Sandy soil, homogeneous profile to depth of 1.8 m	50	50	50	38	38	25	25	13
Sandy soil over heavier soil	45	38	32	25	25	18	18	10
Light sandy-loam soil, homogeneous profile to 1.8 m	45	25	32	20	25	15	18	10
Sandy-loam over heavier soil	32	18	25	13	18	10	13	8
Silty-loam, homogeneous profile to 1.8 m	25	13	20	10	15	8	10	5
Silty-loam soil cover heavier soil	15	8	13	7	10	4	8	3
Clay soil, silty clay-loam soil	5	4	4	3	3	2	3	2

Low-pressure systems

Lateral move and centre-pivot irrigators are precise irrigating methods. They use low pressure and have low labour requirements. Large areas can be irrigated very efficiently and application rates are easily varied by changing the speed of travel.

Both irrigators consist of a series of horizontal spans with irrigation sprinklers mounted on droppers. Each span is mounted on a tower; large diameter wheels, driven by electric motors, move the towers. Sensors in each tower keep the irrigation line straight.

Lateral move irrigators

Lateral (or linear) move irrigators move in a straight line down one or a number of fields and then water back over the ground just covered. Widths of up to 1.5 km can be used, but the maximum width is limited by the available water supply. Water is obtained either directly from open channels or through a flexible hose.

Capital costs are around $1250 to $3000 per hectare (Wigginton *et al.* 2011). The cost of pumping can also be quite high when the irrigator is fed from an open channel because diesel motors need to be used. Offsetting this are low labour requirements when the system is operated on a suitable layout. The system can be largely automated.

Above: Lateral move irrigator. *Photo courtesy of Steve Attard.*

Centre-pivot irrigators

Centre-pivot irrigators travel in a circle and can irrigate large areas (up to 1.6 km in diameter covering 200 ha). Most machines will cover 80 ha to 100 ha. They can operate continuously without attention because of the circular path.

The need for circular fields is a severe limitation for the system in the Australian sugarcane industry. Extra nozzles (end guns) can be used to fill in these areas, but the application efficiency of these nozzles is generally low and this can affect the efficiency of the whole machine.

As the length (radius) of the machine increases so does the amount of water that needs to be supplied to the outermost spans. This can cause problems with irrigation if the volume of water being applied at the end of the pivot is more than the infiltration rate of the soil.

Both fixed-pivot and mobile-pivot systems are available. Mobile-pivot systems, which can be towed from site to site, will irrigate up to 80 ha. Fixed-pivots will irrigate larger areas.

Irrigation spans vary from 40 m to 60 m in width. The shorter spans should be used on undulating country. The rate at which the towers advance is set by the outermost tower. If one tower becomes bogged or obstructed, irrigation will stop automatically. The irrigation towers easily make their own path across the cane rows. These systems are operational in the Atherton Tablelands area of North Queensland and in the Central district and Southern districts.

Above: Centre-pivot irrigator.

Boom irrigators

Boom or low-pressure travelling irrigators consist of a wheeled cart supporting a large irrigation boom. Water is supplied through a flexible hose up to 300 m long.

Like water cannons they need regularly spaced irrigation lanes from 60 m to 80 m apart depending on the boom length. Because boom irrigators operate at pressures as low as 70 kPa, operating costs are much lower than for water cannons which operate at higher pressures.

Since water is applied directly from the boom, these irrigators can be used effectively under windy conditions. Because operation times are less restricted by wind, two boom irrigators should be able to do the work of three water cannons.

Irrigation runs up to 600 m long, covering 4.8 ha, are possible. Application rates are varied with the ground speed. For example, the irrigation time for a 400 m run can be varied from five hours to 24 hours.

Above: Boom irrigator.

Drip irrigation

Drip irrigation allows small irrigations as frequently as daily (or even a number of times per day) to accurately supply crop needs. The system can be used to wet only the plant root zone and has the potential to water the crop evenly throughout each cane block. Other advantages include flexibility with fertiliser application and use with automation.

An essential part of the drip system is the filtration system, which must be adequate for the size of the system.
As drip irrigation is a very precise method, correct system design and management is critical. Poor design and a lack of backup have led to poor irrigation and low crop yields. This has resulted in overly long or infrequent irrigations or the tape being placed too deeply.

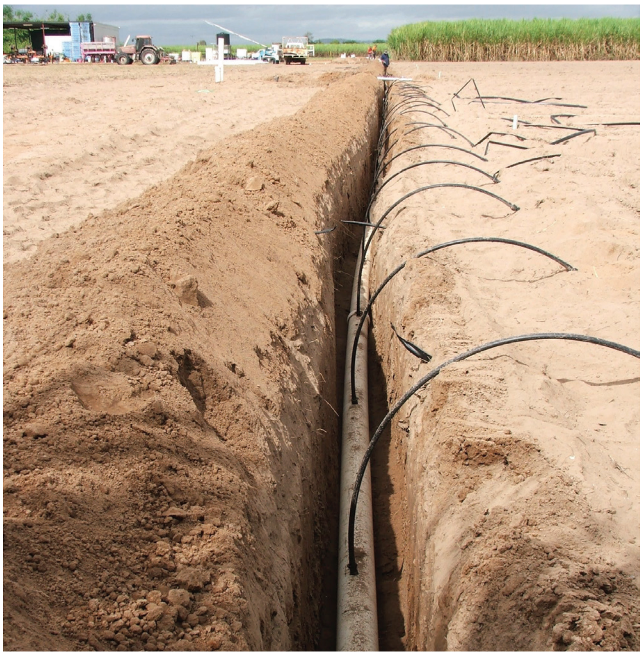
Description

Water is delivered to the plant root zone via thin-walled tubing with regularly spaced emitters. Modern emitters are pressure compensating and will deliver the same volume of water regardless of their distance from the pump.

Tape can be laid on the soil surface, but sub-surface systems are more common. The drip tubes (tapes) are connected to a mains line which in turn is connected to an outlet. At the other end of the drip tape, the tape is usually blocked off in surface installation or connected to a flushing main in sub-surface systems. Other additions include:

- air valves – purge air in system
- pressure-reducing valves (PRV) – reduce mains pressure and regulate at appropriate pressure
- pressure gauges – facilitate viewing of pressures in the systems
- filters – filter out algae, dirt and other contaminates in water supply
- flow meters – record flow rates and water usage.

Water is supplied at pressures from 40 kPa to 140 kPa, although a pressure of about 80 kPa to 100 kPa is recommended.



Above: Drip tape being installed. *Photo courtesy of Steve Attard.*

Sub-surface systems

In this system, the drip tape is usually placed in the soil before planting. However, if time is restricted, the crop can be planted and irrigated by an existing method for the first watering. The use of GPS guidance systems has made it much easier to place drip tape before planting and to then plant without the risk of damaging the tape. Some planters allow installation of the drip tape while planting, thereby ensuring constant depth settings in relation to cane setts.

The drip tape should be placed about 10 cm (4") below the planting depth. Tape placement should be a maximum of 25 to 30 cm (10–12") below level ground. Deeper placements will cause excessive leaching of irrigation water and unsatisfactory wetting of cane setts, particularly on sandy soils.

The aim with sub-surface tape is to maintain soil moisture in the root zone without significant drainage or wetting of the soil surface.

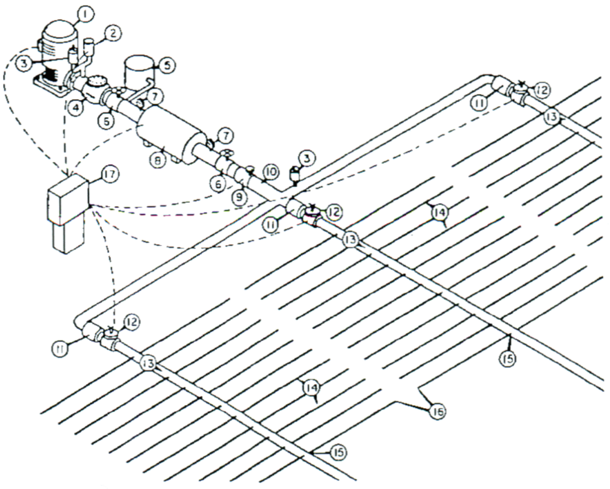
Surface systems

Drip tape is laid out with a tape layer near the 'out-of-hand' stage. The tape is laid either down the middle of the interspace or to one side of the crest of the row. In some cases, drip tape has been used every second row for cost savings and under low water availability. Generally, yields will be less than systems where every row is irrigated.

