INCREASED FURROW IRRIGATION EFFICIENCY THROUGH BETTER DESIGN AND MANAGEMENT OF CANE FIELDS

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Abstract

The application efficiency of furrow irrigation for sugar cane production was studied in the Burdekin region. Average commercial irrigation efficiencies in this area were found to vary between 31 and 62% with individual irrigation efficiencies ranging from 14 to 90%. Differences in efficiency were found to be directly related to the farm design, type of soil irrigated and specific management practices. Application efficiency was found to decrease with both increasing furrow length and amount of cultivation. Other factors found to affect efficiency were irrigation cut-off time, water application rate, soil type, furrow shape and tailwater recycling practices. These results indicate that significant improvements in irrigation efficiency could be achieved through the adoption of design and management practices that are appropriate to the farm's environmental and management constraints.

Keywords : furrow, irrigation, farm design, efficiency, water.

Introduction

Approximately 30% of the Australian sugar industry is furrow irrigated with the majority of this area within the Burdekin region. The irrigation requirement of sugar cane in this area is 9.8 ML ha^{-1} $annum^{-1}$ based on the long term rainfall (Anon, 1991). However, rainfall in the past three years has been less than 500 mm yr^{-1} with evaporation greater than

2000 mm yr^{-1}. This has increased irrigation demand and reduced the underground water levels in the delta area. In the Burdekin River Irrigation Area (BRIA), growers have been using above allocation water with periodic demand exceeding the capacity of the surface channel system. However, additional expansion in the BRIA has resulted in above allocation water being no longer available and the possibility of water restrictions being imposed during peak demand periods.

Proper design and management of furrow irrigation systems is necessary to achieve efficient water use and maintain an adequate water supply for all growers or provide water for additional irrigations. It is also necessary to prevent salt accumulation in the root zone and rising water tables in areas irrigated from surface channels. Poor design and management may also lead to poor germination, waterlogging and losses of fertiliser and pesticides out of the root zone. The cost of lost productivity and water wastage from inefficient furrow irrigation practices in the Burdekin delta area has been estimated at $11 M annually (Shannon and Raine, 1996). However, only limited research has previously been conducted to determine the efficiency of current irrigation practices and to determine appropriate irrigation design and management practices for sugar cane production. This paper reports the results of recent research to improve the application efficiency of commercial furrow irrigation design and management practices for sugar cane production.

Materials and Methods

Six sites on commercial sugar cane farms throughout both the Burdekin delta and BRIA were selected for irrigation trials. Sites were selected as representative of the soils, irrigation design and management practices of the region. Irrigations were scheduled according to the farmer’s normal management practice which included either monitoring evaporative demand (mini-evaporation pans), visual assessment of plant stress, or intuition. Irrigation water was applied at low pressures from a head box through collapsible fluming and cut-off fluming cups at the end of each furrow. Between 12 and 20 neighbouring furrows were selected for monitoring at each site with paired blocks established at selected sites to investigate the effect of furrow shape and cultivation practices on irrigation performance. Analyses conducted to investigate the effect of changes in furrow length and to identify the optimum irrigation cut-off time were conducted using the surface irrigation model SIRMOD (Walker, 1993). In each case, input parameters required for model operation were obtained from the measured field irrigations.

Field slope, furrow geometry and furrow length were measured at each site. Electronic inflow and outflow water meters were used to measure the rate and total volume of water applied and lost as tailwater. The inflow meter was mounted in a length of 250 mm PVC pipe and installed in the lay flat irrigation fluming between the head box and monitoring site. The outlet meters were mounted in 50 mm PVC tubing and sited within individual replicated furrows. Float sensors were sited at either 100 or 200 metre intervals along the furrow length to measure water advance time, recession time and depth of flow. Neutron moisture meter access tubes were installed along the length of replicated furrows with readings taken immediately prior to irrigation and two days after the irrigation was completed to provide a measure of the plant available soil water replaced by the irrigation (root zone soil water deficit). These measurements were used to determine an average soil water deficit for each site which was used in the subsequent determination of application irrigation efficiency. The total infiltrated volume for the irrigation event was calculated as the difference between the water applied and tailwater runoff with the deep drainage component calculated as the difference between the infiltrated volume and the soil water deficit. Irrigation application efficiency was calculated as the ratio of the soil water deficit and the total volume applied, expressed as a percentage. Calculations of irrigation efficiency with tailwater recycling assumed a 100% efficiency in recycling.

