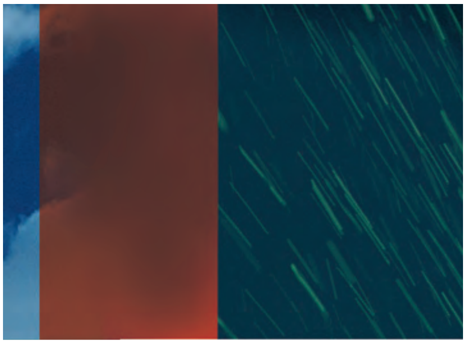


IRRIGATION OF SUGARCANE

Gary Ham, Peter McGuire and Graham Kingston

SUGARCANE is a plant that originated in the wet tropics. Therefore, to achieve maximum productivity, it requires an abundant supply of water, either supplied as rainfall, irrigation or a combination of these.

With suitable conditions of adequate temperature and sunlight, cane grows in direct proportion to the amount of water available. For each 10 mm of soil water used by a hectare of crop, approximately 1 tonne of cane is produced.

Irrigation can increase cane yields and it increases the sustainabilty of crop production by reducing dependence on rainfall. Irrigation also allows for better planning and increased flexibility of farming activities. With irrigation, growers have more flexibility in deciding when to plant a crop, since they are not reliant on rainfall to provide soil moisture. It increases the reliability of ratooning and enables more ratoons to be grown.

SOIL, WATER AND SUGARCANE

The need for irrigation

The irrigated area in Queensland has gradually risen from less than 9000 hectares in 1933 to 173 000 hectares in 1995. More than 40% of the Queensland sugarcane crop is irrigated, which accounts for more than 60% of the total cane production. With the recent and future expansion in the Burdekin and on the Atherton Tableland, the reliance on irrigation is likely to increase. Other districts, generally regarded as having rainfed crops, are increasingly seeking to provide limited supplementary irrigation in the drier months when crops are ratooning.

In most districts, the response to irrigation varies greatly from season to season. In the wetter areas, there may not be an economic yield response that warrants the purchase of irrigation equipment.

'Total' irrigation is used in areas where rainfall is concentrated over a relatively small part of the growing season and so does not provide adequate moisture to grow an economically sustainable crop (Table 1). Outside this period, the crop is totally dependent on irrigation to provide its water

Table 1. Irrigation requirements in sugar districts.

District	Annual crop water use (mm)	Effective rainfall (mm)	Irrigation requirement (mm)	Level of irrigation
Ord	1960	550	1410	T
Cairns (dry tropics)	1630	1360	270	LS
Mareeba/Dimbulah	1550	405	1145	T
Atherton	1170	760	410	MS
Tully/Babinda	1310	1500	nil	NIL
Herbert	1350	1100	250	LS–MS
Burdekin	1520	450	1070	T
Mackay/Proserpine/Sarina	1490	630	860	MS–ES
Bundaberg/Maryborough	1360	580	780	ES
Moreton	1100	1180	nil	NIL
Rocky Point	1150	990	160	LS
Northern NSW	1200	1000	200	LS

NIL No irrigation
LS Limited supplementary irrigation
MS Moderate supplementary irrigation
ES Extensive supplementary irrigation
T Total irrigation

requirements. Supplementary irrigation is used in areas where natural rainfall may be sufficient to produce moderate cane yields, but where insufficient rainfall in the growing season generally limits crop production. In these cases, supplementary irrigation increases available water, which stabilises yields and often improves the ability of crops to ratoon.

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 ha. 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 mean daily temperature). Growth measurements (stalk elongation) of over 33 mm per day have been recorded (Figure 1). As the moisture is removed from the soil by the growing crop, growth rates decline rapidly in response to the increasing moisture stress (Figure 2).

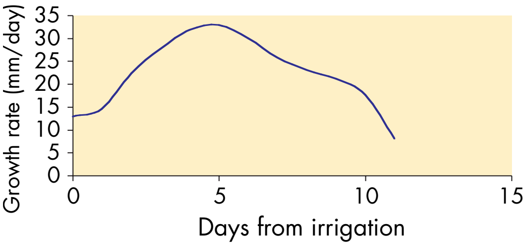


Figure 1. *Typical crop growth rates after irrigation of an early plant Q117 crop (Burdekin).*

While irrigation for maximum growth produces high cane yields, it reduces CCS. Research in Queensland and overseas has shown that supplying approximately 85% 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 closely related to and can be calculated from evaporation from a standard ‘class A’ evaporation pan, as defined by the Australian Bureau of Meteorology. Therefore, for maximum sugar accumulation, the crop water use and, hence, irrigation requirement of sugarcane (after canopy closure) is calculated as 85% of the evaporation from the 'class A' pan. Crop yield responses to irrigation vary between districts because of climatic conditions. Table 2 shows estimated yield increases from irrigation.

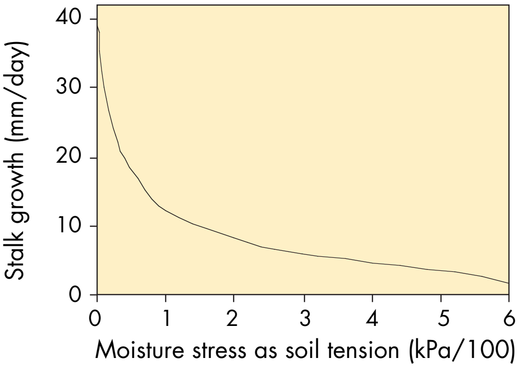


Figure 2. *Bundaberg irrigation trial.*

Table 2. Estimated yield increase from irrigation.

District	Tonnes cane/ha	Tonnes sugar/ha
Ord	116	16.2
Herbert		
Bambaroo	27	3.5
Burdekin	65	9.8
Mackay		
BSES Station	9.6	1.4
Pioneer Valley	10.5	1.6
North Eton	18	2.5
Bundaberg	22.2	3.6

Soil, water and the crop

Soil is composed of different amounts of sand, silt and clay. These three groups of particles are of different sizes (sand is the largest and clay is the smallest), and the proportion of each in a soil determines the texture, size and number of pore spaces in the soil. A loam soil has roughly equal amounts of sand, silt and clay. A very sandy soil has proportionally larger and fewer pores than a heavy clay soil, which has much smaller pores but many more of them.

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.

Unavailable water is made up of gravitational water (water that drains away because of gravity; a very small amount will be used by the crop) and water that the plant roots cannot physically extract. This water is either held very tightly around or between soil particles and clumps of particles (soil aggregates) or is below the roots of the crop.

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**.

Within Plant Available Water is **Readily Available Water** (RAW). This is water that plants can easily extract (Figure 3). Irrigation scheduling should aim to replace this fraction of the soil water.

In sandy soils, approximately 80% of Plant Available Water (PAW) is readily available. In clay soils, because more of the water is held in small pores, plants have more difficulty

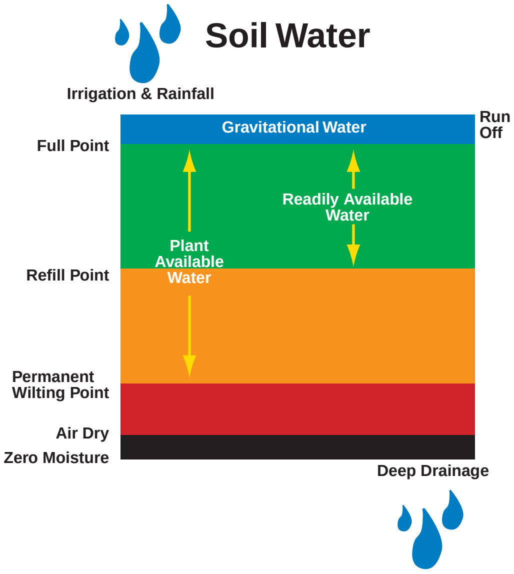


Figure 3. *Different types of soil water.*

extracting the water. Therefore, only 45–50% of the PAW is readily available water (RAW). However, clay soils still have approximately twice the amount of RAW of sandy soils (Table 3).