The tapes are connected to the mains (either at the top or middle of the block) via connectors. The flushing end is either tied in a knot or bent back and crimped with extra tape. The mainline is usually made of high-density hose such as Layflat® or Sunny Hose®.

Removal of surface tape is completed with a tape winder. The winder is usually attached to the back of the tractor and uses a hydraulic motor driven by the tractor. Stainless steel reels are made to suit block size and amount of tape.

Joining the tape for this process is generally done with small pieces of electrical conduit (5 cm long) which have been tapered at each end. A product similar to silicon is used for sealing. Electrical tape can be used for holding joins together for winding. The winding out for the following year is the reverse process.



1. Pump
2. Pressure relief valve
3. Air vents (at all high points)
4. Check valve
5. Fertiliser injector or tank
6. Mainline valve (gate or butterfly valve)
7. Pressure gauges
8. Filter
9. Flowmeter
10. Mainline
11. Submain secondary filter (only if required)
12. Field control valves (manual or automatic)
13. Submains
14. T-Tape Laterals
15. Lateral hook up
16. Drain/flush valves
17. System controller

Figure 2: Typical drip system layout.

Fertiliser application (fertigation)

Fertiliser can be applied via the tape throughout the year in a readily available form for the plant to use. In this way the crop can be supplied with small amounts of nutrient at frequent intervals rather than a large amount all at once.

Nitrogen and potassium can be supplied through the tape. It is generally recommended that phosphorus fertiliser be applied just before planting to allow time for it to become available for early root development. Most phosphorus is required early in the crop life so applying small amounts throughout the year is not necessary.

Solid fertilisers can be dissolved in water or use a range of liquid products suitable for fertigation systems. When applying different fertiliser products it is usually better not to mix them because of the danger of precipitates forming. If products are to be mixed, do a bucket test first – mix the different products in the same application ratio and see if the mix is compatible.

Technical-grade prilled urea or ammonia nitrate can be used to provide nitrogen. Potassium is best supplied as potassium sulfate rather than potassium chloride (muriate of potash) to reduce the risk of salts in the root zone.

Automation

Growers with numerous drip blocks have utilised the benefits of automation systems. Generally, hydraulic tubing is run from the block back to the pump shed where the automation system is located. Simple automation systems will irrigate blocks for predetermined times. More elaborate and expensive systems will also inject fertilisers and maintenance chemicals. Importantly, automation allows time for other jobs on the farm and for more frequent irrigation.

Filtration

Adequate filtration is essential because it removes algae, dirt, iron precipitates and other suspended solids from water. The filtration needs will depend on the area being irrigated and the quality of the water supply. Before installing drip irrigation, obtain a full water analysis (including iron) to determine any problems with the water supply. Apart from water quality parameters mentioned previously in this manual, iron is a major problem in some water supplies. Levels of iron up to 1 ppm are acceptable. Often associated with the iron are iron bacteria, which can also cause blockages.

Types of filters include sand, media and disc filters. Each differs in application and ability to remove sediment. If the water quality in the supply is variable, always ensure that the filtration system will cope easily with the worst scenario. Although filtration can be expensive, inadequate filtration will create ongoing maintenance and management problems that cost more in the long run.

Above: Disc filters for a drip irrigation system. *Photo courtesy of Steve Attard.*

Maintenance

Chlorination is needed to kill bacteria and algae associated with the water supply. It will reduce chances of any blockages caused by these organisms. Chlorine is added to the water supply in either a liquid or solid form.

Acid (in the form of hydrochloric acid) can be used to drop the pH of the water to an acceptable level for chlorine injection. Chlorine needs acidic conditions to work effectively. Larger amounts of acid can be used to bring iron precipitate back into the solution and results in further cleaning.

Flushing

Flushing of tapes and flushing mains is important to remove any sediment or precipitates. The high flow causes mixing of sediment which is flushed from the lines. Flushing can be used in conjunction with other maintenance procedures.

Costs

Costs depend on block layout, topography and water source. Although capital costs often exceed $4000/ha (Qureshi, 2001), well-maintained sub-surface systems can have a long lifespan. Ongoing costs include maintenance and pumping costs.

Summary of irrigation systems

Table 5: Summary of irrigation systems.

Irrigation system	Furrow	Water cannon	Hand-shift sprinkler	Lateral move	Centre-pivot	Boom	Drip
Capital cost	Low-medium	Medium	Medium-low	High	High	Medium	High
Labour	High	Medium	High	Low	Low	Medium	Medium
Management needs	Low	Medium	Low	Medium	Medium	Medium	High
Special requirements	Land levelling	Lanes	Nil	Lanes	Suitable slopes	Lanes	Maintenance filtration
Potential application efficiency	Medium-high	Medium	Medium	High	High	Medium	High
Limitations	Slope, hard-setting soils, permeable soils	Wind	Wind	Speed of operation	Speed of operation	Speed of operation	Water quality
Relative costs to apply 1 ML	Low	High	Medium	Medium	Medium	Medium	Low

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Irrigation scheduling

Correct irrigation scheduling aims to apply the correct amount of water at the correct frequency to produce the optimum yield.

The optimum frequency and amount of water will vary depending on the soil type and the crop growth stage. Different soil types store different amounts of Readily Available Water (RAW) – the water that plants can easily access. Crops that are actively growing with a full canopy will require more moisture than those that have been recently planted or are nearing maturity.

Water is lost from the soil by a combination of transpiration (water lost from the leaves) and evaporation from the soil surface. Taken together, evaporation and transpiration are known as crop evapotranspiration (ET) or crop water use. If the time that the soil depletes down to the refill point can be estimated in advance, then irrigation times can be planned and crop stress will be minimised. This is the basis of irrigation scheduling.

There are many available scheduling methods and their costs vary widely, chiefly depending on accuracy. Waiting for the crop to begin to show moisture stress or irrigating on a set cycle is inaccurate, and leads to lower yield and inefficient water use.

Soil water

The first step to accurate irrigation scheduling is determining the amount of RAW in the soil. RAW is the amount of water stored in the soil between the refill point and the full point. Ideally, scheduling should maintain the soil moisture between these points.

Research conducted by BSES determined the RAW content of a number of major soil types for the Burdekin, Central and Bundaberg districts **(Table 1)**.

Table 1: Storage capacities of RAW in the Burdekin, Central and Bundaberg districts.

Burdekin (measured)

Soil type/texture	Location	RAW in the root zone (mm)
Cracking clay (Barratta)	BHWSS area	90
Clay loam and silty clay loam	Delta/BHWSS area	80
Loam and silty loam	Delta	70
Sandy loam	Delta	60
Loamy sand	Delta	50
Loamy sand	Delta	30–40
Loamy sand	BHWSS area	40–90

Central (estimated)

Soil type	RAW in the root zone (mm)
Sand	20–30
Alluvial	50–70
Non-caltic brown	60–70
Podzolic	30–80
Solodic	50–60
Black earth/grey clay	60–70
Prairie	70–85
Krasnozem	60–70

Bundaberg (measured)

Soil type	Texture	RAW in the root zone (mm)
Alluvial	Clay loam	90
Red volcanic	Clay loam	90
Humic clay	Silty clay loam	70
Red earth	Sandy loam	60
Red podzolic	Sandy loam	60
Yellow podzolic	Fine sandy loam Sandy loam	60–70 40–50
Gleyed podzolic	Fine sandy loam Sandy loam	60–70 40–50
Black earth	Medium clay	50–60
Alluvial	Sand	40

Irrigation scheduling methods

Reference evapotranspiration rates and crop factors

This method of irrigation scheduling uses reference evapotranspiration (ET_o) rates and crop factors (K_c) to estimate crop water use. If the RAW of the soil or the amount of water applied in the last irrigation (for example, by an overhead irrigator) is known it is possible to estimate when the crop will next require irrigation.

Reference evapotranspiration rates are published by the Australian Bureau of Meteorology on its Water and the Land website (http://www.bom.gov.au/watl/index.shtml). Sugarcane crop factors have been calculated for different growth stages. Because these factors are not the same as those for Class A pans, take care not to confuse the numbers.

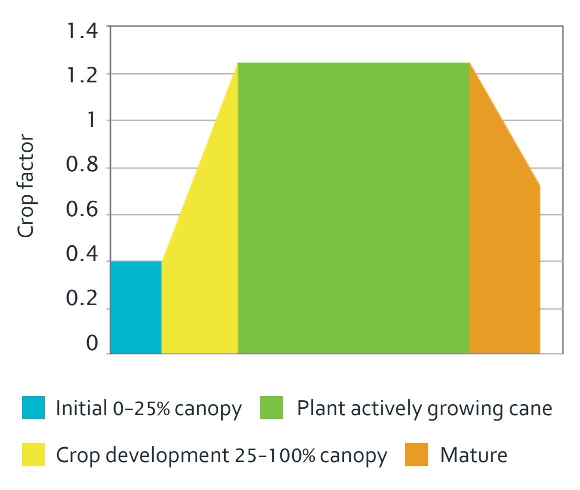

Figure 1: Crop factors for use with reference evapotranspiration.

