FURROW IRRIGATION IMPROVEMENT AT DWANGWA SUGAR ESTATE IN MALAWI

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Abstract

Long-term mean annual rainfall at Dwangwa Sugar Estate in Malawi is 1370 mm, and occurs mainly from mid-December to mid-April, while the long-term mean annual Class A pan evaporation is 1720 mm. Dwangwa Sugar Estate is predominantly furrow irrigated (>95%). In recent years, the estate expanded horizontally and has implemented ISO 9001:2000. This necessitated a review of the factors that affect performance of furrow irrigation systems, including hydraulics of surface irrigation, water use management, irrigation scheduling and soil water characteristics. Changes to scheduling techniques led to improvements in seasonal water applications and management.

Keywords: Malawi, sugarcane, furrow irrigation, water management, irrigation scheduling

Introduction

Dwangwa Sugar Estate is situated in the Dwangwa River delta at latitude 12º30’S and longitude 34º11’E, and the estate is approximately 500 metres above sea level. Long-term mean annual rainfall is 1370 mm, falling from mid-December to mid-April. The mean annual Class A pan evaporation is 1720 mm.

The estate commenced production in 1979. In 1981, the cultivated area on the estate attained the designed target of 5300 ha. Further gradual expansion took place to 5546 ha in 1997, and then to 6159 ha in 2001. Approximately 95% of the sugarcane is furrow irrigated. Cane yields increased during the first four years, but thereafter remained static. From 1996, there was a marked decrease in cane yields. The capacity of the conveyance structures did not increase at the same rate as the increase in cultivated area and many of the existing conveyance structures were not well maintained.

In recent years, Dwangwa Sugar Corporation introduced ISO 9001:2000 as a Quality Management System (QMS). The introduction of ISO 9001:2000 led to a review of furrow irrigation practices, with a view to identifying non-conformities that affected the performance of furrow irrigation and water management practices. The review results of key performance areas were used as a basis for the case study reported here.

Background

Although furrow irrigation is often perceived to be one of the most inefficient systems, it has been the mainstay of the Dwangwa estate since 1979. The main sources of water are Lake Malawi and the Dwangwa River, which has the Rupashe River as its main tributary upstream of the estate. During the later months of the year, usually from September to early December, there is reduced river flow in both the Dwangwa and Rupashe Rivers and supplementary water is pumped from the lake to meet irrigation requirements. Although water is not limiting, the conveyance structures, i.e. canals and pumps, cannot handle peak water requirements for the estate.

The irrigation standards at the estate have been such that one-third of the irrigated area is above the night storage dams, and two-thirds of the area below the dams. This means that for every field irrigated above the dam, there should be three fields irrigated below the dam. The canal design was based on eight-hour irrigations. The flow from the feeder gate, assuming free flow, was designed at 85 L/s to irrigate a 24 ha field in not more than seven days, with a target gross application of 70 mm. Spear (1992) in a survey of estate irrigation, observed that while the intention was that each pair of irrigators had 85 L/s at their disposal, in practice this flow was closer to 50-60 L/s, which resulted in less than the desired 3.5 ha irrigated in a day. Furrow length is usually 300 m, with a gradient of 1:500. The scheduling technique from 1990 to 2002 was the use of a set of notched rulers that were developed to estimate the date of the next irrigation, given a certain harvest date. The notched rulers were used in the dry months of the year (April to November) and rainfall was not accounted for. This irrigation scheduling method was used across the estate, and a constant Total Available Moisture (TAM) value of 105 mm was assumed for all fields.

Of the four main factors that influence contact time, and hence water application depth, only alterations to the size of the stream flow and width and shape of the irrigation furrow can be made during the cropping season or at ratooning. The choice of the stream size will affect intake rate. When the intake rate of the soil is known, irrigation cut-off times can be estimated to produce least run-off during irrigation whilst achieving sufficient water distribution and infiltration depths. Alterations to the grade and the length of the furrow can only be made after ploughout. It is to these former factors that the irrigators must look for controlling and maintaining a high standard of efficiency of application (James, 1988). Clowes and Breakwell (1998) observed that the tendency of the industry in the past has been to avoid interfering with the lateral spread of the cane row on the ridge. This resulted in the irrigation furrow becoming increasingly narrow so that in old ratoons, only 25% or less of the field surface area is wetted. In 1998, Mwale observed that, at Dwangwa, only 41% of the furrow was wetted due to high velocities and narrow V-shaped furrows. Although narrower, smaller furrows lead to greater advance fronts and shorter advance front times that result in better uniformity, the experience at Dwangwa showed that the advance fronts were too fast, especially for heavy soils. This resulted in low water applications and poor uniformities along the furrows, as evidenced by poor wetting patterns and validated by the results of auguring. Since the date of the next irrigation was predetermined by the set of notched rulers, and the TAM used for the entire estate was assumed to be 105 mm, it was not possible to adjust the irrigation cycles to meet the irrigation water requirements. Increasing the number of irrigation cycles would also have demanded more irrigators. The width and shape of the furrow has a marked effect on contact time and hence on the amount of water applied.