Table 3. Typical readily available water (RAW) levels for a range of soil types.

Soil type	RAW (mm)
Cracking clay	90–100
Clay loam	80–90
Loam	70–80
Sandy loam	50–60
Loamy sand	30–40
Sodic clay*	40–90

*The large range here is due to variations in sodicity levels.

Rooting depth

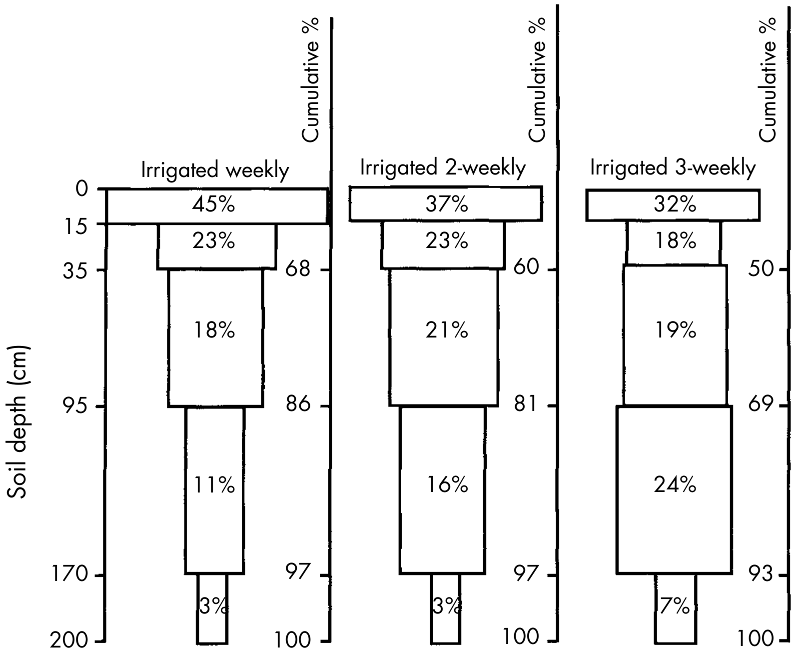
The effective rooting depth (or effective root zone) is the depth of soil containing most of the roots which actively extract water. In irrigated deep soils (e.g. a clay loam), the effective rooting depth of sugarcane may vary from 0.9–1.2 m. Under rain-fed conditions, the effective rooting depth may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

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, which can vary considerably.

The distribution of roots in the soil is affected by irrigation practices. As shown in Figure 4, 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.

Practical implications

Variations in the water holding capacities of soils can cause management difficulties. Where possible, irrigation runs should only include soils with similar water storage capacities to ensure all parts of the run will be ready for irrigation and cultivation at the same time. Optimum block design should have minimal mixing of soil types along the row.



Root distribution by weight in successive strata of soil, after Baran *et al.*

Figure 4. *Root distribution by weight in successive strata of soil.*

IRRIGATION SCHEDULING

Since stored water is a scarce resource in Australia and irrigation faces increasing competition for a share of this water, its efficient use in crop production assumes increasing importance. Irrigation is artificially delivering water for plant growth. Irrigation scheduling is the frequency at which water is delivered. The optimum frequency varies according to soil type. This is because different soils store different amounts of readily available water. The aim of irrigation scheduling is to produce the optimum yield and to apply water efficiently. The less RAW a soil holds, the more frequently it needs to be irrigated.

Soil water

The first step to accurate irrigation scheduling is determining the amount of readily available water in the soil. Readily available water is the amount of water stored in the soil between the full point and the refill point. The refill point is when the plant begins to suffer moisture stress because the easily extracted water has been used; this significantly reduces plant growth. The full point is also known as 'field capacity'. It is the maximum amount of water the soil can hold against gravity, when excess water has drained away. Ideally, irrigation scheduling should maintain the soil moisture between the refill and the full points. Table 3 shows typical amounts of RAW for a range of soil types.

Soil water depletion

It is then necessary to know how much moisture is in the soil at a given time and the rate of depletion of the moisture. The depletion will be by transpiration (water lost from the leaves) and evaporation from the soil surface. Together evaporation and transpiration are known as evapotranspiration or 'crop water use'. If the time taken for the soil to deplete 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 scheduling methods available. The cost of the systems vary widely, chiefly depending on accuracy.

Scheduling methods

'Class A' pan evaporation rates

Since plant water use is strongly correlated with evaporation rates, monitoring evaporation can provide a useful indicator of crop irrigation needs.

The standard procedure for measuring evaporation rates uses the 'class A' evaporation pan. The relationship between the amount of water required by the crop and the evaporation rate is referred to as the crop factor. This will vary with crop size and is related to the proportion of ground covered by the crop canopy (Table 4).

Table 4. Sugarcane crop factors.

Canopy cover	Class A pan crop factor
Bare ground	0.3
$\frac{1}{4}$ canopy	0.4
$\frac{1}{2}$ canopy	0.6
$\frac{3}{4}$ canopy	0.7
Full canopy	0.85
Maturing crop	0.65

The maximum crop factor used for sugarcane (to obtain maximum sugar accumulation) is 0.85 for a growing crop with a full canopy. For example, during summer, 'class A' pan evaporation rates of 7.0 mm/day are common. However, only 85% of this amount of water (6 mm/day) needs to be replaced by irrigation. Thus, if a soil holds 50 mm of readily available water, for a crop factor of 0.85, then 59 mm of evaporation should occur between irrigations. At evaporation rates of 7.0 mm/day, this would mean irrigation intervals of 8–9 days for that soil type.

For a maturing crop (crop factor of 0.65) on the same soil, irrigation should occur after 77 mm has evaporated. If the evaporation rate was 4 mm/day, the irrigation interval would be 19–20 days. One difficulty in using this system is estimating the quantity of readily available soil water. The availability of a 'class A' pan can also be a problem. In many irrigation districts, BSES announces the evaporation each week over regional radio services. However, this may not be accurate for a crop located some distance away from the BSES station.

Evaporation minipans

Since 1991, BSES extension staff in the Burdekin have been encouraging the use of evaporation minipans (Figure 5) as a tool for scheduling irrigation. These are probably the simplest and cheapest scheduling tool available, providing good accuracy and reliability. The success of the minipan can be attributed to its simplicity and the fact that growers can easily calibrate minipans to individual soil types.

Figure 5. *Minipan in the field.*

The minipan calibration procedure is a simple one and is usually commenced soon after canopy closure. The minipan is placed at a position on the field where it will be subjected to similar winds, sunlight and temperature as the crop growing in the field. It is preferable to support the minipan above the ground to allow air circulation and minimise the risk of animals drinking from it. Then 25 stalks are selected from adjacent rows and individually labelled, commencing 10–15 m into the field. The height of each stalk to the top visible dewlap or collar is recorded (Figure 6). These initial steps should be completed just prior to irrigating this section of the field; record the date. Immediately following the completion of irrigation, the minipan should be filled. Once the ground is firm enough to support your weight, measure and record the height of each stalk as before, but also record the reading for the minipan water level and the date.