Calculating crop water use using ET_o and crop factors – an example

To calculate crop water use from evapotranspiration and crop factors it is first necessary to obtain reference evapotranspiration figures from the Australian Bureau of Meteorology **(Table 2)**. These numbers can then be used with the crop factors in **Figure 1** to estimate the crop water use **(Table 3)**.

Table 2: Reference evapotranspiration from BOM.

Day	1	2	3	4	5	6	7
ET_o	5.2	4.9	3.6	5.0	5.0	4.5	4.6

Table 3: Crop water use (ET_c) for different crop stages.

Crop cover (%)	Crop factor (K_c)	Daily ET_o (mm) from BOM							Total crop water use for 7 days (mm)
		5.2	4.9	3.6	5	5	4.5	4.6	
10	0.40	2.08	1.96	1.44	2.00	2.00	1.80	1.84	13.12
75	1.00	5.20	4.90	3.60	5.00	5.00	4.50	4.60	32.80
100% actively growing	1.25	6.50	6.13	4.50	6.25	6.25	5.63	5.75	41.00
100% maturing	0.70	3.64	3.43	2.52	3.50	3.50	3.15	3.22	22.96

Once the crop water use has been estimated, the time to re-irrigate can be calculated. In this example, if the soil held 45 mm of RAW in the root zone, irrigation intervals would be:

- 3.5 weeks at 10 per cent cover (45 mm RAW ÷ 13 mm crop water use)
- 10 days at 75 per cent cover
- 1 week at 100 per cent cover and actively growing
- 2 weeks at 100 per cent cover and maturing.

Evaporation minipans

Evaporation minipans are a simple scheduling tool that can be used in furrow-irrigated systems where the soil profile is completely filled after each irrigation.

After irrigating, the minipan is filled with water. Evaporation occurs from the pan until a predetermined (via calibration) draw-down level is reached. Irrigation recommences and the minipan is filled with water again. The minipan should be calibrated for each soil type.

Left: Evaporation minipan.

Calibrating an evaporation minipan

The minipan is filled immediately after irrigation and daily crop growth rates are collected over the irrigation cycle. Generally, crop growth rates reach a maximum four to seven days after irrigation and then quickly drop off (**Figure 2**).

When the growth rates fall to 50 per cent of the maximum recorded in that irrigation cycle, the draw-down level in the minipan is noted. This becomes the minipan deficit for that soil type. The calibration procedure reinforces the concept that different soils have different levels of RAW.

Note: Minipan deficit figures are not a measurement of actual soil moisture deficits.

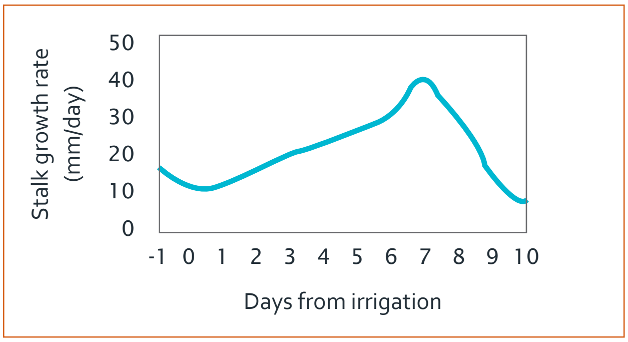

Figure 2: Typical crop growth rates after irrigation of an early plant Q96 crop.

Summary of minipan calibration procedure

- Mark out 25 stalks from adjacent drills about 10 m into the block of cane.
- Cane to be measured should have about 1 m of stalk growth (the canopy should be closed).
- Using marking tape, individually label each stalk.
- Record the height of each stalk to the top visible dewlap or collar. Do these three steps just before irrigating this section of cane.

Above: Measuring to the top visible dewlap.

- When irrigation ceases on the measured cane, fill up the minipan.
- Begin stalk measurements when the ground is firm enough to hold your weight.
- Record at roughly the same time each day.
- When growth rates fall to 50 per cent of maximum growth, record the draw-down on the minipan – this becomes the minipan deficit figure. For irrigation scheduling of a maturing crop, add 30 per cent to your minipan deficit, i.e. if the normal deficit is 75 mm, then the deficit for maturing cane would be 100 mm.

Some useful hints on evaporation minipans

- Daily readings are recommended for greater accuracy.
- Locate minipans in open locations, upwind of pumps and cylinders.
- Place the minipan on concrete blocks to allow circulation under the pan and to stop animals from drinking the water.
- Calibration is needed for only one to two irrigation cycles to set the minipan deficit.

Tensiometers

Tensiometers consist of a hollow tube joined to a ceramic tip at the base, and a vacuum gauge and reservoir at the top. Tensiometers measure the force that plants need to exert to obtain moisture from the soil. As the soil dries, water moves out into the soil from within the tensiometer through the ceramic tip. The loss of water creates a vacuum in the tensiometer and is recorded as a suction reading. The higher the suction reading, the drier the soil. Irrigation begins again when the tensiometer gauge reads a predetermined level **(Table 4)**. After irrigation or rainfall, water moves back through the ceramic tip and the vacuum is reduced in the tensiometer.

Above: Tensiometer installed in a field.

Tensiometers can also be calibrated to soil type with growth measurements in a similar way to minipans. During the calibration when the daily growth rate of cane falls to 50 per cent for full irrigation districts, and 30 per cent for supplementary irrigation districts of the maximum recorded, the tensiometer reading is taken. This reading is used to initiate irrigations from then on.

Table 4: Typical tensiometer deficits for a range of soil types.

Soil type	Deficit (kPa)
Cracking clay	60
Clay loam	50
Sandy loam	40
Sand	30
Sodic duplex	30-50

Some useful hints on tensiometers

- Tensiometers should be installed to a depth of 60 cm in the plant line, except in very sandy soils where they should be installed to a depth of 30 cm in the plant line.
- Tensiometers must be installed carefully and maintained regularly to ensure they do not run out of water.
- Two per site gives more accurate readings.
- Tensiometers are most useful in overhead and trickle irrigation.

Gypsum blocks

Electrodes are embedded in porous gypsum blocks placed in the soil at different depths. Soil water will reach an equilibrium with water in the gypsum blocks. The electrical resistance is measured and related to soil moisture as a tension. In a similar way to tensiometers, irrigation commences when a predetermined tension is reached. Gypsum blocks should last for several years under ideal conditions. However, under low pH or heavily leached conditions, they may deteriorate within three months.

Automatic soil moisture monitoring equipment

Automatic or real-time irrigation scheduling equipment is also available. Because these systems link soil moisture monitors to dataloggers, the results can be downloaded and viewed on a computer.

Time-domain reflectometry

Time-domain reflectometry (TDR) sends an electromagnetic pulse into the soil via stainless steel rods called waveguides. Soil moisture influences the speed of the electromagnetic wave: the drier the soil, the faster the wave.

TDR is primarily a research tool. SRA has used TDR for measuring soil moisture in pot trials.

Capacitance probes

Capacitance probes (e.g. EnviroSCAN, AquaSpy^{TM}) consist of an electronic probe that measures soil moisture content by detecting how easily an electric charge travels through the soil. They measure only a small area around the probe with most of the information gained from within a 5 cm radius.

The probe consists of several sensors that are placed at different depths within a sealed PVC tube. Normally, between six and eight sensors are required per probe. The probes are connected to a logger by cables. Readings are automatically taken by a logger at preset intervals which can range from once a minute to once a week.

The data can be downloaded directly from the logger in the field or sent via mobile phone or radio telemetry to a computer. The probes come with software that presents the moisture data graphically (**Figure 3**). It also allows the setting of full and refill points. These can be used to schedule irrigation times and amounts.

Above: EnviroSCAN probe installed in the field.

Above: EnviroSCAN logger installed in the field.