Results and Discussion

The average water application efficiency for all irrigations monitored at each site ranged from 30% on the permeable alluvial soils to 62% on the heavy cracking clay soil (Table I). However, application efficiencies for individual irrigation events ranged from 14 to 90%.

(Insert Table I near here)

Soil Type, Furrow Length and Tailwater Recycling

Soil type was found to have a major effect on the efficiency of irrigation (Table II). For all soils, increasing the furrow length reduced furrow irrigation efficiency due to greater deep drainage losses. However, the effect was more dramatic on the high infiltration alluvial and non-sodic duplex soils where increasing the furrow length from 300 to 700 m and 100 to 500 m decreased application efficiency from 73 to 42% and 57 to 34%, respectively. In these cases, the majority of the excess irrigation water was lost as deep drainage and little benefit would be gained from recycling the small amount of tailwater running off these blocks.

Furrow irrigation efficiencies on the low infiltration cracking clay soils were found to be in excess of 70% (Table II). Increasing in furrow length from 400 to 1200 m on this soil produced only a small decrease in application efficiency. Even with long furrows, deep drainage losses were small and a significant amount of excess irrigation water was lost as surface run-off. Thus, these soils are suited to tailwater recycling with at least 12% of the applied irrigation water able to be recycled from furrows that were shorter than 1200 m in length.

(Insert TABLE II near here)

Effect of Irrigation Cut-Off Time

Growers in the Burdekin generally continue to irrigate after the water has reached the end of the furrows to ensure that the root zone soil water is completely recharged. However, growers generally have no measure of the period of time required to recharge the soil water deficit, irrigation controllers or timers are not widely used, and the irrigation is often continued until it is convenient to be manually switched off. Thus, under commercial conditions, a significant component of the irrigation water applied may be lost as excessive tailwater (Table III). For the specific irrigation example presented in Table III, 20% of the applied water would have been saved if the irrigation was stopped as soon as the soil water deficit was fully recharged. It is important to note that for this soil, switching off the irrigation at the appropriate time reduced not only the volume of tailwater discharged but also significantly reduced the volume of water lost as deep drainage. This is consistent with other irrigation results for the alluvial soils which show that on average more than 10% of applied water would be saved by more accurate timing of irrigation cut-off.

(Insert Table III near here)

Effect of Application Rate

The effect of water application rate on irrigation efficiency appears to be a function of soil type (Table IV). Changing the rate of water application on the cracking clay soils produced no significant difference in the volume of water applied and the application efficiency. This may have been expected as the majority of the infiltration in this soil occurs by filling the crack volume. Thus, a change in the rate of water applied to this soil would not be expected to affect the crack volume, the volume infiltrated nor the irrigation efficiency.

Reducing the rate of water application on the high infiltration alluvial soils resulted in less infiltration and an increased application efficiency (Table IV). These soils have no appreciable cracks and infiltration is a function of the soil's saturated hydraulic conductivity. Thus, it seems reasonable to expect that the reduction in intake associated with lower application rates is primarily a function of the reduced wetted perimeter and surface area available for infiltration. However, it should be noted that further reductions in application rate may not produce comparable increases in irrigation efficiency. At very low application rates, the rate of water application may exceed the intake rate of the furrow resulting in irrigations which do not reach the end of the furrows and a reduction in irrigation efficiency.