Make growth and minipan readings at about the same time each day.

Figure 6. *Measuring the height of cane to the top visible dewlap or collar.*

By progressively plotting the daily growth against days after irrigation (as in Figure 1), the maximum growth rate can be determined. By locating the day on which the growth rate fell to 50% of this maximum, the corresponding draw-down in the minipan can be found and this becomes the minipan deficit figure to be used to schedule subsequent irrigations. Once recorded, the deficit figure can be marked on the inside of the minipan with a thin black line (using a permanent marker felt pen) making an easy reference point for future irrigations. Calibration is only needed every one or two irrigation cycles to set this minipan deficit. It can be used for scheduling into the drying-off period preharvest by adding 30% to the calibrated value and delaying irrigation until this increased value is reached.

However, minipan deficit figures are not a measurement of actual soil moisture deficits, but do reflect well the actual readily available soil water.

The effectiveness of irrigation scheduling using minipans is shown in Table 5. The crops were not grown in formal trials but in fields on growers' properties in successive years of very similar rainfall distribution, temperature and incident radiation. The data clearly suggest that considerable benefits can accrue from irrigation scheduling, given that in each case yields increased substantially.

Minipans are most useful in furrow irrigation. This is because, when the pan is filled, it represents the soil at field capacity, as it should be after a furrow irrigation. With other types of irrigation, for instance overhead, the soil is not generally filled completely. Therefore, it is more difficult to estimate how much water to put in the pan after an irrigation.

Tensiometers

Tensiometers consist of a hollow tube, which is joined to a ceramic tip at the base, and a vacuum gauge and reservoir at the top. They measure the force that plants need to exert to obtain moisture from the soil. As the soil dries out, a small amount of water moves out into the soil from the tube of 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 reading, the drier the soil. Irrigation begins again when the tensiomenter gauge reads a predetermined level.

Usually, tensiometers are installed in the plant line with the ceramic cup at 600 mm except for sandy soils where the cup depth should be 300 mm. Preferably, two tensiometers should be installed at each site to improve accuracy. They need careful installation to ensure effective soil-cup contact and regular maintenance to ensure they do not run out of water.

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 the cane falls to 50% of the maximum recorded, the tensiometer reading is taken. The reading is then used to initiate irrigations from then on. Some typical deficits for a range of soil types are shown in Table 6. While minipans can be used and calibrated for overhead and trickle systems, tensiometers are most useful and more commonly used.

Table 5. Sugarcane yield response to irrigation scheduling using evaporation minipans.

Soil type	Variety	Non-scheduled 1993 (t/ha)	Scheduled 1994 (t/ha)	Production increase (%)
Alluvial	Q117	124 (1R)	136 (2R)	10
Non-sodic duplex	Q117	107 (1R)	120 (2R)	12
Sodic duplex	Q96	88 (2R)	110 (3R)	25

1R, 2R and 3R refer to first, second and third ratoon crops, respectively.

Table 6. Typical tensiometer deficits for a range of soil types.

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

Most tensiometer gauges are calibrated in centibars rather than the metric kPa, although some have both units marked on the gauge (1 kPa = 1 centibar).

Other equipment

The EnviroSCAN® is an electronic probe which uses the differences in electrical properties of different materials (soil, water, air) to measure the soil moisture status. Sensors are placed in the soil at several depths within a sealed PVC tube. Commonly, between six and eight sensors are installed on each probe; these are connected by cables to a logging system and readings are made at chosen preset intervals to suit the particular irrigation environment. Collected data are downloaded to a computer on a regular basis, and the software provided with the unit is used to track the soil moisture status over time. This is compared with the desired soil moisture for irrigation scheduling. These units are expensive and require a reasonable level of computer literacy, and are not readily transportable from field to field for monitoring purposes.

A variation of these units, the Diviner®, using the same principles of measurement, has recently been released. It has a considerably lower cost but a higher labour requirement. A probe comprising a single moisture sensor, with sensors for placement depth, is used to measure the soil moisture as it moves down previously installed PVC tubes within a field. It can be readily transported from field to field and the data are electronically recorded for field, site and depth.

Again, downloading these data sets, with software processing, allows the monitoring of the soil moisture status of a number of fields by a single unit, providing accurate information for scheduling decisions.

There are numerous other systems available to monitor soil moisture status and make scheduling decisions.

Generally these are too expensive and/or too technical (e.g. neutron moisture meters, time-domain reflectometry units) to be suitable for routine farm use for irrigation scheduling.

IMPROVING IRRIGATION APPLICATION EFFICIENCIES OF SUGARCANE

An 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. For instance, if 1.0 ML/ha (or 100 mm) is applied to a sandy loam soil with a readily available water content of 0.5 ML/ha (50 mm), the irrigation application efficiency is 50%.

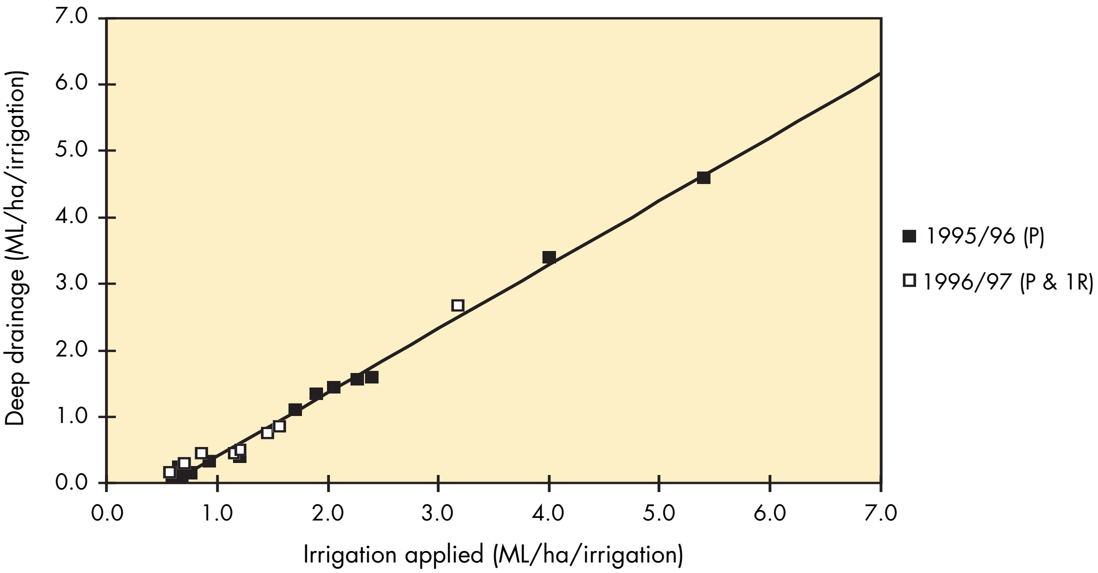
Maximum irrigation application efficiencies can be achieved by reducing losses of irrigation water. Irrigation losses occur through storage and transmission, evaporation from the soil surface or from the leaves of the plant, and deep drainage or run-off as tail-water. Irrigation systems in common use often reflect the need and capacity of the system to manage water efficiently.