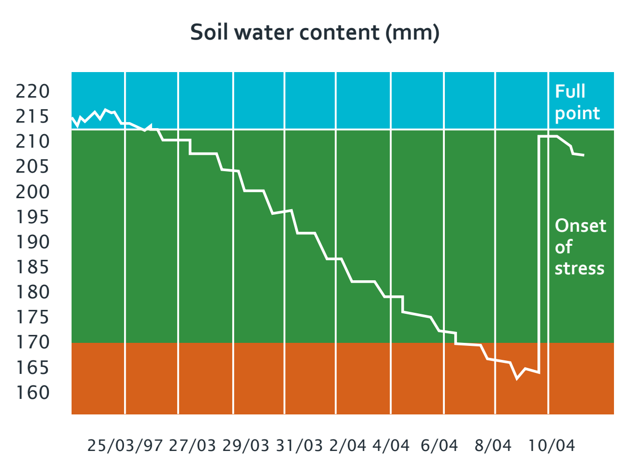

Figure 3: An example of an EnviroSCAN soil moisture graph.

References

Allen RG, Pereira LS, Raes D and Smith M. (1998). *Crop evapotranspiration – guidelines for computing crop water requirements.* FAO Irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome.

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Improving irrigation application efficiences

Irrigation application efficiency is the amount of irrigation water applied to the soil that is available for crop use. In other words, it is the proportion of the total irrigation water applied to the field that is stored in the soil as Readily Available Water (RAW).

For instance, if 1.0 ML/ha (or 100 mm) is applied to a sandy loam soil with a soil water deficit of 0.5 ML/ha (50 mm), the irrigation application efficiency is 50 per cent.

Maximum irrigation application efficiencies can be achieved by reducing losses of irrigation water. The four main irrigation losses are through:

- storage and transmission
- evaporation from the soil surface or from the leaves of the plant
- deep drainage
- run-off of tail-water.

Depending on the irrigation system, some losses will be more important than others.

Furrow irrigation

Freely draining alluvial soils

On freely draining alluvial soils such as those found in the Burdekin Delta, the main irrigation loss is through deep drainage. Deep drainage occurs when more water is applied to the soil than it can hold and the excess drains below the root zone (**Figure 1**).

There are some simple ways to reduce deep drainage losses. Changing furrow shape from a broad U shape to a narrow V (see **Chapter 4**), reducing cultivations, and compacting the base of the furrow will all help limit infiltration through the furrow base **(Table 1)**. Increasing inflow rates so that water moves faster down the furrow can also help reduce losses.

Trials showed that reducing water usage on very freely draining soils with these approaches did not reduce yield. This was because growers were still applying more than the RAW content of the soil at each irrigation.

Other more expensive options (e.g. reducing furrow length, **Table 2**) could also improve efficiencies on freely draining soils.

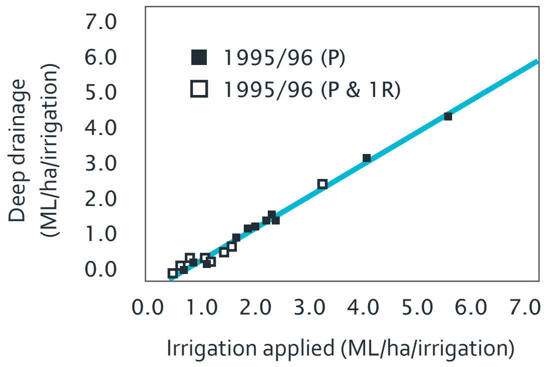

Figure 1: Deep drainage loss as a function of total water applied to alluvial soils in the Burdekin Delta. Assumes 0.1 ML/ha irrigation tail water loss.

Table 1: The effect of furrow shape and cultivation practices on irrigation water usage of sugarcane.

Tillage practice	Reduced cultivation		Conventional cultivation	
Furrow	Broad	Narrow	Broad	Narrow
Shape	U	V	U	V
Water usage (ML/ha/ irrigation)	1.97	1.32	3.18	2.19

Experiment was a plant crop on a sandy loam soil, with RAW content of 0.4 ML/ha. Inflow rate of irrigation water was 0.6 L/s. Reduced cultivation included one residual herbicide spray plus two cultivations after planting. Conventional cultivation was seven cultivations after planting.

Table 2: The effect of furrow length on furrow irrigation efficiencies of an alluvial soil. Application rate was 2.8 L/s (Raine and Bakker 1996).

Furrow length (m)	Water applied (ML/ha)	Application efficiency (%)
300	0.82	73
500	0.94	64
700	1.44	42

Surface-sealing soils

Some light-textured soils infiltrate water well while they are being cultivated, but seal after the last cultivation. After the last cultivation, these soils should be irrigated with low inflow rates. Wide U-shaped furrows are best on sealing soils to allow higher rates of infiltration.

In the longer term, a soil ameliorant, such as gypsum or lime (depending on the soil pH), should be used to 'open up' the soil surface. Take care not to apply excessive amounts of these soil ameliorants because over time, deep drainage problems may occur (i.e. the soil will become very freely draining).

The alternative to gypsum or lime is water with higher levels of salt which might be sourced from an underground bore. Again, take care not to use excessive amounts of salty water. Otherwise, deep drainage problems and salt accumulation in the root zone are likely to occur (for more information, see the **Water quality section on page 9**).

Green cane trash blanketing may improve the infiltration on surface-sealing soils because the advance rate of water will be slowed by the trash, allowing more time for infiltration. Organic matter will also be added to the soil by the trash blanket which, over time, also improves infiltration rates. Applying mill mud will also improve soil organic matter levels.

Cracking clay soils

On the cracking clay soils of the Burdekin Haughton Water Supply Scheme Area (and similar soils in other irrigation districts), the main irrigation loss has been shown to be from tail-water run-off. After cracking clay soils initially 'wet up', water drains though the soils only very slowly (less than 10 mm/day of deep drainage is common).

Therefore, if tail-water can be minimised, very high efficiencies can be achieved with furrow irrigation on cracking soils. **Table 3** shows that good efficiencies are possible with long furrow lengths on these heavy soils and that recycling tail-water markedly improves irrigation application efficiencies.

Table 3: The effect of furrow length and tail-water recycling on irrigation application efficiencies of a cracking clay soil. Application rate was 2.7 L/s (Raine and Bakker 1996).

Furrow length (m)	Water applied (ML/ha)	Application efficiency without recycling (%)	Application efficiency with recycling (%)
400	1.19	76	91
800	1.22	74	87
1200	1.23	73	85

Sodic soils

Much like cracking soils, sodic soils have very low rates of through drainage. Likewise, the main irrigation loss with sodic soils is from tail-water run-off. However, unlike cracking clays, they do not infiltrate water at high rates initially, and poor soakage is a common problem on sodic soils.To overcome poor soakage, keep inflow rates low and use a wide U-shaped furrow to maximise the area exposed to irrigation water. On alkaline sodic soils, gypsum should be applied either in the irrigation water or to the soil. On acid sodic soils, lime should be used. Green cane trash blanketing will also improve the soil structure of sodic soils (for more information, see the **Sodic soils section on page 18**).

Overhead irrigation

Overhead irrigation systems are used extensively in the Bundaberg and Central districts. They have the potential to be very water efficient because they can be managed to replace only the water that has been used by the crop (soil moisture deficit).

However, some inefficiencies may still occur, particularly with water winches, as water is blown by the wind outside of the cropped area. Wind can also cause uneven distribution of water applied by the water winch within the field. A strong crosswind will increase application rates downwind of the winch which may lead to losses from run-off and lower efficiencies. A strong crosswind will also decrease application rates upwind of the winch, leading to potential plant stress and loss of yield. Watering in calm conditions (most commonly at night) overcomes this problem.

With centre-pivot irrigation systems, take care to ensure that the application rate at the end-spans does not exceed the infiltration rate of the soil. With very large centre-pivots, the application rate at the end-spans can be excessive. With all overhead systems, green cane trash blanketing may be beneficial because the trash blanket delays the time taken for water to reach the soil surface, allowing more time for infiltration.

References

Raine SR and Bakker D. (1996). Increased furrow irrigation efficiency through better design and management of cane fields. *Proceedings Australian Society of Sugar Cane Technologists*, 18, 119–124.

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▶ Drainage

Drainage

Too much water is as great a problem in crop production as not enough. When cane is waterlogged, it stops growing.

Studies conducted by BSES in North Queensland showed a yield loss of 0.5 tonnes per ha for each day the watertable remained within 0.5 m of the soil surface.

Since, in some years, soils may remain waterlogged for 100 days, yield losses up to 50 tonnes per ha can occur.

Effects on cane growth

Where cane is grown in poorly drained soil, there is often a general yellowing of the crop. Germination, stooling and ratooning is poor, and this leads to gappy plant stands.

In waterlogged soils the pore spaces are filled with water rather than air which creates anaerobic conditions. Low oxygen levels cause roots to congregate in the better aerated soil near the surface. This leads to shallow root systems that are then not able to make full use of applied fertiliser (**Figure 1**).

