BENEFITS FROM PERFORMING IRRIGATION SYSTEM EVALUATIONS

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Abstract

In this paper the potential benefits of irrigation system evaluations are explored through the analysis of results from a case study. The effects of application depth, operating pressure, distribution uniformity and scheduling technique were evaluated using the *ZIMsched* 2.0 irrigation systems and crop yield simulation model. Data measured from on-farm irrigation system evaluations performed in Pongola in 2001 and again in 2003, were used in *ZIMsched 2.0* to simulate sugarcane yield and water use for the period 1980 to 2000. The simulated crop yield and water use results facilitated a comparison of relative profit margins. The system performance, in terms of uniformity and application depth, was poorer in 2001 than in 2003, largely as the result of low system operating pressures in 2001. Results from the simulations show that with the scheduling practice followed by the farmer in 2001, these low system pressures resulted in reduced water applications. This in-turn resulted in reduced simulated sugarcane yields but an increase in irrigation efficiency, as there were fewer losses due to runoff and deep percolation. The calculated electricity and water costs were also lower in 2001 than in 2003. The system was upgraded in 2002 and the simulations undertaken using the 2003 system evaluation data showed increases in crop yield, water use and profitability, despite the accompanying increases in the calculated electricity and water costs. The improvement in the uniformity of the system from a DU_{lq} of 61% to a DU_{lq} of 68% had little effect on the simulated yields. For the case study, the greatest benefit of an irrigation system evaluation was that it provided information which facilitated making improvements to seasonal water applications. Based on simulated yields and water use, the impacts of these improvements on profitability ranged from R164 to R1882/ha.

Keywords: sugarcane, mobile irrigation laboratory, MIL, irrigation scheduling, *ZIMsched*, irrigation systems, crop models, economics

Introduction

Effective and efficient irrigation is only possible with effective management. In order to facilitate effective management, information on the performance of irrigation systems is needed. One way to determine how well a system is performing is to pay to have the system evaluated by a Mobile Irrigation Laboratory (MIL). However, many growers may be averse to paying for a system evaluation by a MIL, unless a tangible benefit exists.

The aim of the study reported in this paper was to investigate and quantify potential benefits from irrigation system evaluations. In a case study analysis, the effects of operating pressure, application depth, distribution uniformity and scheduling were evaluated using the *ZIMsched* 2.0 (Lecler, 2003a) irrigation systems and crop yield simulation model. Together with representative information on electricity, water and harvesting costs and the Recoverable

Value (RV) price, the simulated crop yield and water use results facilitated a comparison of relative profit margins, given the various performance and management scenarios before and after evaluation by a MIL.

Methodology

Mobile irrigation laboratories (MIL) were used to evaluate irrigation systems in the Pongola area in 2001, and again in 2003. Detailed descriptions of the evaluation techniques are described in Koegelenberg and Breedt (2003) and Ascough and Kiker (2002). One of the systems that was evaluated 2001 had improvements made subsequent to the 2001 evaluation and the effects of these improvements were assessed when the system was re-evaluated by the authors in 2003. The evaluation results for this system were used as a basis for the case study analysis reported here.

Table 1. Irrigation system and scheduling parameters used for simulation scenarios in *ZIMsched* 2.0.

Parameter description	Scenario			
	1 Ideal system with ideal uniformity and scheduling	2 Actual 2001 system performance and farmer scheduling	3 Actual 2003 system performance and farmer scheduling	4 Ideal system with ideal uniformity and farmer scheduling
DU_{lq} of applied water (%)	75^c	61^a	68^b	75^c
Coefficient of Variation of applied water (%)	19.69	30.82	25.2	19.69
Wind and spray losses (%)	10	10	10	10
12-hour application depth (mm)	43^d	28.7^a	48.2^b	43.0^d
Scheduling practice	Apply up to the 12 hour application depth when soil water is depleted to 50% of TAM or the stress threshold, which ever is less	14 day cycle, 6 hours stand time in winter, 12 hours stand time in summer	14 day cycle, 6 hours stand time in winter, 12 hours stand time in summer	14 day cycle, 6 hours stand time in winter, 12 hours stand time in summer
Drying-off time	A period of time such that 190mm of evaporation (2 x TAM) was accumulated between the final irrigation application and harvesting	As for Scenario 1	As for Scenario 1	As for Scenario 1