(Insert TABLE IV near here)

Effect of Furrow Shape

The shape of the furrow has a significant effect on infiltration and irrigation efficiency on the alluvial soils of the delta area (Table V). The two furrow shapes in common usage within the Burdekin sugar industry are the broad based "U" shape and the narrow based "V" shape. Both are commonly formed using a set of hill-up boards with the "V" shape being produced by tilting the boards forward. The narrow based furrow was found to significantly reduce the amount of infiltration compared to the broad based furrow. This was presumably due to greater surface compaction and a smaller wetted perimeter for infiltration in the narrow based furrows. With smaller infiltration rates, the water in the narrow furrows advanced faster reducing the irrigation period from 13 hours to 8 hours and reducing the total volume applied comparably. Over ten successive irrigations, the broad based furrows required the application of 16.8 ML ha^{-1} while the narrow based furrows required only 10.6 ML ha^{-1} representing a water saving of 37%. This has important implications not only for reducing the volume of water applied but also for reducing the time to conduct irrigation cycles and the pumping capacities required.

(Insert TABLE V near here)

Effect of Cultivation Practices

Cultivation practices have a significant effect on the infiltration characteristics and irrigation efficiency of alluvial soils (Table VI). Normal post-harvest cultivation practices are conducted for weed control, the incorporation of cane trash using inter-row discs or tynes, and the re-forming of furrows using boards. These activities disrupt the soil surface and generally increase infiltration. On highly permeable soils, this may lead to excessive deep drainage losses and reduced irrigation efficiencies. However, repeated wetting and drying cycles associated with subsequent irrigations cause the soil surface to slake and seal reducing infiltration.

Reducing cultivation on these soils and adopting minimum tillage practices was found to reduce the volume of irrigation water applied (Table VI). However, irrigation efficiencies under minimum tillage were also low for the first few irrigations after harvest compared to later in the season. Generally, slower advance times and greater depths of flow were measured for the irrigations conducted immediately after harvesting suggesting that the unconsolidated trash acts to impede advance and increase infiltration. Successive irrigations presumably act to consolidate the trash, reducing impedance and increasing the rate of irrigation advance. However, there appears to be no difference in the irrigation efficiencies between the cultivated and minimum till treatments after the first few irrigations.

(Insert TABLE VI near here)

Conclusions

Application efficiencies for furrow irrigation of sugar cane in the Burdekin area have been presented. The low infiltration cracking clay soils were found to be ideally suited to furrow irrigation with application efficiencies in excess of 70% for furrows up to 1200 m in length. For these soils, significant improvements of between 10 and 15% in irrigation efficiency could be obtained through the adoption of tailwater recycling strategies.

For many commercial irrigations conducted on the more permeable alluvial and non-sodic duplex soils, less than half of the applied water was found to be available for plant use. As most of this inefficiency was due to deep drainage losses, no justifiable benefit would be obtained by tailwater recycling systems on these soils. However, there is the potential for significant improvements in irrigation efficiency on these soils through the adoption of appropriate design and management practices. Specific practices that have been shown to increase irrigation efficiencies in these soils include the adoption of shorter furrow lengths, better timing of irrigation cut-off, selection of appropriate water application rates, narrow furrow shapes and a reduction in cultivation practices after harvest.

Acknowledgments

The authors would like to thank J Linton, G Pasquale, E Jones, R Searle, I Kovacich and C Williams for providing the field sites and A Fairfull and R Geddes for assistance with the field work. This research was funded by the Sugar Research Development Corporation and the Bureau of Sugar Experiment Stations.

REFERENCES

Anon. (1991). Irrigation of sugar cane. SRDC/BSES, Brisbane.

Shannon, E.L. and Raine, S.R. (1996). Improving the irrigation efficiency of Burdekin canegrowers. Proc. 8th Australian Agronomy Conf., Toowoomba.

Walker, W.R. (1993). SIRMOD. Irrigation simulation software. University of Utah, Logan, Utah.