In hot, dry weather the cane crop will wilt because the shallow roots are unable to take up water from deeper in the profile.

Anaerobic conditions also result in the denitrification (nitrogen lost as gas to the air) of nitrogen fertiliser and reduced mineralisation of organic nitrogen present in the soil. Waterlogging also reduces the availability of some other nutrients such as phosphorus and molybdenum.

Excessive moisture reduces soil temperature and, in some areas, can cause yield losses due to slower germination and ratooning, particularly where trash conservation is practised.

Other pest and disease problems also occur on poorly drained soils.

Chlorotic streak disease is spread by drainage water, and causes significant crop losses in wet areas.

Wireworms occur more in poorly drained areas where they are a common cause of poor germination.

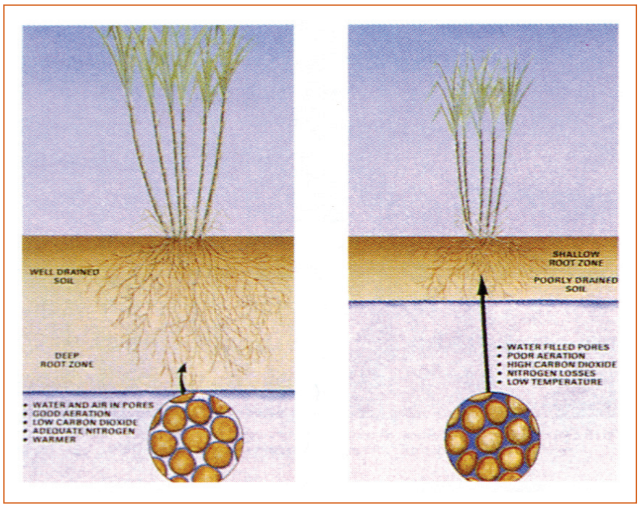

Figure 1: Poorly drained soils lead to shallower root growth and reduced uptake of water and nutrients.

Benefits of good drainage

Good drainage improves the timeliness of farming activities. Where high watertables or salinity are problems, better sub-surface drainage should improve crop yields. The use of preformed beds or mound planting often allows planting to occur sooner or at a more favourable time than conventional planting.

During harvest, good drainage helps to limit the damage to the hills from harvesting equipment. Expensive cultivation to repair compaction is then not needed. If it is needed, working the soil at the correct moisture content reduces compaction and loss of soil structure.

Improved drainage provides the opportunity to grow legume crops during the fallow period and it allows for better weed control since blocks can be accessed when necessary.

Surface drainage

Because all Queensland cane-growing districts have high intensity summer rainfall, good surface drainage is essential. Eliminating surface ponding can prevent many of the problems caused by excessive soil wetness and reduce the need for sub-surface drainage.

Above: Poor drainage can result in crop death.

Land planing fills small depressions and provides a continuous slope of the soil surface. In areas where furrow irrigation is practised, GPS-controlled land levelling provides more even grades and reduces the labour required for irrigation. In other areas, conventional land planes or graders may be used. For larger cuts and fills, it may be necessary for a bulldozer to remove topsoil and a scraper to level the subsoil. This is sometimes practiced where a shallow topsoil overlays a sodic subsoil. A land plane should do the final grading.

Before the land is levelled, a grid survey should be completed to confirm the direction of slope and to determine the most efficient way to cut and fill.

Drain design

Drains should have sufficient capacity to remove surface water from the crop within 72 hours for a one-in-three-year rainfall event. To avoid erosion, water velocity in the drain should not exceed 0.6 m/s in loams and silts, and 1.2 m/s in clays and gravels.

Drain capacity is calculated from the volume of run-off from the block being drained. The volume of run-off is calculated by:

$$V = \frac{KRA}{100}$$

where:

V = volume of run-off (ML)

K = volumetric run-off coefficient (for most soils this is between 0.6 and 0.7)

R = rainfall in 72-hour period (mm) (from **Table 1**)

A = area drained (ha).

Drain capacity is then:

$$Q = \frac{V}{3.6\,T}$$

where:

Q = drain capacity (m^3/s)

V = volume of run-off (ML)

T = period of inundation (h).

Table 1: Design rainfall intensities for some centres in the wet tropics (Ridge and Reghenzani, 2000).

Centre	Design rainfall: 1-in-3-year, 72-hour rainfall	
	Total rainfall (mm)	Average intensity (mm/h)
Mossman	347	4.8
Cairns	346	4.8
Babinda	550	7.6
Innisfail	504	7.0
Tully	537	7.5
Ingham	377	5.2
Abergowrie	290	4.0

Sub-surface drainage

Sub-surface drainage is necessary where high watertables occur for a significant part of the cane-growing season. Yield losses of 0.5 tonnes per ha can be expected for each day of waterlogging (watertable within 0.5 m of the soil surface). The decision on whether to install sub-surface drainage will depend on the average number of days for which the crop is waterlogged each year and the cost of installation.

Where there is a risk of salinisation due to a shallow saline watertable, it is necessary to lower the watertable to a depth of one to two metres, depending on soil texture.

Seepage areas

To drain a spring or seepage area, identify the source of the water by digging test holes above the wet area with a backhoe. With the stream identified, install an interceptor pipe to collect the water and lead it away from the area to be cultivated (**Figure 2**).

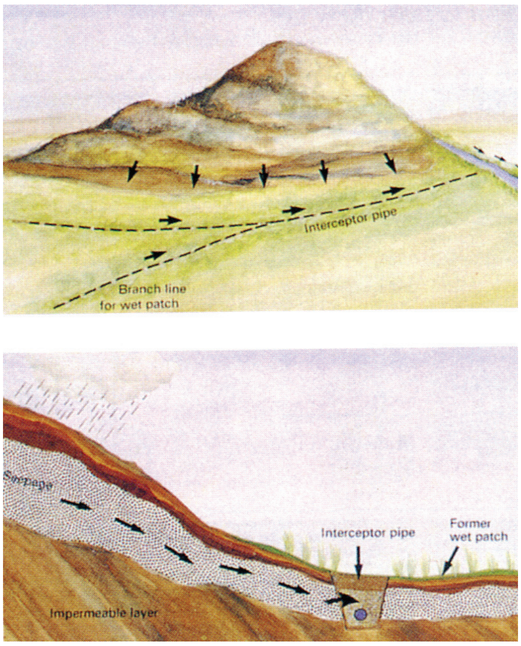

Figure 2: Typical drainage location for seepage area.

Total field drainage

A total field drainage system may be necessary in heavily textured soils, on flat flood plains or in former swamp areas. A grid or herringbone system of sub-surface pipes or open drains is used in these areas. Sub-surface plastic drainage pipe is preferred since it does not interfere with farm layout and farm operation. On clay soils, mole drains can be used to reduce costs.

Mole drains

Soils with a clay content between 33 and 50 per cent are most suitable for mole drainage. Sodic soils are not suitable as they disperse when wet and mole drains collapse.

Mole drains are installed by pulling a 'torpedo', attached to the end of a blade, through the soil at a depth of between 0.5 m and 0.75 m. For best results, a 'plug' or 'expander' should follow the torpedo, expanding and consolidating the channel formed by the torpedo.

A torpedo with a diameter of 50 mm gives the best results. Larger ones will not only be more difficult to pull, but the mole drains they form are more prone to collapse.

Spacing of mole drains will depend on their depth, the slope of the land and the hydraulic conductivity (rate of water flow through the subsoil) of the soil. Common spacings range from 1.5 m to 7.5 m, although wider spacings may be used where the soil has a high hydraulic conductivity. Close spacing will allow for failure of a proportion of the moles while still maintaining adequate drainage.

The aim of sub-surface drainage is to maintain the watertable at least 0.5 m below the soil surface. To do this, moles should be located between 0.5 m and 0.75 m deep.

Mole drains should have a regular gradient to prevent water lying in low spots and causing collapse of the drain.

The maximum recommended length of mole drains is 200 m but under stable soil conditions and adequate slope (above 0.1 per cent), longer mole drains are permissible. They have to be renewed after each crop cycle.

Mole drains can empty into either an open drain or a sand envelope surrounding a sub-surface pipe.

Sub-surface drainage pipe

The spacing of drainage pipes depends on soil hydraulic conductivity, pipe depth, amount of water to be drained and the depth to any impermeable layer.

In general, drainage pipes should be at least 1 m below the surface if the water to be drained is not saline. For saline water, the minimum depth should be 1.5 m.