Furrow irrigation

Freely draining alluvial soils

In the Burdekin Delta, the main irrigation loss is through deep drainage. Figure 7 shows that, if more water is applied to the soil than it can hold, most of the excess water is lost to deep drainage on these freely draining soils.

Several factors have significant impacts on the irrigation efficiencies of these soils. These include inflow rate, furrow length, furrow



P = plant, 1R = first ratoon
Assumes 0.1 ML/ha/irrigation tail water loss

Figure 7. *Deep drainage loss compared to total water applied Burdekin alluvial soil.*

shape, cultivation practices, duration of irrigation and slope. Obviously, if the water inflow rate to the furrow is not sufficiently above the soil's infiltration rate, then advance of the water along the furrow will be too slow to prevent excessive downward movement of the water to deep drainage. Similarly, if final infiltration rates are high, then the longer the furrows, the greater the opportunity for water to move below the root zone and be lost. Table 7 illustrates the impact of furrow length on irrigation efficiency for these soils.

Changing the water furrow from a broad based 'U' shape to a narrow 'V' shape reduces the area of surface in contact with the water and so reduces total infiltrated volume and the total application necessary (Table 8). Reduced cultivation decreases soil disturbance, decreases the porosity of the 'cultivated layer', and increases the rate of advance of water along the furrow, all of which reduce deep drainage losses. Slopes of 0.2–0.35% are appropriate for these soils provided that erosion is not a problem. The duration of irrigation events should only be sufficient to ensure thorough wetting of the crop root zone; prolonged irrigation after water has reached the end of the furrows, as was practised in the Burdekin Delta in the past, is wasteful and reduces irrigation efficiency sharply.

Table 7. The effect of furrow length on furrow irrigation efficiencies of an alluvial soil.

Furrow length (m)	Water applied (ML/ha)	Application efficiency (%)
300	0.82	61
500	0.94	53
700	1.44	35

RAW of the soil = 0.5 ML/ha. Inflow rate = 2.8 L/sec.

Research shows that reducing water usage on very freely draining soils with these approaches does not reduce yield.

Table 8. The effect of furrow shape and cultivation practices on irrigation water usage (ML/ha/irrigation).

Reduced cultivation		Conventional cultivation	
Broad 'U'	Narrow 'V'	Broad 'U'	Narrow 'V'
1.97	1.32	3.18	2.19

Surface-sealing soils

Some light-textured soils infiltrate water well while they are being cultivated, but seal soon after cultivation ceases. After this sealing, these soils should be irrigated with low inflow rates (less than 1.0 L/sec). Wide 'U' shaped furrows are best on sealing soils to increase the total wetted surface and total infiltration.

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

Where possible, manipulation of irrigation water quality, e.g. by conjunctive use of supplies of differing quality, may assist in alleviating this problem. Additionally, green-cane trash-blankets can improve the total infiltrated volume by increasing the opportunity time for water to move into the soil.

Cracking clay soils

On cracking clay soils, the main irrigation loss is tail-water run-off. After cracking clay soils initially 'wet up', water drains though the soils only very slowly (less than 3 mm/day deep drainage is common).

If tail-water can be minimised, very high efficiencies can be achieved with furrow irrigation on cracking clays. Table 9 shows that good efficiencies are possible with long furrow lengths on these heavy soils and that recycling tail-water improves irrigation application efficiencies.

Table 9. The effect of furrow length and tail-water recycling on irrigation application efficiencies of a cracking clay soil.

Furrow Length (m)	Water applied (ML/ha)	Application efficency without recycling (%)	Application efficiency with recycling (%)
400	1.19	73	88
800	1.22	71	84
1200	1.23	71	83

The readily available water of the soil was 0.87 ML/ha.

Sodic soils

Much like cracking clay 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 the poor soakage, a wide 'U' shape should be used to maximise the area exposed to irrigation water and low inflow rates (less than 1.0 L/sec) should be used. On alkaline sodic soils, the soil ameliorant, gypsum, should be applied either in the irrigation water or to the soil. On acid sodic soils, lime or gypsum can be used. Green-cane trash-blanketing will also improve the surface soil structure of sodic soils and increase opportunity time for infiltration to take place.

Overhead irrigation

To achieve high efficiencies with all irrigation systems, the amount of water applied must be matched to the amount of water stored in the soil. Therefore, growers must be aware of the water holding capacities of their soils (Table 10). Once the water holding capacity of the soil has been determined, the irrigation system can be set to apply only the amount of water held by the soil at a rate not exceeding the infiltration rate of the soil.

Table 10. Storage capacities of Readily Available Water (RAW) in the Burdekin, Central and Bundaberg districts

Burdekin (measured)		
Soil type/texture	Location	RAW in the root zone (mm)
Cracking clay (Barratta)	BRIA	90
Clay loam/silty clay loam	Delta/BRIA	80
Loam & silty loam	Delta	70
Sandy loam	Delta	60
Loamy sand	Delta	50
Sand	Delta	30–40
Sodic clay (Oakey)	BRIA	40–90

Central (estimated)	
Soil type	RAW in the root zone (mm)
Sand	20–30
Alluvial	50–70
Non Calcic 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	60–70
	Sandy loam	40–50
Gleyed Podzolic	Fine sandy loam	60–70
	Sandy loam	40–50
Black Earth	Medium clay	50–60
Alluvial	Sand	40

When a water winch or hard-hose irrigator is used, the application rate can be altered by increasing or decreasing the speed at which the unit travels (Table 11). The faster the speed, the less water that will be applied in one pass.

From Table 11, it can be seen that, if a soil with 60 mm of readily available water was being irrigated with a water winch, using a 33 mm nozzle at an operating pressure of 60 m of head, and a travel speed of 20 m/h, then 58 mm of water would be applied.

Therefore, irrigation loss would be minimised and application efficiencies would be high.

Once the application rate is matched to the soil water holding capacity in this way, irrigation application efficiencies of overhead systems will be good.

Table 11. Typical application rates for water winch and hard-hose guns.

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

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 cross-wind will increase application rates downwind of the winch, which may lead to losses from run-off and lower efficiencies. A strong cross-wind will also decrease application rates upwind of the winch, leading to potential plant stress and loss of yield, particularly if this occurs regularly. Watering when conditions are calm minimises this problem. Still conditions are most common at night.

With centre-pivot irrigation systems, care must be taken 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. Lateral move or boom irrigators can minimise both of these problems.

With all overhead systems, green-cane trash-blanketing may be beneficial as the trash blanket delays the time taken for water to reach the soil surface, allowing more time for infiltration. Drying of the upper layers of the trash blanket in windy conditions will act to reduce application efficiency.

Drip (or trickle) irrigation

Application efficiency is often quoted as one of the biggest advantages of drip irrigation and a strong argument for its wider adoption. Efficiencies in the 80–90% range are frequently quoted. The flexibility of fertigation techniques and the availability of good quality economical fertiliser products provide definite advantages in convenience and timeliness of fertiliser application. In some instances, reductions in rates of fertiliser applied have been achieved without any loss of production.

However, as with any irrigation system, correct installation and management are necessary to achieve application efficiencies of this level. Factors such as depth of tape placement, tape emitter spacing, tape size, pressure regulation, mainline and submain sizing, filtration, and water quality must be considered.