Over the years, due to horizontal expansion at Dwangwa, the water reticulation system has been tested to the limit. This problem has been aggravated by the fact that capital to improve existing systems is limited. It is against this background that a water management review was deemed necessary.

Methodology

Several interventions were introduced from 2001, with the aim of irrigating a field with the right amount of water at least once every week. These included:

- Irrigators had to irrigate ≥ 3.5 ha per day from a gate flow of ≥ 85 L/s.
- Semi-permanent dropfalls were introduced in 2001 to ease the irrigator's burden of controlling water in the feeders.
- In fields which were more than 24 ha in extent, and which had several partitions, the possibility of one offtake to each partition was pursued.
- Fields immediately below the night storage dam that used to get water from the canal were then supplied directly from the dam.
- CaneSched (McGlinchey and Inman-Bamber, 1996), an irrigation software program, was installed in 2002 to improve water management and scheduling. Different values of TAMs were calculated from clay and silt fractions based on the relationships developed by van Antwerpen *et al.* (1994), to cater for specific soil classes.
- In areas that had floodgates, canal sides were raised to improve the hydraulic head.
- In fields that were constantly dry after irrigation, verified by auguring 24 hours later, a wider middle buster (from 0.4 to 1.0 m) was introduced.

Data on the amount of water applied per cycle, number of days taken to irrigate a field, maximum discharge from a gate and hydraulic head were collected and compared with data recorded before the changes were effected. At the same time, portable flumes were used to measure the amount of water in the feeder. Equation 1 (James, 1988), which relates head and discharge for contracted fully submerged orifices when the velocity of approach is negligible, was used to determine the amount of water passing through the gate for the selected fields. The flows were visually monitored to guard against erosion.

$$Q = CA(2g \times h)^{1/2} \qquad (1)$$

Where: Q = orifice discharge [L/s]
C = discharge coefficient [0.6 L]
A = orifice area [m²]
g = gravitational acceleration [m/s²]
h = difference in water level [m]

CaneSched was introduced and soil textural analyses were done to establish estimated TAM values for individual fields. Effective rooting depths for different soil types were determined from soil pits dug across cane rows. Soil auguring as a means of estimating moisture status was introduced. The number of irrigation cycles were recorded and compared with that from the previous notched ruler scheduling technique.

A middle buster, designed to create a 1.0 m wide U-shaped furrow, was introduced in 2001 to improve contact time in the furrows. Data on siphon discharge, cut-off time and contact time were collected. In this study, a combination of double ring infiltrometer and the 'two-point method' for estimating infiltration was then used, together with advance and recession front derived contact times in different positions in the furrow, to estimate coefficient of uniformity (CU) and application efficiency (AE). Equations 2 and 3 were used to calculate CU and AE (Koegelenberg and Breedt, 2003).

$$CU = \left[1 - \frac{\sum_{i=1}^{n} \left| \bar{y} - y_i \right|}{\bar{y}n} \right] \times 100 \qquad (2)$$

Where: CU = Christiansen's uniformity coefficient [%]

$\bar{y}$ = average application [mm]

= $\sum_{i=1}^{n} y_i / n$

y_i = application at peg no i [mm]

n = number of pegs or measuring points

$$AE = \left[\frac{\bar{x}}{GAR} \right] \times 100 \qquad (3)$$

Where: AE = application efficiency [%]

$\bar{x}$ = desired average application [mm]

GAR = actual gross application [mm]

Results and discussion

The amount of water applied per irrigation cycle and the number of days per irrigation cycle are shown in Table 1. After installation of more than one offtake to fields that were more than 24 ha in extent and had more than one partition, both the number of days required to complete a cycle and the amount of water applied decreased (Table 1), in line with the initial design of irrigating a field once a week. Both Spear (1992) and Mwale (1998) concluded that the amount of water applied per cycle before intervention was less than 50 mm. This was so because the amount recorded was calculated using time and siphon size and assumed head in the feeders of 100 mm and not through direct measurements as it is now. In most cases, the time recorded was wrong and the feeder head was much less than 100 mm.

Table 1. Average amount of water applied and number of days per irrigation cycle.

		Water applied per cycle (mm)		Days per cycle	
	Sample size	Before intervention	After intervention	Before intervention	After intervention
Own offtake	19	65.7	60.0	9	6
Fields below dam	21	63.4	60.1	8	6

The hydraulic analysis using equation 1 shows that all the selected fields had more than 85 L/s of water passing through the gate after raising the canal. This was an improvement on the observations made by Spear (1992). The improvement in the flow through the gates for the other fields below the dam can also be attributed to the removal of the butterfly gate that was installed on the canal to improve head to two fields immediately below the dam. Overall, the flow through the gates on all the tested fields was above the required 85 L/s and flows became limited more by the ability of irrigators to manage higher flows and erosion concerns rather than by the infrastructure.

Results of soil textural analysis are shown in Table 2. This analysis revealed that the previous use of 105 mm as the assumed TAM value for the whole estate meant that some soils were over-irrigated and some were under-irrigated. Six soil classes were identified, and values of TAM were calculated and are now being used for scheduling with CaneSched.

Table 2. Soil texture analysis results.