Installation costs are lower when a chain trench digger is used. However, these machines can be operated only in relatively dry soil conditions. Machines with a trenching depth up to 2.0 m are available. The speed of operation varies from 40 m per hour to 100 m per hour depending on the size of the machine and the required trench size.

Pipe should be laid at a grade of 0.1 per cent or more to prevent sedimentation in the pipe.

The pipe should be installed on a 50 mm bed of coarse sand or gravel and should be covered with an additional 200 mm of filter material.

Specialised equipment

Specialised equipment to reduce the costs of laying sub-surface pipe is available in some districts. This includes tractor-drawn injection lines with a hopper for placing a gravel envelope around the pipe as it is laid; and, a hopper which can be placed in a backhoe trench to feed gravel around the corrugated pipe as the trench is dug. The latter is more versatile as it can be used for a range of trench depths.

References

Ridge R and Reghenzani J. (2000). Drainage. In: *Manual of cane growing* (eds Hogarth M and Allsopp P), pp. 227–240. Bureau of Sugar Experiment Stations, Indooroopilly.

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Economics

The main reasons for irrigating are to stabilise and improve crop yields, but at what point does the cost of irrigating outweigh the returns?

To decide whether the irrigation is providing an economic return, it is necessary to calculate the cost of applying water and compare that to the return.

If the irrigation cost is greater, then the system should be investigated to find possible efficiency improvements. These improvements could be in the physical system but also in management. This is particularly important where water supplies are limited. Studies of best use of limited water (Hardie *et al.*, 2000; Attard and Inman-Bamber, 2011; Eden, 2011) have shown that the return from the same volume of irrigation water can be quite different depending on how that water has been used.

Cost of applying irrigation

In its simplest terms, the cost of applying irrigation includes the amount of water applied, the costs of water and of pumping. A full economic evaluation should also include the cost of interest and depreciation, labour and increased growing costs (fertiliser, harvesting, levies etc.).

An agricultural economist should be consulted for a full irrigation costing. However, some 'back of the envelope' calculations can also be used to give an idea of the value of irrigating.

How much water is being applied?

Knowing the amount of water is the first step. This is relatively easy to measure in metered systems. In unmetered systems it is more difficult but an estimation of water use can still be made.

Measuring water applied with a meter

The most commonly used water meters are:

- Dethridge long wheels – large and small
- in-line propeller-activated (PA) meters.

Dethridge long wheels measure water by volume. With each revolution the wheel displaces a set volume of water that is recorded on the register attached to the wheel. For the wheel to operate accurately, the water levels at the wheel must be correct. Weeds and other debris that choke channels and pipework will reduce the meter's accuracy.

Above: Dethridge long wheel.

In-line PA meters use the flow velocity of the water in the pipeline to measure volume. To be accurate, these meters must be installed correctly. The meter should be placed in the pipeline according to the manufacturer's recommendations, with suitable lengths of straight pipe either side.

The register on the meter varies with the size and type of meter. The numbers on the register generally go down to 1/100 of the unit of water shown.

To measure the water used for an irrigation, read the meter at the start and end. Keep a record of all the irrigations over the season to determine the most accurate water applications for the crop.

Estimating water application

If a water meter is not available the flow rate can be measured with external meters, or a crude estimate can be made by measuring the outflow to the paddock using a bucket and stopwatch (see **Appendix 1: Simple calculations for furrow irrigation** steps 1–4).

What is the cost of water?

Water supplied from irrigation schemes usually has a $/ML charge. In the Burdekin Delta, some of the water supplied by Lower Burdekin Water is charged per hectare. This will need to be converted to a per megalitre cost.

Pumping costs

Pumping costs can be a major component of irrigation costs. To calculate the pumping cost, three amounts are needed:

1. the flow rate in megalitres per hour (ML/h) – measured with the normal operating head placed on the system
2. the power consumption in kilowatt hours (kWh) – read from the pump's electricity meter
3. the cost of electricity ($/kWh).

Measuring pump flow rate

If the pump has a water meter, record the reading at the start of the irrigation and again at the end. The difference will be the volume of water applied. If the pump doesn't have a meter, the flow rate can be estimated using the stopwatch and bucket method.

Pump flow rate (ML/h) = volume applied (ML) ÷ time taken to irrigate (h)

Cost to apply 1 ML of water

Pumping cost ($/ML) = (power consumption (kWh) × electricity tariff ($/kWh)) ÷ (pump flow rate (ML/h) x pumping time (h))

Irrigation cost

The cost of irrigating is the amount of water applied multiplied by the cost of supplying that water, both the megalitre charge and any pumping costs.

Cost of irrigation ($/ha) = number of ML applied (ML/ha) × (cost of water ($/ML) + cost of pumping ($/ML))

Return from irrigation

The return from irrigation is the value of any increase in yield minus the cost of irrigating. In a 100 per cent efficient system each megalitre of applied irrigation water should increase the yield by approximately 10 tonnes. However, no system is 100 per cent efficient so the actual increases are likely to be less.

Return from irrigation ($/ha) = value of increased yield – cost of applying irrigation

Value of increased yield ($/ha) = increased yield (t/ha) × price of cane ($/t)

Application efficiency

The application efficiency is a comparison between the volume of water applied in an irrigation and the soil water deficit at that irrigation. For example, if the soil water deficit is 75 mm, and 100 mm of irrigation is applied, then that irrigation would be considered to be 75 per cent efficient. The greater the application efficiency, the better the return from irrigation. A saving of even 30 mm per year on 24 ha is equivalent to 7.2 ML of water.

Irrigation pump efficiency

Rising energy costs are driving the need for increased energy efficiency. Cost savings for energy used in irrigation can be gained from improved water use efficiency and lower pumping costs from optimal pump efficiency.

For a given volume of water the energy requirement for pumping can only be reduced in one of two ways:

1. Reducing the pressure at the pump.
2. Increasing the pump efficiency.

Water pressure

Table 1 shows that as the pressure in the system increases so does the power requirement and the cost of pumping the water. Any measures which can reduce the pressure required at the pump, while maintaining the desired flow rate, will reduce the power required by the system and result in lower operating costs.

The operating pressure of the irrigation system can be reduced by addressing the following:

- Converting the system from a high pressure water winch to a low pressure boom – this could save 173 kw/hrs per ML pumped and $34.05 per ML if power costs 20c/kWh.
- Is the underground main line suitable for the current flow rate? Large diameter underground mains have lower friction losses and may reduce pump pressure.
- Can a ring main be formed to reduce friction losses and pressure?
- Are there any gate valves in the system which are not fully open? A partly open gate valve at the pump will increase the pressure on the pump and reduce the water flow resulting in a higher energy requirement for each ML of water pumped.
- Are moveable aluminium pipes used with high water volumes? Friction losses in moveable aluminium pipes are often much greater then losses for a similar length of underground main.
- Are there restrictions in and around the pump which reduce the water flow and increase the pressure at the pump?

Any steps which reduce the pressure at the pump while maintaining the flow rate will reduce the energy required by the pump and therefore the pumping cost.

Table 1: Shows the power requirement to pump water at various pressures at a constant flow.

Typical system	Pressure at pump kPa	Flow L/s	Power needed to drive pump kW	Electricity used to pump 1 ML kWh	Cost of electricity at 20c kWh to pump 1 ML
Furrow irrigation	100	30	5.0	52	$10.40
Low pressure over head	400	30	17.7	182	$36.40
Water winch well-designed system	800	30	34.5	355	$71.00
Water winch high lift or high friction loss	1000	30	42.9	441	$88.40

* *A suction lift of 2 m, a pump efficiency of 70 per cent and an electric motor efficiency of 90 per cent were used in the above calculations.*

Pump efficiency

Pump efficiency is the water power divided by the power input at the pump shaft.

The principal causes of power loss or efficiency loss in a pump are:

- Friction loss in the pump passages.
- Disc friction from the impeller rotating in the water.
- Internal leakage of water from the discharge back to the suction side of the pump via balance holes and sealing clearances.
- Shaft bearing losses.
- Seal/gland losses.

What efficiency should you aim for?

- You should aim for an efficiency greater the 70 per cent at the pumps normal operating duty.
- Over 80 per cent is very good.
- Poor efficiency is less than 70 per cent.

Table 2 shows that as pump efficiency improves the power required by the pump falls. The extra power required over a season to pump 100 ML thought a water winch with a pump which has an efficiency of 50 per cent compared to a high efficiency pump with an efficiency of 80 per cent is 16 700 Kw hrs. This extra electricity would cost $3340 if the power cost 20 per kWh.

Factors which effect pump efficiency include:

- Is the pump the right pump for the job? In some cases the irrigator has been changed to a lower pressure unit and the old high pressure pump is still being used.
- Is the pump worn-out?