For subsurface use, depth of tape placement should be varied with soil type, ensuring always that emitters are facing upwards towards the soil surface. In sandy soils, installation at 200–250 mm below level fallow surface (natural ground level), combined with short, frequent irrigations, will allow refill of the soil to the effective rooting depth. As only a narrow band around the tape is wetted in such soils with a small storage capacity, the root zone will be wetted without the loss of water to deep drainage. Excessive irrigation time or outflow rate from the emitters will result in the tape becoming a line source for deep drainage. For a clay loam, placement depth can be increased to 250–300 mm below level fallow surface with larger application volumes as water spreads laterally into the root zone, which has a larger RAW. In clays, placement depth can be increased further to 300–350 mm because of their higher RAW and increased spreading about the tape, allowing less frequent, longer irrigation cycles. However, drainage losses in permeable clay soils (e.g. red soils) and waterlogging in black soils with low permeability are possible. For duplex soils such as a clay loam overlying a clay subsoil, tapes should be placed into the subsoil, especially if root activity is concentrated in the topsoil. Irrigation should effectively supply the root zone, without over-watering, if the subsoil is impermeable. Emitter spacing of the tape chosen should ensure that the root zone between emitters can be fully replenished at each irrigation. Knowing the RAW for the soil and the extent of the effective rooting volume will allow optimum design of the system.

Tape size must be selected to enable water transmission along its full length is sufficient to maintain pressure within the design criteria for uniform output from each emitter. Pressure-regulating valves reduce mains pressure to relatively constant-design operating pressure in the tapes. Both mainline and submain must be of adequate size to transmit the total required volume to the tapes at sufficient pressure to meet output flow rates from the emitters. Most efficient management of this system requires that the soil surface not be wet by water from the tapes, thereby reducing evaporation losses from the soil and weed growth. Water quality, filtration and scheduling are dealt with elsewhere in this chapter.

Surface systems have advantages of easy and cheaper installation by using collapsible submains on top of the ground without the need for flushing mains and the more obvious advantages of easily finding and repairing problems. These have to be balanced against the disadvantages, such as the need to delay installation until after cultivation (and irrigate by other means for that time), greater exposure to rodent and insect damage, the need for weed control, difficulties with tape retrieval pre-harvest, and evaporative loss at each irrigation. Otherwise, all the criteria for subsurface tapes apply. Any decision to use surface tapes must be made well in advance to allow for correct row/interrow profile formation, and pre-emergent weed control, and to plan additional irrigation before tapes are laid.

WATER QUALITY AND IRRIGATION OF SUGARCANE

The importance of the quality of irrigation water cannot be over-emphasised. The success or failure of many irrigation projects has depended on the quality and subsequent management of irrigation water. The following section provides a detailed explanation of water quality and explains how waters of different quality should be managed.

Irrigation waters contain many types of salts. Some are harmful to crop growth, while others have beneficial effects. For example, sodium and bicarbonate salts in the water can affect soil structure adversely, while calcium salts can improve soil structure.

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 sodium hazard will produce sodic soils.

To decide whether irrigation water is suitable for long-term use, a prediction must be made on what the state of the soil will be 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 (sodium adsorption ratio [SAR] and residual alkali [RA]), the presence of toxic ions, and the presence of materials that may clog or corrode irrigation systems. Water analysis is the best way for determining the suitability of a water source for irrigation (Figure 8).

Figure 8. *Irrigation water is analysed at Sugar Experiment Stations.*

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 is the electrical conductivity.

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. The scales on the meters are often incorrectly labelled as mS or µS instead of mS/cm or µS/cm. TDS is also commonly expressed as milligrams per litre (mg/L). Conversions between all these units are:

EC (dS/m) = EC (mS/cm)
EC (dS/m) = EC (µS/cm)/1000
TDS (mg/L) = 640 × EC (dS/m) (approximate)

The sodium adsorption ratio (SAR) of a water is a prediction of how that water will affect the sodicity of the soil—its sodicity hazard. Over time, the sodicity or exchangeable sodium percentage (ESP) of the soil will approximate the SAR of the irrigation water. Sodic soils disperse, are consequently 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 12 indicates the risk of soil dispersion for 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.

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

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

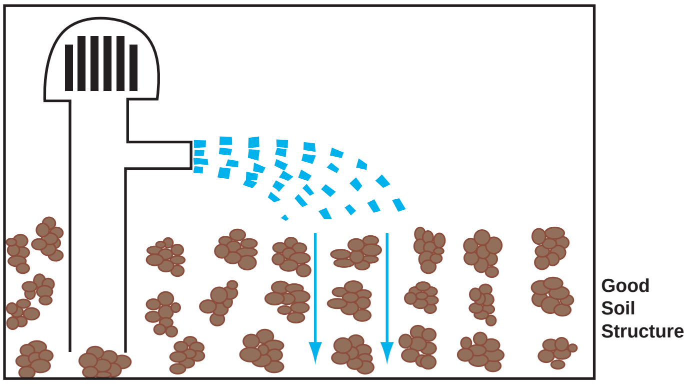
The most important characteristic influencing corrosion rate is pH. Acidic waters with a high proportion of chloride ions are the most corrosive, and turbine pumps are highly susceptible to corrosion.

Effect of water quality on crop growth

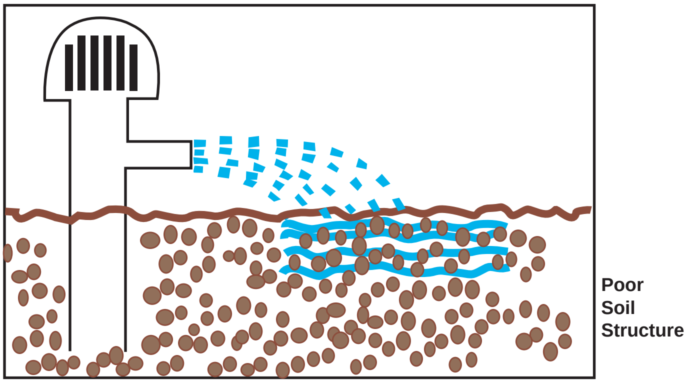
There are seven quality types of irrigation water depending on electrical conductivity and residual alkali content. Water penetration and soil dispersion are illustrated in Figure 9.

Table 12. 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	Over 2.8
1–10	High	Medium	Low	Low	Low
10–18	High	High	Medium	Medium	Low
18– 26	High	High	High	Medium	Low
Over 26	High	High	High	High	Low



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.



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 9. *Schematic diagram of impact of low salinity waters.*

Type 1. Low salinity waters

Electrical conductivity : 0–0.6 dS/m.

Residual alkali : 0–0.2 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.

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.

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.

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.

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 having 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.

With higher salinity waters, irrigation management is important. Slow, heavy irrigations aimed at leaching salt from the crop root zone must be carried out. Light irrigations will result in a rapid build-up of salt. Deep ripping the soil may improve leaching to 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.

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 1 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.

Symptoms of water quality problems

Poor water penetration

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. 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 still 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. Also, water in the soil does not soak to the top of the hill formed in the cane row. Excessive runoff occurs when overhead irrigation is used on blocks such as these. Digging in the water furrow following irrigation will show that only the top 80 mm to 120 mm of soil has been wetted; this limited moisture storage leads to the rapid onset of moisture stress.

Sugarcane in blocks where poor water penetration occurs may show symptoms of water stress as soon as one or two days after irrigation. Also, crops in these blocks are slow to ratoon.

