A PRELIMINARY INVESTIGATION OF ALTERNATE FURROW IRRIGATION FOR SUGAR CANE PRODUCTION

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Abstract

Alternate furrow irrigation (AFI) has been successfully used in a variety of cropping systems and climatic conditions to conserve water without loss in production. Recent experimental work investigating AFI in Columbia for sugar cane production, found that AFI resulted in both substantial water and labour savings. This led to a preliminary investigation into the potential for AFI to reduce water use in the Burdekin. Crop growth rates, water extraction, water advance rates and final yield were measured on several sites and soils. The use of AFI was found to reduce yield compared to every furrow irrigation (EFI) when the same irrigation frequency was applied to both treatments. However, when AFI was applied more frequently in response to the crop's evapotranspirative demand, there was no decrease in yield. Except for the cracking clay soil, less water was applied to the individual AFI treatments than the EFI treatments, coinciding with a reduction in the irrigation deficit used to schedule irrigations. AFI was also found to produce an improved crop water use efficiency. This work suggests that AFI may be successfully used within the sugar industry in areas or periods of restricted water supply. However, further research is required to determine the full range of conditions and management practices necessary to develop practical guidelines.

Key words: sugar cane, alternate furrow irrigation, irrigation efficiency, stalk elongation

Introduction

Alternate furrow irrigation (AFI), skip row irrigation or wide-spaced furrow irrigation is the technique whereby water is applied to every second furrow rather than to every furrow. It has been widely used in the USA (Box et al., 1963: Fishbach and Mulliner, 1974; Tsegaye et al. 1993; Mitchell et al., 1995) to improve irrigation efficiency with good results in potatoes, corn, sorghum, cotton and peppermint. Large water savings (up to 50%) without a loss in yield have been achieved in the USA with substantial reductions in the labour required to carry out the irrigation (Stone and Nofziger, 1993; Mitchell et al, 1995). However, in those cases where yield was reduced under AFI (Samadi and Sepaskah, 1984: Crabtree et al, 1985) significant savings in the volume of water used were also achieved which, depending on the price of the water, resulted in an improved crop profitability.

Torres et al. (1996) investigated the potential of AFI for sugarcane production over a seven year period. An initial experiment conducted on a disturbed Vertosol soil found that AFI yielded 38 t/ha cane less than conventional every furrow irrigation (EFI). However, AFI was found to be much more successful on other soil types with water savings of 43-50% achieved under the Columbian conditions. The effect of alternating the actual furrow wetted using AFI was also investigated with no difference in yield found between this treatment and the traditional alternate furrow irrigation where the same furrows are wet on each irrigation. However, it should be noted that the number of irrigations conducted varied from two to five throughout the season with the cane yields ranging from 70 to 150 t/ha.

In the Burdekin region, growers often have to apply 10-15 irrigations or more in a season, depending on soil type and effective rainfall. On average, irrigation need is high at about 10 Ml/ha

(Robertson etal., 1997). Soils in the Burdekin region vary from loamy sands to heavy clays with seasonal application efficiencies commonly ranging from 30-60% (Raine and Bakker, 1996). However, irrigation application efficiencies in this area can be improved through the adoption of appropriate design and management practices (Raine and Bakker, 1996) with substantial benefits worth in excess of $11M annually to the industry (Shannon and Raine, 1996). Several growers in the Kalamia Mill area have reported using AFI for several years and reported anecdotal evidence of a reduction in water use. This paper reports on a preliminary investigation conducted to assess the potential of this technique to improve the irrigation efficiency of sugarcane production in the Burdekin.

Methodology

Experiments were conducted using four different alluvial soils (Block 52, 76, 37 and 11) on CSR's Kalamia Estate and on a cracking clay soil (Block 267) in the Mulgrave area of the Burdekin River Irrigation Area. Blocks were selected to provide a range of soils, slopes, furrow lengths and cane varieties (Table I). The experimental plots were part of larger commercial blocks and the treatments consisted of applying irrigation water to every furrow (EF) and to alternate furrows (AF) within the experimental plot. Prior to imposing the AF treatments, irrigations were conducted in these blocks using the conventional EF technique.