Table 2: The effect of pump efficiency on power usage at two pressures with a flow rate of 30 L/sec.

Typical system	Pressure kPa	Flow rate L/s	Pump efficiency %	Power needed for the pump kW	Power needed to pump 1 ML kWh	Cost of electricity at 20c kWh to pump 1 ML
Low pressure boom	400	30	50	24.7	229	$45.80
	400	30	60	20.6	190	$38.00
	400	30	70	17.7	164	$32.80
	400	30	80	15.5	143	$28.60
Water winch	800	30	50	48.3	447	$89.40
	800	30	60	40.2	372	$74.40
	800	30	70	34.5	319	$63.80
	800	30	80	30.2	280	$56.00

* *A suction lift of* 2 m *and an electric motor efficiency of* 90 *per cent were used in the above calculations.*

Calculating pump efficiency

Step 1

Measure the power consumed from the power meters.

Step 2

Measure the flow rate in L/sec.

Flow rate (Q) = litres pumped/time in seconds.

Step 3

Determine the head pressure.

The head pressure is the pressure read from the pressure gauge fitted at the pump when the system is at full operational pressure.

Equivalent meters of head

Convert the pressure gauge reading to equivalent metres of head.

Head m	5	10	15	20	25	30
Pressure kPa	50	100	150	200	250	300

If your pressure gauge reads in psi, convert psi to kPa by multiplying by 6.9.

Step 4

Determine the suction head

Suction head is the distance between the centre line of the pump and the water level plus losses in the suction pipe. Typical suction head figures are between three and five metres. Add this to the pressure head to give **total head**.

Many pumps connected to irrigation scheme outlets have a positive pressure on the inlet side of the pump. In these situations the pressure on the inlet side of the pump should be ducted from the pressure on the discharge side of the pump to determine the total head.

Step 5

Determine motor efficiency

Electric motors have an efficiency value (Me): that is, they lose some of the energy going into them as heat. This energy loss changes with the size of the motor and the load on the motor. Assume an efficiency of 85 per cent for motors up to 15 kW, and 90 per cent above 15 kW.

Step 6

Determine transmission losses

If the motor is not directly coupled to the pump, there is a loss of energy through the transmission.

Our calculations can include this loss by using a drive factor (Df). For example, if the loss of energy through the transmission is 5 per cent, then the drive factor (Df) is 0.95.

- For V-belt drives, Df is 0.9.
- For gear drives, Df is 0.95.

Step 7

Calculate pump efficiency

Pump efficiency = (Q × H) ÷ (power used × Me × Df)

(Pump efficiency (Pe) is expressed as a percentage.)

The following is a worked example of how to complete a pump efficiency calculation.

Step 1

Power consumed 22 kW

Step 2

Flow rate (Q) 30 L/s

Step 3

Pressure at pump 400 kPa

= 400 × 0.1 m

= 40 m head

Step 4

Suction lift 2 m

Total head = pressure head + suction lift = 42 m

Step 5

Motor efficiency 0.9 Me

Step 6

Transmission loss 0.9 for V-belt Df

Step 7

Pump efficiency = (Q × H) ÷ (power × Me × Df)

= (30 ×42) ÷ (22 × 0.9 × 0.9)

= 70 per cent

Seeking advice

The engineering design of the irrigation system can have a large impact on the ongoing operational cost of the system. High pressure systems with inefficient pumps can lead to more power consumption that reduces the enterprise's profitability.

To reduce energy costs every effort should be made to reduce any restriction in the system which could lead to increased pressure in the system and higher pumping costs. Over time all pumps and equipment wear and efficiency falls. This may be a slow process and may go unnoticed.

As the area of irrigation design and engineering is relatively complex many growers may find it useful to engage the services of a specialist irrigation design and assessment consultant. A number of these consultants work throughout the industry and can conduct an irrigation system audit to identify if economic changes can be made to the irrigation system to reduce operating costs.

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Technical information

Terms

CCS – a measure of pure sucrose that is obtainable from cane.

Effective rooting depth – the soil depth from which the crop obtains most of its water.

Evaporation – water lost from the soil surface.

Evapotranspiration – the total water lost as evaporation and transpiration, sometimes called crop water use.

Exchangeable sodium percentage (ESP) – the ratio of sodium ions to other positively charged ions in the soil solution.

Field capacity – the water content of a soil when the gravitational water has drained away, essentially the most water the soil can hold.

Gravitational water – the water that drains away through gravity.

Hydraulic conductivity – rate of water flow through the subsoil.

Megalitre (ML) – 1 million litres. 1 ML is equivalent to a water depth of 100 mm over a hectare.

Permanent wilting point – the soil is at permanent wilting point when plants wilt permanently (i.e. irrigation or rainfall will not revive them) because they can extract no more water from the soil.

Plant available water (PAW) – the difference between the amount of water in the soil at field capacity and the amount of water in a soil at the permanent wilting point.

Primary salinity – salinity that has developed in old marine areas or on rocks that release salts on weathering.

Readily available water (RAW) – soil water that is easily extracted by the crop; varies between 45 per cent and 90 per cent of plant available water.

Residual alkali (RA) – a measure of the amount of sodium carbonate and sodium bicarbonate in the water.

Saline soils – soils where the concentration of soluble salts in the soil water solution is sufficient to restrict plant growth.

Salinity – the total quantity of dissolved salts in the water.

Saturation – the pore spaces in the soil are filled with water.

Secondary salinity – salinity that has been caused by the rise of groundwater into the root zone. Salts in the water are then concentrated in the root zone.

Sodic duplex soils – soils that have a sodic subsoil. The depth of the sodic layer varies with different soils and management.

Sodic soils – soils with a clay complex dominated by sodium ions. These soils disperse and seal when wet.

Sodium adsorption ratio – a prediction of how the irrigation water will affect soil sodicity.

Transpiration – water lost from the plant as part of normal physiological processes.

Conversions

1 g = 1000 milligrams

1 g = 1/1000 kilogram

1 ha = 10 000 m^2 (100 m × 100 m)

1 kg = 1000 grams

1 L = 1000 millilitres

1 m = 1000 millimetres

1 mg = 1/1000 gram

1 mg/L = 1 kg/ML

1 ML = 1 000 000 litres

1 mL = 1/1000 litre

1 ML/ha = 100 mm/ha

1 mm = 1/1000 metre

1 t = 1000 kilogram

Abbreviations and symbols

CCS = commercial cane sugar content

dS/m = decisiemens per metre

EC = electrical conductivity

ESP = exchangeable sodium percentage

ET_o = reference evapotranspiration

h = hour

ha = hectare

kg = kilogram

L = litre

m = metre

mg = milligram

ML = megalitre

mL = millilitre

mm = millimetre

PAW = plant available water

PWP = permanent wilting point

RA = residual alkali

RAW = readily available water

s = second

SAR = sodium adsorption ratio

t = tonne

t/ha = tonnes cane per hectare

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Simple calculations for furrow irrigation

Appendix 1

Calculations

1. **Average inflow rate (L/s)**
2. **Area watered per irrigation (ha)**
3. **Volume applied per irrigation (ML)**
4. **Volume applied per hectare (ML/ha)**
5. **Compare application to crop use**

Some simple measurements and calculations are valuable when evaluating a furrow irrigation system. These measurements and calculations provide a baseline and can be used to evaluate the effect of any changes.

1. Average inflow rate (L/s)

The simplest way to measure the inflow rate is with a bucket and stopwatch. Fill a bucket with water at the cup and record the volume (L) and time (s). Take three or four readings per row over four or more rows, the more the better.

Calculate the average volume and time for each row. Then calculate the average inflow rate (L/s) for each row by dividing the average volume by the average time. Calculate the average inflow rate across all measured rows by adding the inflow rates for each row and dividing by the number of rows.

2. Area watered per irrigation (ha)

To calculate the area watered per irrigation: multiply the number of rows being watered by the row spacing (metres) and the block length (metres), then divide by 10 000 to get an area in hectares.

Area (ha) = **(row spacing x no. rows per irrigation set x row length) / 10 000**

3. Volume of water applied per irrigation (ML)

The total volume of water applied during irrigation in megalitres (ML) is: the inflow rate (L/s) multiplied by 3600 (to convert to L/h) by the number of rows being irrigated by the irrigation duration (h) divided by one million.

ML = (inflow rate x 3600 x rows watered x irrigation duration) / 1 000 000

4. Volume applied per hectare (ML/ha)

To calculate the volume of water applied per hectare, divide the total volume of water applied by the area being irrigated.