[a] Data from MIL evaluations undertaken in 2001

[b] Data from MIL evaluations undertaken in 2003

[c] Information from Pitts et al. (1996)

[d] The depth of irrigation water applied for Scenarios 1 and 4, i.e. reflecting ideal performance of irrigation system hardware was calculated assuming a sprinkler with an 4.36 mm nozzle, operating at a pressure of 315 kPa, on an 18x18 m spacing, and having 10% spray evaporation and wind drift losses. Thus, the net application rate was calculated as 3.58 mm/h. This was multiplied by the maximum stand time (12 hours) to obtain the maximum application depth of 43 mm.

The *ZIMsched* 2.0 irrigation systems and crop yield simulation model (Lecler, 2003a) was used to simulate crop yields and irrigation water use with distribution uniformities (DU_{lq}), irrigation application depths and irrigation scheduling practices adjusted to reflect information/data gathered by the MILs in 2001 and 2003, and also an ideal situation. A 20-year weather data set for Pongola spanning the period 1980 to 2000 was used for the simulations. A total of four simulation scenarios were used for comparison. The irrigation system parameters and scheduling practices used in each scenario are described in Table 1. The soil type simulated was a sand clay loam with a maximum rooting depth of 1 m and total available moisture (TAM) content of 95 mm/m.

A normal distribution was assumed for the variation in sprinkler depths (Warrick *et al*., 1989; Heermann *et al*., 1992; de Juan *et al*., 1996). The effect of the distribution uniformity was modelled by simulating three separate water balances. Each water balance was assumed to account for a third of a field. Thus, the amount of irrigation applied to the portions of the field could be represented as follows:

Mean application : Depth of irrigation = d_{mean} (mm)
Below mean application : Depth of irrigation = $d_{mean} (1 - CV/100)$ (mm)
Above mean application : Depth of irrigation = $d_{mean} (1 + CV/100)$ (mm)

where CV = Coefficient of Variation (%).

The coefficient of variation (CV) of the system was calculated from the measured, or assumed, low quarter distribution uniformity (DU_{lq}, (%)) using Equation 1 (Warrick *et al*., 1989).

$$CV = (100 - DU_{lq})/0.798 \qquad (1)$$

For the economic analysis, only the variable costs which were likely to vary with changes in water use and crop yield were considered. These were power costs associated with pumping, water costs, catchment management levies, harvesting costs and transportation costs.

The three scenarios which were considered with regard to the water costs were:

- The user pays per hectare irrigated, i.e. unrelated to actual water volume used, as is presently the case at Pongola.
- The user pays a volumetric water charge, dependent on the amount of water used, but has no opportunity to store or bank water savings and no land on which to expand, i.e. the water savings have no realisable revenue opportunities.
- The user pays a volumetric water charge dependent on the amount of water used and can either store water for use in a subsequent drought season, or has land available for expansion, i.e. there is opportunity for saved water to be used or sold to realise additional revenues.

It was assumed that capital, fertiliser, land preparation, labour and management costs would be the same for all scenarios. A management factor of 70% was applied to simulated yields when calculating returns and costs associated with harvesting and transport. This was because the simulated results represent yields attainable under ideal, research type conditions, not typically representative of normal farming practice. Pumping costs were estimated using the total depth of water applied and the operating head of the system. It was assumed that the same pump was used for all simulations. Therefore, at lower head requirements the efficiency was set at 55% compared with an efficiency of 70% at the higher pumping heads.

The operating head was calculated based on the following assumptions:

- 10 m static head
- actual operating pressure of the sprinklers as measured in the 2001 and 2003 MIL evaluations
- a 1000 m mainline was assumed with a maximum design pipe friction loss of 15 m (1.5%) for the system with the greatest application depth (Scenario 3).

Pipe friction for the other scenarios were calculated using Equation 2.

$$\text{Pipe friction} = 15\left(\frac{\text{Total application Scenario}_i}{\text{Total application Scenario}_3}\right)^2 \tag{2}$$

The assumptions made for the economic analysis are shown in Table 2.

Table 2. Information and costs used for the economic analysis.