Water stress symptoms in wet soil: salinity

When saline water is used for irrigation, symptoms of water stress such as a poor, yellowish crop with brown leaf tips and margins show up. Although the soil may be wet, the plant cannot take up sufficient water. The symptoms may be particularly noticeable at the bottom end of canefields 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. Irrigation water should not simply follow the tractor wheel mark. Using small irrigation outlets and larger watering sets will also improve soakage. Trickle irrigation may also be of benefit in soils that have 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%. Re-levelling of blocks may be necessary in severe cases. Soil amelioration or modified water quality may be sufficient to overcome the problem.

Trash blanket

Where green-cane harvesting is practised, trash-blanketing 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 of up to 25% have been observed. As the trash breaks down, soil structure at the soil surface is improved and this aids water infiltration. However, this effect is of limited value as soil dispersion still occurs below the immediate surface where the benefits of organic matter in improving soil structure are not present. Soil amelioration by other means is likely to remain necessary.

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

Soil ameliorants

Water penetration can be greatly improved by applying a soluble form of calcium. Gypsum applied at 10 t/ha is the most suitable product. Good results have also been obtained with earth lime (crushed limestone) in soils with a pH 6.5 or less. Solubility of various calcium-containing products is shown in Table 13.

The best result from these products is obtained when they are applied before planting. Applications to ratoon cane do not allow adequate incorporation of the product into the mound of the cane row where it is most needed. Depending on the severity of the problem, these products should be effective for 3–5 years.

Table 13. Typical solubility of various calcium products (saturated solution).

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

*Earth lime is more soluble in acid soils and less soluble in alkaline soils

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.

Improving water quality

Mixing water containing ‘too little salt’ 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.

Dissolvenator

Water quality is also improved by adding a salt such as gypsum to Type 1 and Type 2 waters. The addition of dissolved gypsum to low-salinity waters changes these waters to Type 3 irrigation water which is suitable for all soil types. A dissolvenator (Figure 10) is used to dissolve gypsum in a portion of the irrigation water, which is diverted from the main outlet. As the gypsum has been dissolved, this water is mixed with the remaining irrigation water. The percentage of water to be diverted through the dissolvenator depends on its salinity and is given in Table 14.

Gypsum will also improve Type 4 waters by removing the residual alkali. Increasing the salinity of a Type 4 water may change it to a Type 5 (high-salinity water).

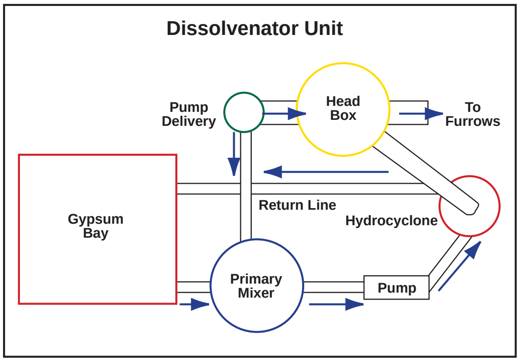


Figure 10. *Schematic diagram of dissolvenator unit.*

Table 14. Irrigation water diversion through dissolvenator as affected by original salinity.

EC untreated water (dS/m)	% water diverted from pump outlet
0.16	29
0.23	25
0.31	21
0.39	17
0.47	12

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.

The amount of water applied for leaching will also affect the quality of the resultant 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 15. In most situations, rainfall can be relied on to provide adequate leaching.

Table 15. Irrigation leaching requirements.

Quality of irrigation water (dS/m)	Tonnes salt per ha per metre of water applied	Leaching requirement* as % 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

*Rainfall effects are ignored

Deep drainage can 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. Subsurface drainage and disposal of the drainage water are then necessary.

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.

SALINE AND SODIC SOILS

Cane yield response to irrigation can be severely restricted by soils which are saline, sodic or both saline and sodic.

Saline or sodic?

Saline soils are those in which the concentration of soluble salts in soil water is sufficient to restrict plant growth. Sodium chloride (table salt) is the most common salt in problem areas of the sugar belt.

Sodic soils occur where sodium represents more than 10–15% of the elements attached to clay particles. Sodic soils may or may not be saline. Often saline soils are also sodic.

Saline soils

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. This form of salinity is caused by the rise of saline or non-saline ground water tables into the crop root zone. Capillary action and evaporation then cause concentration of salt near the soil surface. Watertable rise can be 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. Watertable rise occurs more quickly 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 on a district level can cause a watertable rise that results in secondary salting. Secondary salinity is more severe where subsoils contain a store of salt, or where ground waters are saline and are under pressure.

Where does salinity occur?

In most cane-growing districts, primary salting affects soils in small areas which adjoin tidal areas; this has greatest relevance in the Rocky Point and Moreton mill areas. Secondary salinity occurs in the Burdekin, Bundaberg, Isis, Maryborough and Mareeba-Dimbulah irrigation areas.

Soil salinity will develop where a source of salt or shallow ground water 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 ground water systems are subjected to more leaching and less evaporation, thus less concentration of salt occurs.

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 tend to absorb fresh soil water. As soil water becomes more saline, the difference in osmotic pressure between roots and soil 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 as well as reducing growth of individual stalks.

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 a 1:5 soil:water extract ($EC_{1:5}$) or a saturation 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 16). In the field, Electromagnetic Induction Meters can be used to measure soil salinity quickly.

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. Technology and expertise are now available to recognise areas where salinity is likely to prevent sustainable economic production and cause land degradation. Not developing these areas for cropping should be the first step in future management of salinity.

In existing saline areas, or where only 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 subsurface drainage or ground water pumping will be required to prevent the rise of watertables into the root zone. Care must be exercised in the disposal of drainage water to prevent adverse impacts on others or the environment. Bare fallows in the wet season should be avoided to assist with deep drainage control. Where surface and subsurface 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. 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.

Table 16. Approximate conversion factors between electrical conductivity of a 1:5 soil:water extract ($EC_{1:5}$) and a saturation extract (EC_e).

Texture	Clay content (%)	To convert $EC_{1:5}$ to EC_e, 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

The high cost of subsurface 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.

Tree planting alone is unlikely to lower watertables and control salinity unless 35–45% 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. A saline area should be drained, and then gypsum may be required if the soil is sodic. Gypsum can be added progressively as the original salt load is reduced.

Sodic soils

Where do sodic soils occur?

Sodic soils were 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 canegrowing districts. In the Burdekin River Irrigation Area (BRIA) and Mareeba-Dimbulah Irrigation Area (MDIA), soil mapping has identified sodic soils, and the maps and accompanying soil descriptions are useful tools.

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 BRIA and MDIA, and solodics or soloths in the southern and central districts. Sodic soils may be any colour. 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 in the profile than 600 mm generally do not restrict cane growth, but do reduce drainage through the soil profile. When a sodic soil is wet, the clay is dispersed, it has a very low load-bearing capacity and tends to be boggy. When dry, sodic soils set very hard. Sodic soils are poorly structured and the lighter-textured topsoils turn into dust or, when cultivated using ripper tynes, the disturbed soil breaks into large, hard clods.

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 beef wood (*Grevillea 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 (*Melaleuca quinquenervia*) swamp mahogany (*Tristania 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 considered sodic when the ESP is greater than 6 and severely sodic when above 15.

The development of a 'Sodic Soil Tool Kit' for the rapid field diagnosis of sodic soils has recently been completed.

How does sodicity reduce yield?