ML/ha = total volume (ML)/area (ha)

5. Compare volume applied to crop water use

Crop water use (mm) can be calculated using WaterSense or crop factors. The crop water use can then be compared to the amount of water applied by irrigation (mm) to see if the irrigation is supplying sufficient water or an excess amount. If the irrigation application efficacy is greater than 1, the amount of water being applied by irrigation is more than is being used by the crop. If the number is less than 1, then the irrigation is not replacing the water used by the crop. Water that is applied in excess of crop use can be lost through run-off or deep drainage.

Irrigation water applied (mm/ha) = ML/ha x 100

Crop water use (mm) = days between irrigations x daily water use (mm/day)

Irrigation application efficacy = applied water / crop water use

Example

Variables

Row spacing: 1.52 m

Row length: 580 m

Number of rows per irrigation set: 50

Irrigation duration: 24 hours

Days since last irrigation: 14

Average crop water use: 4.8 mm/day

1. Measuring and calculating inflow rates

Reading	Row 1		Row 2		Row 3		Row 4	
	L	S	L	S	L	S	L	S
#1	7.5	7.0	7.5	7.5	7.0	6.5	7.5	6.5
#2	7.2	6.5	7.0	7.0	8.5	6.0	8.0	7.5
#3	8.4	8.0	8.0	6.5	7.0	7.0	8.5	7.5
#4	6.5	6.0	6.5	7.0	8.0	8.0	7.0	7.0
Average*	7.4	6.9	7.3	7.0	7.6	6.9	7.8	7.1
L/S*	1.1		1.0		1.1		1.1	
Average for measured rows (L/s)*						1.1		

** answer rounded to one decimal place*

2. Area watered per irrigation (ha)

Area (ha) = (row spacing x no. rows per irrigation set x row length) / 10 000

Area (ha) = (1.52 m x 50 x 580 m) / 10 000

= 4.41 ha (answer rounded to 2 decimal places)

3. Volume of water applied per irrigation (ML)

ML = (inflow rate x 3600 x rows watered x irrigation duration) / 1 000 000

ML = (1.1 L/s x 3600 x 50 x 24 h) / 1 000 000

= 4.75 ML (answer rounded to 2 decimal places)

4. Volume applied per hectare (ML/ha)

ML/ha = total volume (ML) / area (ha)

ML/ha = 4.75 ML / 4.41 ha

= 1.08 ML/ha (answer rounded to 2 decimal places)

5. Compare volume applied to crop water use

Irrigation water applied (mm/ha) = ML/ha x 100

= 1.08 ML/ha x 100

= 108 mm/ha

Crop water use (mm) = days between irrigations x daily water use (mm/day)

= 14 days x 4.8 mm/day

= 67.2 mm

Irrigation application efficacy = applied water / crop water use

= 108 / 67.2

= 1.6

Therefore, in this scenario the irrigation is replacing 1.6 times the amount of water used by the crop since the last irrigation.

Crop water use

Appendix 2

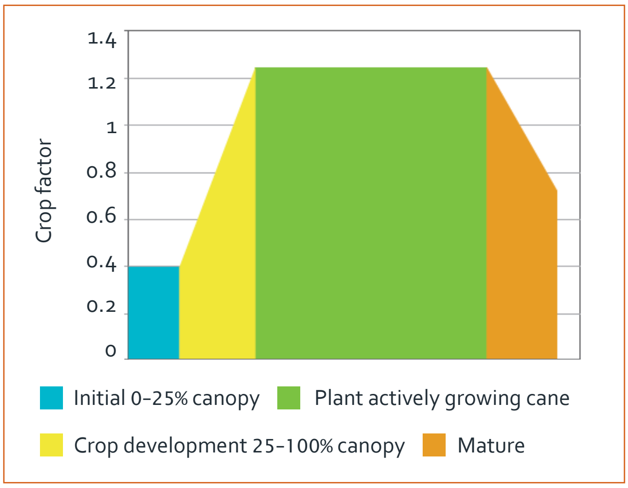
Crop water use varies greatly throughout a season depending on the time of year and the crop growth stage. Understanding the variation in crop water use is important for adjusting irrigation schedules and the volume of water being applied.

Crop water use can be calculated in two ways, either by using WaterSense or by a manual calculation.

For a manual calculation, two pieces of information are required: the crop factor (K_c) and local reference evapotranspiration (ET_o). The crop factor is combined with regional ET_o to estimate crop water use at different growth stages.

Note: These crop factors are for use with ET_o not Class A Pan evaporation.

Regional ET_o can be obtained from the Australian Bureau of Meteorology at the following website – http://reg.bom.gov.au/watl/eto/



Calculating crop water use using ET_o and crop factors

Table 1: Example reference evapotranspiration.

Day	1	2	3	4	5	6	7
ET_o	5.2	4.9	3.6	5.0	5.0	4.5	4.6

Example 1

Crop cover: 10% Crop stage: initial (see graph)

Crop water use on Day 1 = ET_o x crop factor

= 5.2 mm x 0.4 = 2.1 mm

Example 2

Crop cover: 100% Crop stage: plant actively growing cane

Crop water use on Day 4 = ET_o x crop factor

= 5 mm x 1.25 = 6.3 mm

Table 2: Crop water use (ETc) for crops with 10% and 100% cover.

Day	1	2	3	4	5	6	7	Total crop water use for week
Daily ET_o	5.2	4.9	3.6	5.0	5.0	4.5	4.6	
ET_c 10% cover (K_c 0.4)	2.1	2.0	1.4	2.0	2.0	1.8	1.8	13
ET_c 100% cover (K_c 1.25)	6.5	6.1	4.5	6.3	6.3	5.6	5.8	41

Using crop water use for irrigation scheduling

In situations where it is possible to accurately regulate the amount of water applied, for example, overhead or drip irrigation, the crop water use can be used to determine how much water to apply to refill the profile. For the example above if the crop was at full canopy, you would need to apply 40 mm to replace the water the crop has used.

If the water-holding capacity of the soil is known, the crop water use can be used to estimate when the next irrigation will be. For the example in **Table 2**, if the crop is at 100 per cent canopy, then the water-holding capacity is 80 mm and the soil profile is full. The crop will need watering in about two weeks (crop using 41 mm per week), providing the weather conditions are similar. A soil that only holds 40 mm of water will need watering after a week.

Irrigation scheduling with minipans

Appendix 3

Evaporation minipans are an inexpensive and effective irrigation scheduling tool. Crop growth is recorded against evaporation to determine the trigger point for irrigation. Calibrating is easy, but to be effective all blocks and varieties need to be done individually.

This type of irrigation scheduling cannot be used until the crop starts to develop cane.

Making a minipan

Take a large bucket or drum and cut a V at the top of the bucket. Glue a ruler into the drum with zero placed at the bottom of the V.

Selecting the site

- The crop should be near full canopy and actively growing.
- The monitoring site should be at least five to eight rows from the edge and 2–3 m into the paddock.
- Select 25 main stalks, 12 stalks on one side and 13 on the other side. Mark each stalk with flagging tape and place bottle lids at the base of the stalk (this provides a fixed base for measuring). Number each stalk so that there is a reference for recording.

Using the minipan

- Place the minipan in an open location close to the paddock that it will be used to schedule. Ensure that the crop or trees will not shade the minipan and that animals can't drink out of it.
- After irrigation is complete, fill the minipan.
- Commence stalk measurements. Measure each day, making sure it is at the same time. Take the stalk and measure from the ground to top visible dewlap (**see photo to the right**). If the tape measure is hard to use, attach it to a piece of conduit or something similar.
- Record the stalk measurements **(Table 1)**. Add these readings together and divide by 25 to give the average growth for the day. Also take the minipan reading.
- The irrigation trigger point is when the average growth reduces to below 50 per cent of the maximum recorded for two or more days. In **Table 1** this would be on December 19.
- Mark on your evaporation minipan the water level at your trigger point.
- Refill minipan after irrigation. When the minipan evaporates and reaches the mark, it is time to irrigate again.

Table 1: Minipan recording sheet.

Date	**12.12**	**13.12**	**14.12**	**~**	**18.12**	**19.12**
Stalk #	**mm**	**mm**	**mm**		**mm**	**mm**
1	1730	1760	1780		1850	1860
2	158	1600	1620		1670	1680
≀						
25	1850	1870	1880		1900	1920
Average	1834	1856	1877		1942	1950
Difference		23	21		9	7

Crop growth can stall for a number of reasons not just due to water stress. When recording crop growth it is especially important to note any weather changes. To avoid having a biased calibration it is best to complete the stalk measurements over more than one irrigation.

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