Parameter	Value	Units
Water costs		
i) Per hectare	1233	R/ha
ii) Per m^3	0.1233	R/m^3
iii) Opportunity[a]	4	R/mm
CMA levy	0.01	R/m^3
CMA levy[b]	100	R/ha
Electricity costs	0.45	R/kWh
Harvesting and haulage costs	42	R/t/ha
RV price	1250	R/ton

[a] Opportunity costs were calculated assuming a margin of R4000/ha (excluding interest and management costs) could be attained using 1000 mm of water for the production of sugarcane.

[b] Based on an irrigation water allocation of 10 000 m^3/ha, the Catchment Management Association (CMA) levy was determined to be R100/ha when water costs were determined on a per hectare basis.

Results and discussion

Irrigation water use

The results for simulated irrigation water use are shown in Figure 1. For Scenarios 2, 3 and 4, the same amount of water was applied each year. The variations between scenarios were purely a function of pressure at the sprinkler nozzles which resulted in different flow rates through the nozzle and hence different application depths for the 12-hour stand times. Scenario 2, which corresponded to the system performance in 2001, had substantially lower irrigation water applied than Scenario 3, which represented the performance of the system in 2003 after the system pressures had been increased. For Scenario 1, where irrigation water applications were determined according to soil water deficits, the amount of water applied increased in years with low rainfall to a maximum of 1194 mm and decreased in years with higher rainfall to a minimum of 590 mm. Thus the inter-seasonal variation in irrigation water requirements was high. The mean application for Scenario 1 was 871 mm/annum and the standard deviation was 178 mm/annum.

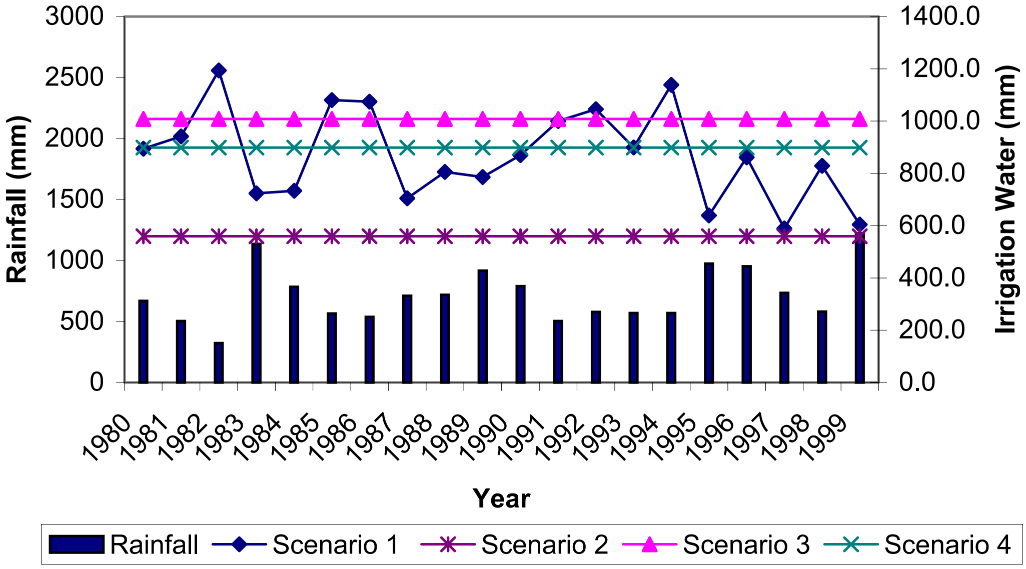

Figure 1. Total irrigation water applied and rainfall for various scheduling options, assuming a drying-off period such that 190 mm of evaporation was accumulated in the period from the final irrigation application until harvest.