Table I - Irrigation efficiencies for commercial sugar cane production in the Burdekin region (1994/95).

Site	Soil	Furrow length (m)	Number of irrigations monitored	Total volume applied (ML ha^{-1})	Average volume applied (ML ha^{-1})	Average soil water deficit (ML ha^{-1})	Irrigation efficiency^{A} (%)
Mulgrave	cracking clay	1647	7	10.2	1.5	0.9	62
Leichardt	non-sodic duplex	480	6	12.5	2.1	0.7	34
Jardine	non-sodic /sodic duplex	1263	5	7.6	1.5	0.6	40
Jarvisfield	alluvial	470	17	24.4	1.4	0.6	42
Rita Island	alluvial	390	10	15.6	1.6	0.6	38
Home Hill	alluvial	470	15	29.8	2.0	0.6	30

[A] without recycling

Table II - Furrow irrigation efficiencies with changes in furrow length for some Burdekin soils.

Soil	Application rate (L s^{-1})	Furrow length (m)	Irrigation time (hours)	Water applied (ML ha^{-1})	Application efficiency without recycling^{A} (%)	Application efficiency with recycling^{A} (%)
alluvial	2.8	300	3	0.82	73	91
		500	7	0.94	64	70
		700	15	1.44	42	43
non-sodic duplex	2.5	100	2	1.23	57	62
		300	8	1.56	45	47
		500	18	2.09	34	35
cracking clay	2.7	400	7	1.19	76	91
		800	15	1.22	74	87
		1200	23	1.23	73	85

[A] Average soil water deficit: alluvial = 0.6 ML ha^{-1}; non-sodic duplex = 0.7 ML ha^{-1}; cracking clay = 0.9 ML ha^{-1}.

Table III - Typical volume balance for a 470 m furrow on an alluvial soil irrigated at 3.4 L s^{-1} furrow $^{-1.}$

Treatment	Application time (hours)	Applied Volume (ML ha^{-1})	Soil water deficit (ML ha^{-1})	Deep drainage (ML ha^{-1})	Tailwater runoff (ML ha^{-1})	Application efficiency (%)
Actual	8.5	1.44	0.60	0.56	0.28	42
Optimum cut-off	6.7	1.13	0.60	0.43	0.10	53

Table IV - Effect of water application rate on the efficiency of furrow irrigation

Soil	Furrow length (m)	Application rate (L s^{-1} furrow^{-1})	Volume applied (ML ha^{-1})	Application efficiency[A] (%)
cracking clay	1647	1.4	1.38	65
		2.8	1.33	68
alluvial	470	1.7	0.92	65
		2.8	1.13	53

[A] Average soil water deficit: alluvial = 0.6 ML ha^{-1}, cracking clay = 0.9 ML ha^{-1}.

Table V - Effect of furrow shape on irrigation efficiency for an alluvial soil.

Furrow shape	Application rate (L s^{-1} furrow^{-1})	Furrow length (m)	Irrigation time (hours)	Water applied (ML ha^{-1})	Application efficiency[A] (%)
Broad based “u”	1.7	470	13	1.09	46
Narrow based “v”	1.7	470	8	0.67	75

[A] Average soil water deficit = 0.6 ML ha^{-1}.

Table VI - Irrigation efficiencies for a 470 m furrow on an alluvial soil after ratooning.

Treatment[A]	Irrigation date	Volume applied (ML ha^{-1})	Application efficiency[B] (%)
cultivated	3/10/94	4.3	14
	18/10/94	1.7	35
	8/11/94	1.5	40
	15/12/94	1.3	46
minimum till	15/9/94	2.0	30
	6/10/94	1.6	38
	21/10/94	1.5	40
	7/11/94	1.4	43

[A] Successive irrigations (a) cultivated = after the last cultivation following harvesting and (b) minimum till = after harvesting

[B] Average soil water deficit = 0.6 ML ha^{-1}.