Irrigations of both AF and EF treatments in Blocks 52 and 76 were scheduled using a mini-evaporation pan (Shannon and Raine, 1996) with a pan water deficit of 90 mm. The AF treatment consisted of a two replicated strips of eight rows (length = 650 m). The irrigation of the EF and AF treatments in Block 37 were scheduled using mini-pans with deficits of 90 mm and 70 mm, respectively. This was based on the rationale that the amount of moisture available for the crop was reduced in the alternate furrow treatment compared to the every furrow treatment. The AF treatment in Block 37 consisted of three replicated strips of eight rows (length = 365 m). The AF treatment in Block 11 consisted of four replicated strips of six rows (length = 50 m) randomly located within the block. Irrigation was applied to both treatments when tensiometers installed at 30 cm depth in the EF treatment reached a suction of 30 cBars. All of the trials conducted on Kalamia Estate were maintained until drying off which was approximately eight weeks prior to harvest.

The trial conducted on Block 267 consisted of a single irrigation of 20 rows (length = 1600 m) of both AF and EF treatments. Volume balance and water advance data were recorded to determine the effect of soil cracking on advance times and irrigation performance.

Stalk elongation measurements were made in October and November 1995 on Blocks 52 and 76 and in January and February 1996 on Block 37. As the soil in Block 52 varied from a loamy clay at the top end of the block to a clay at the bottom, stalk elongation was measured at both the top and the bottom end of this block. For the treatments in Blocks 52 and 76, 20 stalks were initially selected for measurement immediately after initiation of the treatment. However, an additional set of 20 measurements was also taken within each treatment after the first 12 days. Stalk elongation measurements of Block 37 were averaged over three sites within the block, each containing 20 stalks.

In Block 52 and 37, the soil moisture status was determined using a neutron moisture meter (NMM). Access tubes were positioned in the middle of the inter-row space and in the centre of the plant row and readings were taken at regular intervals. The quantity of water applied to the two treatments was monitored only in Blocks 37. Whenever possible, the time taken for the water to reach the end of the furrow was recorded for Blocks 52, 76 and 11. The difference in advance time between AFI and EFI was assumed to indicate differences in water infiltration between the two treatments.

The trials in Block 52 and 37 were commercially harvested with the yields and CCS obtained from the mill analysis. The treatment yields in Block 11 were determined from the total fresh weight of millable material sampled from two sections each of five metres. The yield from Block 76 and 267 was not recorded.

Results and Discussion

Increase in stalk height as an indicator of water stress, showed that the crops in Blocks 52 and 76 both suffered water stress about 10 days after the initial treatment irrigation (Figures 1 and 2). However, the onset of water stress in the alternate furrow treatment occurred earlier than in the every furrow treatment where both treatments were irrigated using the same mini-pan deficit of 90 mm. A similar moisture stress, albeit not to the same degree, occurred during subsequent irrigation cycles progressively increasing the difference in stalk height between the two treatments by up to 300 mm after 40 days. This resulted in a 13% decrease in cane yield and a 12% decrease in the CCS produced by the alternate furrow treatment compared to the every furrow treatment on Block 52 (Table II).

Differences in the yield (Table II) and stalk height (Figure 1a and 1b) observed between the EF and AF treatment are due to moisture stress where the treatments were irrigated at the same soil moisture deficit. The moisture stress applied in each of these treatments is illustrated by the changes in soil moisture content from the wettest profile during the season (ie. the profile which had the most moisture stored in the entire profile) in Block 52 (Figure 3). Although there had been significant differences in the crop growth rates measured after day 10, it was only after day 40 that the soil moisture differences recorded by the NMM between the treatments became obvious (Figure 3). After this time, the AF treatments were forced to dry out to a greater extent between irrigations than the EF treatments. This suggests that the crop in the AF treatment was accessing water from a smaller volume of soil than the EF treatment. Hence, the same rate of water uptake (and growth rate) by the crop in the AF treatment could not be maintained as the crop was required to extract water at higher suctions than the EF irrigated crops.