Crop yields

The simulated yields, after the 70% management factor had been taken into consideration, are shown in Figure 2. Scenarios 1, 3 and 4 had consistently higher yields than Scenario 2, showing that in Scenario 2, irrigation water applied was insufficient, as the crop yields were adversely affected by frequent soil water stress. The effect of a change in distribution uniformity between Scenarios 3 and 4 was negligible relative to the difference in irrigation water applied. Thus, the increase in water applied in Scenario 3 compared with Scenario 4 resulted in slightly greater simulated yields, even though the DU_{lq} of 68 was slightly lower than the ideal DU_{lq} of 75. Using the soil water deficit to determine the timing of irrigation water applications, as in Scenario 1, resulted in greater simulated yields in all years, although in many years the amount of water applied was less than in Scenarios 3 and 4. Thus, with improved timing of irrigation water applications, higher yields were obtained with less water in most years. With Scenario 1 the inter-seasonal variation in yields was high, again highlighting the influence of seasonal climates on system performance. Assuming the 70% management factor, the mean yield for Scenario 1 was 11.4 t/ha (RV equivalent) with a standard deviation of 0.7 t/ha (RV equivalent). Assuming well matched irrigation, higher yields were attained in seasons with the lower rainfall amounts. However, the results also show that the inflexible system and scheduling strategy used in Scenarios 2, 3 and 4 did not adequately meet the crop water demand in years of low rainfall, especially in Scenario 2. For example, in the 1982/83 season, the yield for Scenario 2 was just over half the yield of Scenario 1.

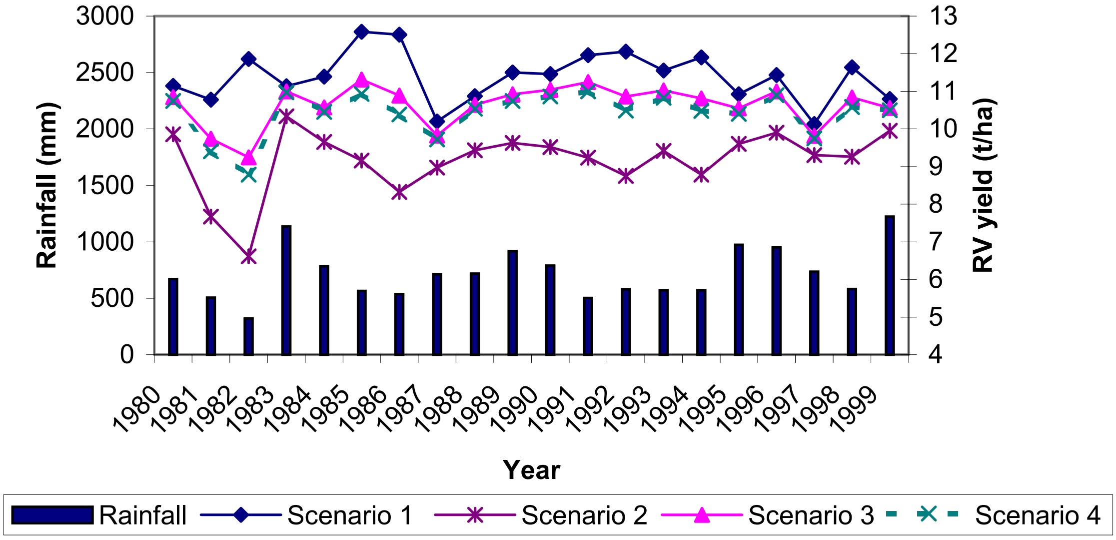

Figure 2. Simulated annual Recoverable Value (RV) equivalent yields.

Irrigation efficiency

Figure 3 shows the efficiency of the simulation scenarios over time. Here the efficiency is defined as the simulated actual transpiration (as opposed to potential) divided by the sum of irrigation water applied and rainfall received. Transpiration was used in favour of evapotranspiration in the numerator because this enables strategies which affect evaporation from the soil surface to be compared meaningfully. For example, if evapotranspiration was used in the numerator and a certain irrigation strategy resulted in a high amount of evaporation from the soil surface, the irrigation efficiency could appear to be high, although a large component of the high evapotranspiration was evaporation from the soil surface, which is actually wasted water.