Recent research on soils with a wide range of sodicity in the fully irrigated Burdekin environment showed that a 20% yield loss had occurred at ESP of 12.25; yield was halved by ESP of 31; and cane growth had failed completely by ESP of 61. This compares with research at Mackay on a strongly sodic soil, not fully irrigated, which showed that a 20% yield loss had occurred up to ESP of 15; yield was halved at ESP of 33; and cane growth had failed completely by ESP of 66.

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 that 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 storage in the soil are reduced.

Management of sodic soils

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

To reduce the degree of sodicity, a soluble calcium source must be added and leached through the soil. As it leaches through the soil, 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 water table 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. Lime may be an effective ameliorant in acid sodic soils, but not in soils with pH greater than 6.5. Gypsum application should be accompanied by ripping. Mill mud and ash, added at high rates also improve production on sodic soils. 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, increasing total infiltration, reduces losses by evaporation and increases the amount of water available for plant uptake and leaching, and holds plant-available water itself.

The behaviour of sodic soils also depends on the quality of irrigation water and the way in which 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 (conjunctive use). 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. The more vigorous varieties, such as Q133, Q138, Q136 or Q127, are generally the best performers on sodic soils.

IRRIGATION SYSTEMS OF SUGARCANE

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

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 3% slope, although greater slopes have been used. However, application efficiency with furrow irrigation is variable, ranging from 30–90%, but low application efficiencies can be improved significantly by good management. Waste water can be collected in tail drains or in on-farm storages for recycling.

In young plant cane, the cane drill is generally used as the water furrow. When cane is planted into dry soil, a light irrigation can be used to encourage germination. To achieve this light irrigation, the bottom of the drill is compacted using a heavy press wheel, often coupled with a higher water inflow rate.

Where such post-planting irrigation is practised, no more than 60 mm of soil cover over the cane sett is generally used. On heavy-textured soils, where waterlogging is a problem, less than 20 mm of soil cover should be used. Alternatively, mounding-up the soil, planting into the mound followed by irrigation of the interspace gives excellent results on these soils.

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 assures good contact with setts.

Furrows are formed between the cane rows, and a hill 150–250 mm high is formed in the cane row when the plant crop is 3–6 months old. Soil in the hill will settle to give a final hill height of 100–200 mm.

Slope and furrow length

Furrow irrigation systems are rarely designed with slopes greater than 3%. Slopes of less than 1% are most often used. For example, in the Burdekin district, most growers prefer slopes between 0.06% and 0.3%. 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 the Table 17.

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% or less, cross slopes in excess of three times the furrow slope may be used.

Table 17. 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

Varying slopes down the length of the furrow can be used 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 poor water penetration occurs, slopes as low as 0.06% 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 River Irrigation Area, row lengths are commonly over 1000 m. Furrow lengths in other areas, such as Bundaberg and Mackay, are commonly 200–400 m.

Low water use efficiency and excessive deep percolation losses may result from the use of very long furrows. In general, the slope should be increased as furrow length increases but, again, adequate water penetration is the overriding consideration. Waterlogging problems are likely where long rows and low slopes are used; this may be worse where green-cane trash-blanketing is practised.

Furrow shape and flow rates

For irrigation of permeable soils, steeper slopes (greater than 0.5%) and shorter row lengths (100–300 m) are used. 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 more quickly in the furrow. The 'V' shaped furrow reduces the soil surface area in contact with the water.

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

Varying the flow rate down each furrow can also dramatically alter the water applied to the soil. Hard-setting soils will need a very low flow rate (as low as 0.1 L/sec per row), whereas some soils may need very high flow rates (2.5–3.0 L/sec per row). This flow rate again will be dependent on slope, infiltration and length of run. The aim with furrow irrigation is to apply an even amount of water throughout the whole block.

Infiltration

Water infiltrates most quickly into dry soil. For example, on a moderately permeable soil, an initial infiltration rate of 200 mm per hour may drop to a steady rate of 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 6 hours. After the initial wetting, infiltration rates may drop to less than 2 mm per hour. The factors which cause such poor water penetration are water with low salinity, high sodicity hazard, 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.

Irrigating a trash blanket

On many soil types, furrow irrigation is suitable where green-cane trash-blanketing is practised. During irrigation of young cane, water passes under the trash without disturbing it. The trash blanket reduces evaporation from the soil, particularly during the early stages of the crop.

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 furrow irrigation of trash-blanketed crops, correct furrow slope, cross fall and hill size in the cane row become more critical because trash slows the flow of water. This results in a greater depth of water in the furrow. Furrow shape may need to be adjusted for green-cane trash-blanketing, e.g. higher hills or a narrower furrow. 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.

Costs

Capital costs will vary according to terrain and the source of irrigation water. Estimated equipment costs for furrow irrigation of a 50 ha farm are about $73 000 (Table 18). This cost includes land levelling and earthworks for tail-water return (Bundaberg Irrigation Economic Assessment Report, SKM, 1996).

Table 18. Equipment costs for furrow irrigation on a 50 ha farm.

Surface water pump	$10 491
Gated pipe	$1 320
Land forming	$25 000
Mainline	$26 204
Tail-water return earthworks	$5 000
Tail-water return pump	$5 000
Total	$73 015

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 alternately. 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 to settle out, while some redistribution of the water takes place in the soil. This reduces the infiltration rate for the next irrigation pulse, which then advances more rapidly over the previously wetted soil.

The use of surge irrigation reduces high water intake at the top end of the field, a common problem with furrow irrigation.

Overhead irrigation

Overhead irrigation systems suit all soil types and provide uniform water distribution under most conditions. Water application efficiencies over 75% 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 result in lower pumping costs.

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 1–2 m per 100 m of pipe should be allowed.

Water cannons

Water cannons operate at high pressures (up to 650 kPa) and require the provision of regularly spaced towpaths. Because towpath spacing is fixed, uneven water distribution occurs if changing wind conditions prevent overlap of water application. Also, towpaths reduce the area available for crop production.

Application rates for most travelling irrigators range from 5–13 mm per hour (mm/h) over 87.5% of the wetted diameter in full circle application. Field tests in light winds showed that precipitation on 70% 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 330° arc (normal operation) the average was 17 mm/h. However, prevailing winds parallel to the towpath 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. Runoff is likely where application exceeds 15 mm/h.

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

Towpaths

The spacing and direction of towpaths should take account of prevailing winds. As a general rule, spacings should be 60% of the wetted diameter. Typically, towpaths used in sugarcane are spaced 80–90 m (53 rows to 60 rows) apart. Towpaths should be oriented, where possible, across rather than parallel to prevailing winds and should not be used as drains. Keeping the towpath dry around the water cannon during irrigation will result in fewer tracking problems.

Costs

Machinery and installation costs (Table 19) will vary according to farm size, shape and topography plus the expected irrigation requirements. In drier districts or seasons, one irrigator may not be sufficient during peak demand.

Because of the high pressure (around 500 kPa) required, operating costs are high. Typical pumping costs at 540 kPa nozzle pressure are $28 per ML of water.

Table 19. Equipment costs for a water cannon on a 50 hectare farm (guide only).

Irrigator plus hoses and fittings	$27 116
Pump and electric motor	$13 348
Mainline	$27 141
Total	$67 605

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 towpath. The hose is used to pull the carriage towards the reel. 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. As the hose is pulled in a straight line instead of being dragged in a loop, the hose is less prone to damage, particularly on stony ground. 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 are approximately $3000 more expensive than their soft-hose counterparts. Operating costs are higher due to the higher operating pressure required to overcome head loss due to friction in the hard hose.