Where a 70 mm mini-pan deficit was maintained for the AF treatment and compared to the EF irrigations conducted using a 90 mm mini-pan deficit, there was no significant ($P<0.05$) difference in stalk growth over a seventy day period (Figure 2b) and no significant difference ($P<0.05$) in the final yield of these two treatments (Table II). The NMM soil moisture data for Block 37 (Figure 4) indicates that the fluctuations in the moisture content during the irrigation cycle for these treatments were much less extreme than where the same soil moisture deficit was maintained for both the EF and AF treatments (Figure 3). This confirms that where the AF treatment is conducted using a smaller mini-pan deficit than the EF treatment, water stress on the crops is significantly reduced and yields similar to the EF treatments can be achieved.

Alternate furrow irrigation usually requires a longer period of irrigation due to slower water advance rates. However, this is dependent on the soil infiltration characteristic and the amount of lateral soil-water movement. Lateral movement is typically minimal in both low infiltration and high infiltration soils and there should be little difference in the advance time of the EF and AF treatments. This was the case for Blocks 11, 52 and 76 where the advance times were not substantially different for the two treatments. As only half the amount of water was applied to the AF treatments in comparison with the EF treatments, and irrigations in each treatment were scheduled at the same time in these blocks, this translated to a 50% saving in the volume of water applied to the alternate furrows (Table II, III). However, the trial conducted on Block 267 with a cracking clay soil, found substantial lateral water movement occurred in this soil through the crack volume. This resulted in the advance time of the alternately irrigated furrows being almost twice as long as for every furrow irrigations with no subsequent improvement in the application efficiency (Table IV). This is consistent with the results of Torres et al. (1996) who also found no improvement in application efficiency on cracking soils and suggests that AFI is inappropriate on these soils.

The amount of lateral soil-water movement also has an effect on the amount of water stored in the soil profile. Water meters were installed in Block 37 to directly measure the volume of water applied to the treatments scheduled at different pan deficits. The average water saving on individual irrigations was 27% while for the whole season it was only 15% due to additional irrigations conducted (Table III). This is substantially less than the 50% saving observed in the Block 52 and 76 trials and implies that using alternate furrow irrigation in this block produced either substantial lateral movement (ie. the entire soil profile is wetted up) or an increase in deep drainage losses. Alternatively, the inflow into the AF and EF furrows may have been substantially different or the irrigation periods of the treatments inconsistent. However, to identify the precise mechanisms affecting these results would require additional irrigation observations including inflow rates, advance rates and soil water moisture distributions.

For Block 11, there was no significant difference ($P<0.05$) between the yield obtained in the AF and EF treatments (Table II). However, there was a significant ($P<0.05$) reduction (35%) in the volume of water applied to the AF treatments producing a 41% increase in the irrigation use efficiency (Table II). This is consistent with the significant improvements in crop water use efficiency that have been associated with alternate furrow irrigation (Talsma et al., 1977; Musick, 1982; Tsegaye et al., 1993) and suggests that AFI has the potential to add significantly to sugarcane productivity under conditions of limited water availability. As both treatments in this trial, were scheduled using tensiometers located in the EF treatment, the AF treatment could have been expected to suffer moisture stress. This did not occur due to the small soil moisture deficit (30 cBar) used for scheduling which resulted in the irrigations being conducted approximately every 6-7 days. Thus, with such frequent waterings, the AF treatment did not suffer the moisture stress observed in the pan scheduled trials. The results may also have been affected by the relatively close (<1.5 m) proximity of the groundwater to the surface throughout parts of this block. However, it is difficult to estimate the contribution of the groundwater to the crop water requirements without measurements. Research is continuing in this block with particular emphasis on water extraction and the recharge by capillary movement from the groundwater.