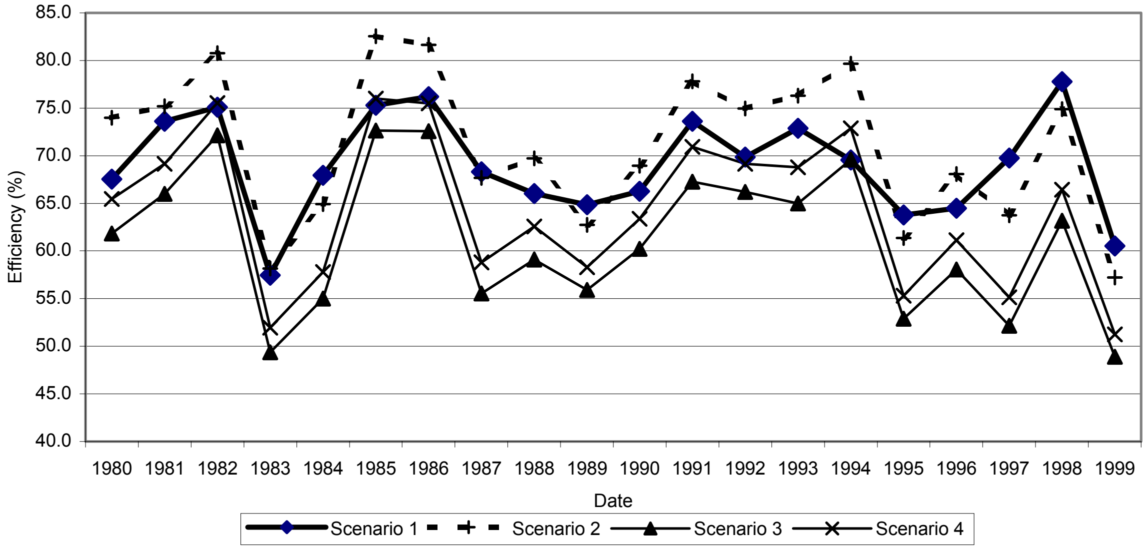

Figure 3. Irrigation efficiency defined as: Actual Transpiration / (Rainfall + Irrigation Water Applied).

Scenario 2 had the highest efficiency, as the runoff and deep percolation were less than in the other scenarios. This was due to a lower application of irrigation water. Scenario 1 was more efficient than Scenarios 3 and 4 in most years. However, there were three years when

Scenario 4 had a higher efficiency than Scenario 1. The reason for this was that it was still possible for there to be high runoff and deep percolation in Scenario 1. This occurred on occasions when a large rainfall event(s) followed shortly after an irrigation application had been triggered. For the simulations it was assumed that no short term rainfall forecasting was being conducted.

Table 3. Economic analysis of simulation scenarios.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Pressure at sprinkler (kPa)	320	201	333	320
Total head (m)	44	57	56	35
Simulated mean irrigation water applied (mm)	880	565	1018	908
Simulated mean cane yield (t/ha)[c]	82	71	81	79
Simulated mean RV equivalent yield (t/ha)[c]	11.4	9.2	10.6	10.4
Power/pump costs (R/ha)	871	454	1123	914
Water infrastructure costs[a] (R/ha)	1084	697	1256	1119
CMA levy[a] (R/ha)	88	57	102	91
Water infrastructure costs[b] (R/ha)	1233	1233	1233	1233
CMA levy[b] (R/ha)	100	100	100	100
Harvesting and transport costs (R/ha)	3460	2982	3380	3327
Affected variable costs (R/ha)[a]	5503	4189	5860	5451
Affected variable costs (R/ha)[b]	5664	4769	5836	5574
Cane revenue (R/ha)	14 238	11 462	13 297	13 031
Relative water revenue (R/ha)	556	1813	0	442
Relative margins assuming per ha water charge (R/ha)	8574	6693	7461	7456
Relative margins assuming per m^3 water charge and no revenue from saved water (R/ha)	8735	7273	7436	7579
Relative margins assuming per m^3 water charge and revenue from saved water (R/ha)	9290	9086	7436	8022

[a] Assuming water charges were based on volumes used, i.e. per m^3
[b] Assuming water charges were based on irrigated areas, i.e. per ha
[c] Yields shown here have been adjusted downwards assuming a 70% management factor