Hand-shift sprinklers

Hand-shift sprinklers are used mostly for strategic irrigation of young plant and young ratoon cane. They are particularly useful where limited water supplies are available. 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 system is the high labour requirement. This makes their use impractical in tall crops in Australia. Where sprinkler risers are mounted in the pipe, each sprinkler set will irrigate 12–14 rows. This requires frequent shifting of irrigation pipes. 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.

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

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 (300–400 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 since running the spray-line uphill results in poor water distribution.

Lateral move irrigators

Lateral or linear-move irrigators use water obtained either directly from open channels or through flexible hose (Figure 11). Unlike travelling irrigators they operate at low pressures. The system consists of a number of horizontal spans with irrigation droppers attached. Spans vary from 30–60 m in width. Irrigation width is increased by adding more spans and total widths up to 1.5 km can be used. Each span is mounted on a pair of large diameter wheels which are driven by electric motors.

Lateral move irrigation is a precise method of irrigating. Large areas can be irrigated with a high application efficiency and application rates are easily varied by changing the speed of travel. Initial equipment costs are high at around $2000 per ha. Offsetting this are low labour requirements when the system is operated on a suitable layout. The system can be largely automated.

Centre-pivot irrigators

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

Centre pivot irrigators use low operating pressure and have very low labour requirements. The need for circular fields is a severe limitation for the system in the Australian sugar industry. However, extra end nozzles can be used to irrigate the areas in the corners of fields not covered by the droppers.

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.

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 60–80 m apart depending on the boom length.

Boom irrigators operate at pressures as low as 70 kPa and because of this, operating costs are much lower than for water cannons.

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 by varying ground speed. For example,

Figure 11. *Lateral move irrigator.*

the irrigation time for a 400 m run can be varied from 5–24 hours.

Cost of an 80 m boom which would be able to irrigate 20–25 ha is approximately $55 000. Also, class 6 PVC pipe can be used for the mainline and this is about 30% cheaper than class 9 PVC pipe which is usually required for water cannons. Operating costs should average $12 per megalitre applied, less than half the cost associated with operating a water cannon.

Drip (or trickle) irrigation

Drip irrigation systems have the ability to deliver water to meet plant 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. An essential part of the drip system is the filtration system, which must be adequate for the size of the system.

Water is delivered to the plant root zone via thin-walled tubing laid on top of or below the soil surface. 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 requirements include air valves to purge air from the system, a pressure reducing valve (PRV) to reduce mains pressure and regulate flow at an appropriate constant pressure, pressure gauges to facilitate monitoring of pressure in the systems and aid in detection of system blockages, filters to filter out algae, dirt and other contaminates in water supply and flow meters to record flow rates and water usage. Water is supplied at pressures from 40–140 kPa, although a pressure of about 80–100 kPa is recommended.

Selection of drip irrigation tape

Typically, growers use 16 mm diameter tape for shorter runs and 21 mm tape for longer runs. The standard emitter spacing is 0.6 m for most soil types but 0.4 m for sandy soils to ensure continuity of wetting along the cane row. Improvement in the design of emitters using a longer flow path and turbulent flow has reduced the incidence of blockages. Standard emitter flow rates are in the range 1.5 to 1.65 L/h, but it is desirable to have a higher flow rate around 2 L/h for waters with high iron or organic matter levels to reduce the incidence of blockages.

Surface system

Here, drip tape is laid out when the cane is 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/or under low water availability. Generally yields will be less than with systems where every row is irrigated.

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

Prior to harvest, removal of surface tape is completed with a tape winder. This piece of equipment is usually attached to the back of the tractor and uses an hydraulic motor driven by the tractor. Stainless steel reels are made to suit block size and amount of tape.

Joining of tape for this removal process is generally done with small pieces of electrical conduit (50 mm long) which have been tapered at each end. Electrical tape can be used for holding joins together during winding. The winding out of the tape in the following year is the reverse process.

Sub-surface system

In this system, the drip tape is usually placed in the soil prior to planting. Some planters have the facility to install the drip tape while planting, ensuring constant depth settings in relation to cane setts. The system can be completed with mainline and fittings before planting. However, if time is restricted, the crop can be planted and irrigated by an existing method for the first watering.

The drip tape should be placed approximately 100 mm below the planting depth. Tape placement should be a maximum of 250–300 mm below level ground. Deeper tape placement will cause excessive leaching of irrigation water and unsatisfactory wetting of cane setts, particularly on sandy soils.

The aim with subsurface tape is to maintain soil moisture in the root zone without significant drainage or wetting of the soil surface. Because of the reduced wetting zone with drip irrigation, frequency and amount of irrigation need to be adjusted compared to other irrigation techniques to avoid deep drainage or, alternatively, crop stress.

Drip irrigation gives the ability to irrigate with small irrigations as frequently as daily (or even a number of times per day). Typically, sandy soils with low water storage capacity are watered on a daily basis and soils with higher water storage capacity once or twice per week. Water applications are adjusted to meet crop water demand which is in the range of 0.6 to 0.8 times ‘class A’ pan evaporation at full canopy.

Tensiometers are a useful tool for monitoring effectiveness of irrigation and deciding when to start up after rain. Soil moisture logging equipment such as the EnviroSCAN® is valuable in determining the wetting/withdrawal pattern in different soils and frequency of application.

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

Filtration

Adequate filtration is essential for the success of this irrigation system. Filtration is used to remove algae, dirt, iron precipitate and other suspended solids from water. The filtration needs will depend on the area irrigated and the type and quality of water supply. In general, bore water does not need as large a filtration system as surface water. Before installing drip irrigation, full water analyses (including iron and maganese) should be obtained to determine any potential problems with the water supply. Levels of iron up to 1 ppm are acceptable. Often associated with the iron are ‘iron bacteria’, which also can cause blockages by the agglutination of bacterial slime and precipitated iron.

Types of filters include sand, media and disk filters (Figure 12). Each differs in application and ability to remove sediment/precipitates. If the water quality in the supply is variable, always ensure that the filtration system will cope easily with the worst times. Although this can be a very expensive portion of the irrigation system, it is important not to accept anything but the best set-up.

Maintenance

Chlorination is needed to kill bacteria and algae associated with the water supply. This 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 as chlorine needs acidic conditions to work effectively. Larger amounts of acid can be used to bring iron precipitate back into solution and this results in further cleaning.

For subsurface installations, twice-yearly injection of trifluralin at 0.1L/h is used to protect emitters from intrusion by cane roots. Regular checking of tape for damage by rats, wireworms and other pests is necessary to preserve efficiency of the drip irrigation system. Checking flow rates and pressures on

Figure 12. *Large sand filters for drip irrigation.*

a regular basis assists in detecting potential problems.

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. Typical costs vary from $900 per hectare for every second row surface tape with simple filtration to $3200 for sloping blocks with surface water (existing mainline and hydrants). Bore water installations tend to cost about $2000 per hectare. Costs for a full installation on a 50 ha farm have been estimated in the Bundaberg Irrigation Economic Assessment Report, SKM, 1996 (Table 20). It is important to note that growers are looking to replant over sub-surface tape, which is expected to have a working life of 10 years. Automation is an extra cost.

Table 20. Equipment costs for drip irrigation on a 50 hectare farm. (guide only).

Pump (surface water)	$22 316
Mainline	$19 615
Sub-mains	$24 050
Drip tube and fittings	$88 773
Total	$154 754

Summary of irrigation systems

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

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