This work indicates that if alternate furrow irrigation is applied without allowing for a reduced irrigation water deficit substantial yield losses may occur. This contrasts with the results of the work carried out by CENICAÑA in Colombia on sugarcane (Torres *et al.* 1996) and by Mitchell et al. (1995) on a wheat, onions, and peppermint where substantial water savings were obtained without a reduction in yield. However, it is in agreement with the results of Stone et al. (1985) and Crabtree et al. (1985) who found a yield reduction in grain sorghum and soybeans under alternate furrow irrigation even though the water use efficiency increased. Stone et al. (1985) also suggested that AFI should be abandoned during high water-stress periods. This is supported by Stone and Nofziger (1993) who found that AFI may result in lower yields because too little water may be applied, particularly during periods of low rainfall and high evaporative demand. However, in neither of these cases, did the authors investigate increasing the irrigation frequency to reduce the moisture stress during these periods.

In some circumstances, incurring a yield reduction under AFI may be economically sensible, for instance where the cost of applying water and the price for sugar dictate that water savings out-weigh any income lost through yield reductions. With the current relatively cheap cost for water in the Burdekin there is little economic justification for incurring yield losses in order to reduce irrigation costs.

The climatic conditions in the Burdekin are characterised by a high evaporative demand and variable rainfall which may result in a large number of irrigations (15-18) throughout the growing season. Under these conditions, particular attention should be paid to the scheduling of the irrigations to avoid undue water stress. The evaporation mini-pan technique is suited for such purposes and with appropriate calibration there should be no yield losses through the use of AFI. However, while AFI should successfully reduce water applied, this reduction may not as much as has been recorded for other cropping systems and climatic conditions.

Little has been documented regarding the labour savings expected from AFI since most of the research has been done on small experimental plots. Even though AFI requires more irrigations, only half the number of furrows are watered in individual irrigations and considerable labour savings could be expected through a reduction in the number and frequency of cup changes. Similarly, as twice the area can be watered in the same irrigation period, AFI may be a useful practice to reduce the time taken to irrigate the whole farm. This may be an important consideration in areas which have been unable to practice irrigation scheduling due to limitations associated with farm water supply rates.

Conclusions

These preliminary investigations suggest that if alternate furrow irrigation is applied without allowing for a reduced irrigation water deficit, substantial yield losses may occur. However, where a smaller deficit is maintained when using AFI, water savings are reduced but yield is maintained. This also demonstrates that crop water use efficiency will be increased by using AFI which may result in substantial benefits under limited water conditions. Labour savings and improved flexibility in farm irrigation management are also expected to be achieved using AFI. However, further work is required to adequately define the conditions and practices appropriate for successful alternate furrow irrigation in the Australian sugar industry.

Acknowledgment

The contribution of D. Mazzucchelli by collecting the data in Block 11 has been greatly appreciated as well as the contribution of D. Quinan, Manager, Kalamia Estate, CSR Ltd. by allowing the work to be conducted on the Estate. Parts of this work were funded by the Sugar Research and Development Corporation.

References

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

Box, J.E., Sletten, W.H., Kyle, J.H., and Pope, A. (1963). Effects of soil moisture, temperature, and fertility on yield and quality of irrigated potatoes in the Southern Plains. Agron. J. 55: 492 - 494.

Crabtree, R.J., Yassin, A.A., Kargougou, I., McNew, R.W. (1985). Effect of alternate furrow irrigation: water conservation on the yields of two soybean cultivars. Agric. Water. Man. 10(3): 253 - 264.

Fishbach, P.E. and Mulliner, H.R. (1974). Every-other furrow irrigation of corn. Trans. ASAE. 17(3): 426 - 428.

Musick, J.T. and Dusek, D.A. (1982). Skip-row planting and irrigation of grade furrows. Trans. ASAE 25(1): 82 - 87.

Mitchell, A.R., Shock, C.C., and Perry, G.M. (1995). Alternating-furrow irrigation to minimise nitrate leaching to groundwater. Conference Proc. 'Clean Water-Clean Environment- 21st Century', March 1995, Kansas City, Missouri, ASAE.