Soil class	Fields		Analysis results				
	No.	% of estate	FC	WP	AMC	ERD	TAM
Clay (C)	43	9.66	45.1	29.3	15.7	570	89.7
Clay loam (CL)	8	1.8	43.6	27.5	16.2	670	108.3
Sandy clay (SC)	25	5.62	41.0	25.0	16.1	570	91.5
Sandy clay loam (SCL)	307	68.99	36.3	21.0	15.4	670	103.0
Sandy loam (SL)	56	12.58	28.1	14.5	13.6	660	89.6
Loamy sand (LS)	6	1.35	20.7	9.2	11.5	740	85.3

FC = Field Capacity (%)
WP = Wilting point (%)
AMC = Available Moisture Content (%)
ERD = Effective Rooting Depth (mm)
TAM = Total Available Moisture (mm)

With a sample size of 10, a comparison of the number of cycles using the notched ruler and CaneSched, together with auguring as a means of scheduling, was carried out. It showed a reduction in the number of irrigation cycles (Table 3). This change can be attributed to two major factors, (i) the fact that a wide range of TAMs from 80-105 mm were used instead of the blanket 105 mm, and (ii) the introduction of CaneSched, which used an apparently more representative water budgeting method of scheduling based on recent climatic and irrigation records.

Table 3. Number of irrigation cycles for the two scheduling methods.

Month	Number of irrigation cycles	
	Notched ruler	CaneSched
May	20	16
June	17	15
July	15	11
August	12	9
September	9	7
October	5	4
November	3	2
Mean	12	9

The results of the effect of changes in the shape of furrows for three major soil classes are shown in Table 4. High uniformity coefficients (CU ≥ 90%) were achieved after the modifications to middle busters from V-shaped (0.4 m wide) to U-shaped (1.0 m wide) furrows. This indicates that the infiltration opportunity time was similar throughout the furrow and there was a more consistent wetted perimeter along the furrow. Results also show that application efficiency improved from the previous AE as low as 27% to as high as 85%. Sandier soils which tend to have a vertical wetted pattern should have closer furrow spacing than clay soils (Withers and Vipond, 1974). Although the AE was within proposed norms for flood irrigation (Koegelenberg and Breedt, 2003) after using a 1.0 m middle buster in sandy soils, there is still room for improvement and hence need for more trials with middle busters of less than 1.0 m but more than 0.4 m. High application efficiencies can also be attributed to the introduction of CaneSched, and use of auguring results. CaneSched visually depicted the interaction of irrigation events, rainfall, evapotranspiration and the moisture status of the soil for each field, and this helped in deciding the actual date of irrigation. Auguring results helped in validating CaneSched.

Table 4. Coefficiency of Uniformity and Application Efficiency results from three soil groups.

Soil group	Before intervention		After intervention	
	CU	AE	CU	AE
Clay	76.0	42.0	90.7	84.5
Loamy	85.0	42.0	97.0	85.0
Sandy	87.0	27.0	97.0	68.0

Conclusions

Through the introduction of semi-permanent dropfalls in the feeders, raising of canals, introduction of one offtake to each partition in fields with more than one partition and more than 24 ha in extent and use of CaneSched for scheduling and monitoring of irrigation, irrigation at Dwangwa was brought back into line with the original design standards. The raising of canal sides resulted in improved head and discharge, hence the irrigators could irrigate the required ≥ 3.5 ha per day. Changes to furrow shape improved water use efficiency due to a uniform wetting pattern and required application depths. The use of different TAM meant that fields were irrigated according to better estimates of actual water holding capacities. The number of irrigation cycles was reduced which would have resulted in savings in pumping and application costs. This exercise indicates that there is potential to improve the efficiency of existing systems through irrigation system evaluation and performance monitoring.

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REFERENCES

Clowes M St J and Breakwell WL (1998). Zimbabwe Sugarcane Production Manual. Zimbabwe Sugar Association Experiment Station, Chiredzi, Zimbabwe.

James LG (1988). *Principles of Farm Irrigation Systems Design.* John Wiley and Sons, New York, USA.

Koegelenberg FH and Breedt HT (2003). Manual for the Evaluation of Irrigation Systems. Agricultural Research Council, Institute for Agricultural Engineering, Pretoria, South Africa.

McGlinchey MG and Inman-Bamber NG (1996). Predicting sugarcane water use with the Penman-Monteith equation. Pp 592-598 In: CR Camp, EJ Sadler and RE Yoder (Eds), *Proc Int Conf Evapotranspiration and Irrigation Scheduling.*

Mwale A (1998). Assessment of furrow irrigation: Infield application. Internal Report, Dwangwa Sugar Corporation, Dwangwa, Malawi.

Spear PT (1992). Irrigation Report. Internal Report, Dwangwa Sugar Corporation, Dwangwa, Malawi.

van Antwerpen R, Meyer JH and Johnson MA (1994). Estimating water retention of some Natal sugar belt soils in relation to clay content. *Proc S Afr Sug Technol Ass* 68: 75-79.

Withers B and Vipond S (1974). *Irrigation: Design and Practice*. Batsford Academic and Educational Ltd, London.