Raine, S.R. and Bakker, D.M. (1996). Increased furrow irrigation efficiency through better design and management of cane fields. Proc. Aust. Soc. Sugar Cane Tech.: 119 - 124.

Robertson, M. J., Inman-Bamber, N. G. and Muchow, R. C. (1997). Opportunities for improving the use of limited water by the sugarcane crop. In: Keating, B. A. and Wilson, J. R. (eds). *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000.* CAB International, Wallingford, UK.

Samadi, A., and Sepaskah, A.R. (1984). Effects of alternate furrow irrigation on yield and water use efficiency of dry beans. Iran Agric. Research. 3(2): 95 - 115.

Shannon, E.L. and Raine, S.R. (1996). Improving the irrigation efficiency of Burdekin canegrowers. Proc. 8th Aust. Agron. Conf., Toowoomba, 502 - 505.

Stone, J.F., Reeves, H.E. and Garton, J.E. (1982). Irrigation conservation by using wide-spaced furrows. Agric. Water Man. 5(4): 309 - 317.

Stone, J.F. and Nofziger, D.L. (1993). Water use and yields of cotton grown under wide-spaced furrow irrigation. Agric. Water Man. 24(1): 27 - 38.

Talsma, T., Judd, P., Perroux, K.M. and Bridge, B.J. (1977). Alternate-furrow irrigation of dry-season crops. Thai J. Agric. Sci. 10(3): 143 - 153.

Torres, J.S., Villegas, F., and Cruz, R. (1996). Alternate-Furrow Irrigation of Sugar Cane. Proc. XXII ISSCT Congress, Cali, Colombia.

Tsegaye, T., Stone, J.F., and Reeves, H.E. (1993). Water use characteristics of wide spaced furrow irrigation. Soil Sci. Soc. Am. J. 57: 240 - 245

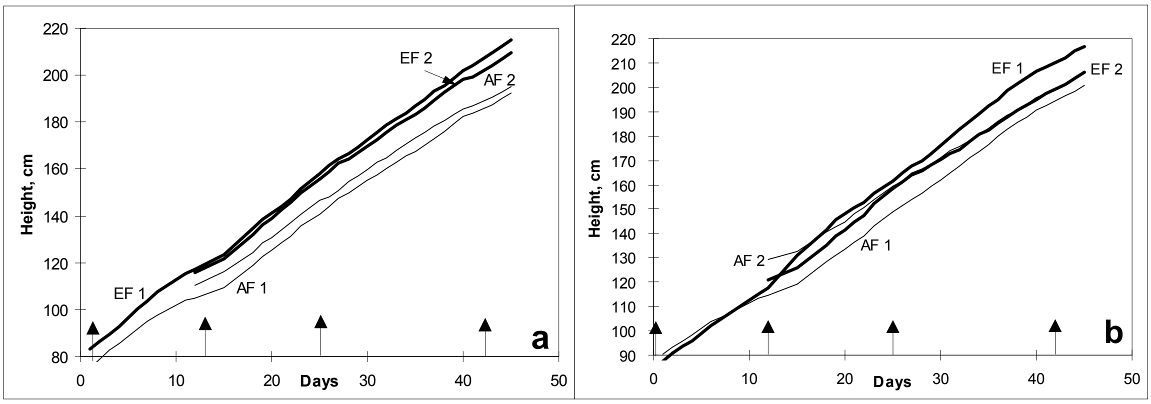

Fig. 1 - Stalk height for plant cane growing in the (a) loamy clay and (b) clay section of Block 52. Irrigations scheduled using 90 mm mini-pan evaporation. (Arrows indicate irrigations)

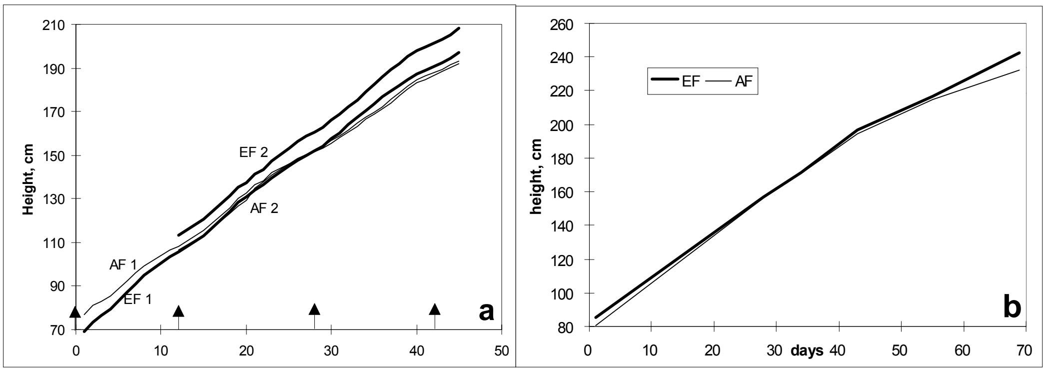

Fig. 2 - Stalk height for (a) plant cane growing in Block 76 and scheduled using a 90 mm mini-pan deficit and (b) ratoon cane growing in Block 37 and scheduled using mini-pan deficits of 90 mm (every furrow) and 70 mm (alternate furrow) (Arrows indicate irrigations)

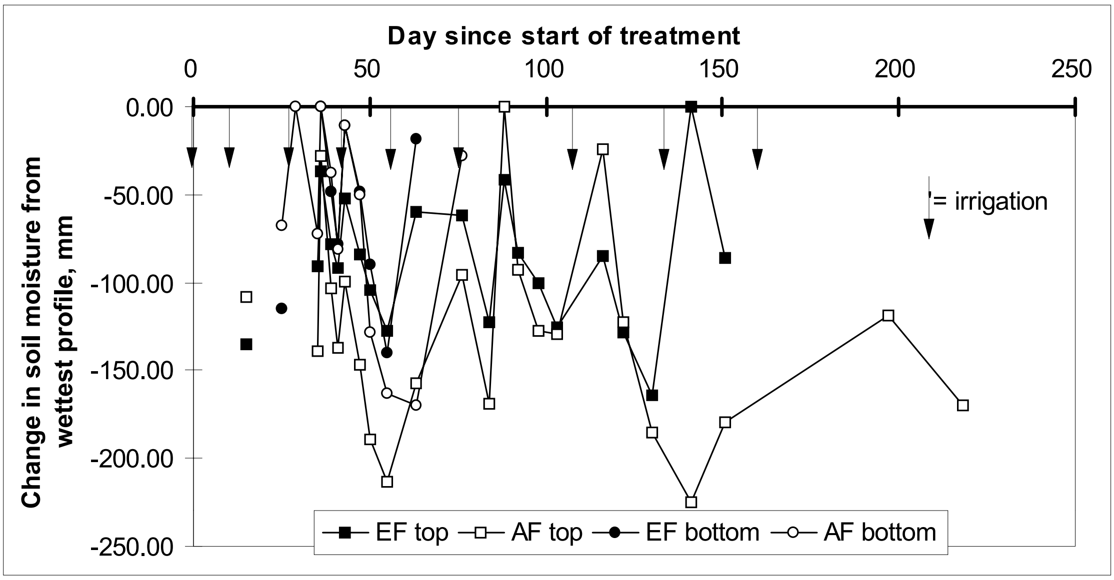

Fig. 3 - Changes in soil moisture content in the plant row for the every furrow (EF) and the alternate furrow (AF) treatments. (Arrows indicate irrigations)

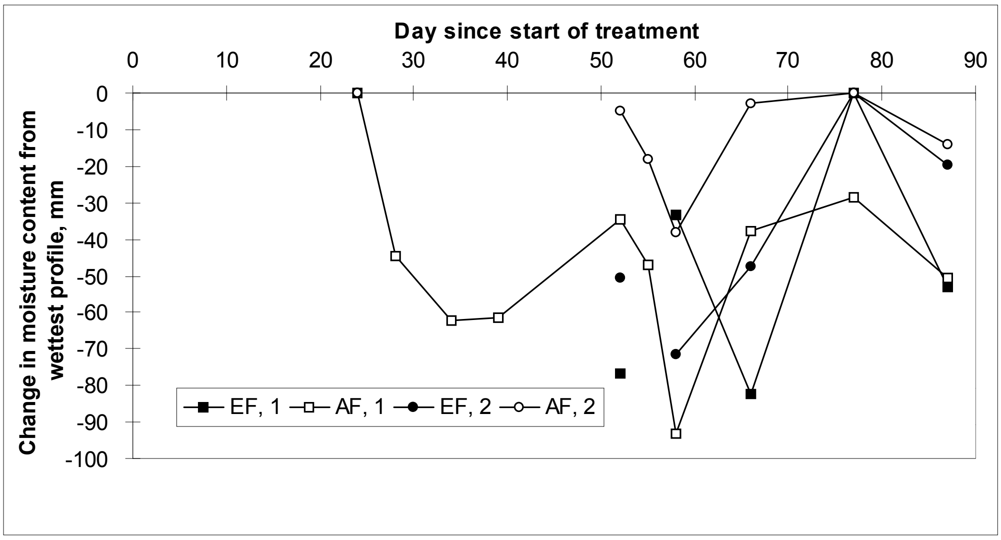

Fig. 4 - Changes in soil moisture content in Block 37 for two different treatments, every furrow (EF) and alternate furrows (AF).

Table I - Details of the blocks used for comparison between every furrow and alternate furrow irrigation

Block	Soil type	Variety and Crop class	Season start and end	Onset of AFI treatment
52	Loamy clay on sand	Q96, Plant	March, '95 - June, '96	November, '95
76	Clayey loam on sand	Q96, Plant	March, '95 - July, '96	November, '95
37	Loamy clay on sand	Q96, 2R	Aug., '95 - Sept., ' 96	January, '96
11	Clay on sand	Q96, Plant	March, '95 - July, '96	January, '96
267	Cracking clay	Q96, 1R	July, ' 94 - Sept., '95	April, '95

Table II - Yield of sugarcane irrigated using the every furrow and alternate furrow techniques

Block	Treatment	Cane Yield (t/ha)	CCS	Irrigation applied (Ml/ha)	IUE* (t/Ml)
52	AF, 90 mm deficit	142 (±4)	11.4 (±0.6)	nm	na
	EF, 90 mm deficit	164 (±11)	12.5 (±0.4)	nm	na
37	AF, 70 mm deficit	132 (± 7)	15.5 (± 0.3)	8.65#	na
	EF, 90 mm deficit	140 (± 3)	15.2 (± 0.1)	10.22#	na
11	AF	133 (± 12)	16.2 (± 0.2)	19.2 (± 0.5)	6.9 (± 0.5)
	EF	143 (± 12)	15.5 (± 0.4)	29.4 (± 1.0)	4.9 (± 0.5)

* IUE, Irrigation use efficiency; #: Only from March to Aug.'96; nm: not monitored; na: not applicable

Table III - Volume of irrigation water applied to the treatments in Block 37.

Every Furrow		Alternate Furrow	
Irrigation Date	Volume (ML/ha)	Irrigation Date	Volume (ML/ha)
4/04/96	2.79	28/03/96	0.85
26/04/96	1.43	9/04/96	1.07
20/05/96	2.08	24/04/96	1.55
5/06/96	1.16	14/05/96	1.19
10/07/96	0.97	31/05/96	1.53
02/08/96	1.79	1/07/96	1.36
		22/07/96	1.10
Total	10.22	Total	8.65

Table IV - Advance time in minutes at 800 m for alternate furrow and every furrow irrigation on a cracking clay soil (Block 267). Time is the average advance time of four furrows and the standard deviations from the average between brackets.

Date	Inflow/furrow (l/sec)	AFI Advance time	EFI Advance time
24/04/95	1.49	2096 (222)	1026 (170)
09/06/95	1.38	1629 (179)	819 (198)
10/07/95	1.51	2616 (84)	1156 (189)