Economic analysis

The economic analysis produced the results shown in Table 3 and Figure 4. Due to the much lower pumping head and volume pumped, Scenario 2 had the lowest pumping costs, almost half that of the other scenarios. Assuming water was paid for on a volumetric basis, the total water costs were similar for all scenarios except Scenario 2, where the water costs were also much lower. Scenario 3 had the highest total variable costs due to increases in the volume of water pumped, the pumping head, and transport and harvesting costs. The total variable costs were lowest for Scenario 2. If the margin between cane income and affected variable costs is considered, Scenario 1 had the highest return and Scenario 2 the lowest. However, if there was potential for earning income through using relative water savings to increase cane production, for example, through banking for use during drought years or through expanding the production area, then Scenario 3 yielded the lowest returns and Scenario 2 gave the second highest relative returns. These returns were only marginally less than Scenario 1, but substantially higher than Scenarios 3 and 4, although the cane yield was much lower. There is therefore strong evidence that a deficit irrigation strategy where the crop is deliberately under-irrigated is likely to be an optimum strategy if water banking or expansion are possible.

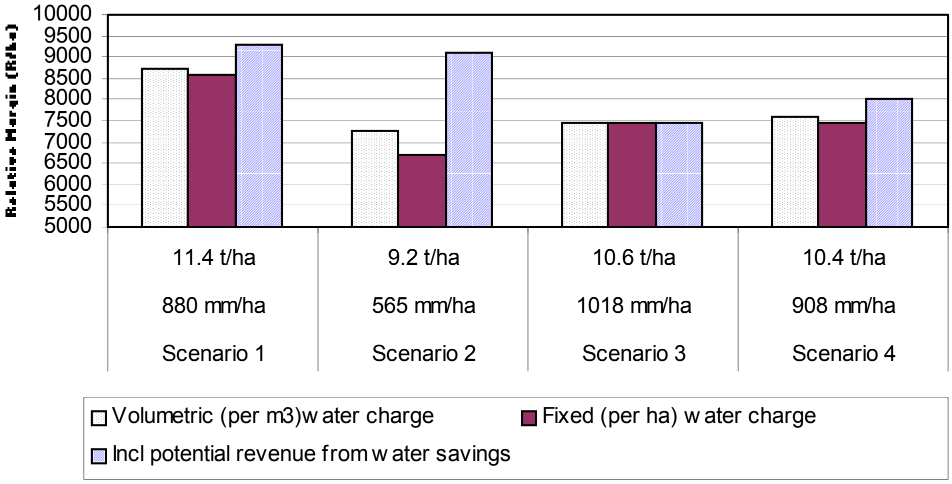

Figure 4. Relative margins.

Discussion and conclusions

Analysis of the results of the study reported here support the argument that terms such as ‘Irrigation Efficiency’, while providing useful standards for comparison, are inadequate from a practical business perspective. The selection of one system or management strategy over another on the basis of, say, irrigation efficiency, may not make business sense. To illustrate, Scenario 2 had the highest simulated irrigation efficiency, but the economic margins were not as good as the less efficient Scenarios 3 and 4 under the present institutional arrangements for water pricing and allocation. Only when institutional arrangements were assumed such that additional revenues could be earned from the relative water savings did the most efficient scenario, Scenario 2, realise close to the optimal returns. Thus, to encourage efficient water use and maximise productivity, policy makers should make every effort to ensure that institutional arrangements allow efficient water users to profit from their gains in efficiency, through, for example, fractional water allocations and capacity sharing/water banking as described by Lecler (2003b). Such institutional arrangements are not yet in place in Pongola where the water pricing and management principles, which are based on area irrigated rather than volumetric water use, could actually encourage less efficient water use by growers.

Analysis of the results also highlighted that assessments of irrigation system performance are more complex than comparing results of MIL evaluations with engineering benchmarks of uniformity and/or operating pressures. Use of a simulation model such as *ZIMsched 2.0* to translate MIL data/information into associated impacts on crop yields and water use, and then relative economic margins, showed that the determination of an optimal irrigation management strategy is relatively complex. For example, while the DU_{lq} and sprinkler operating pressures measured for the case study system in 2001 (Scenario 2) were below accepted engineering benchmarks, the impact of this on the economic margins, was dependent on many other factors. For example, the relatively poor technical or engineering performance of the system in 2001 led to substantially higher returns, of up to R1650/ha compared with returns calculated with its improved technical performance in 2003, *if there* *were opportunities to realise revenues from water savings*. However, given the present institutional arrangements where there is limited opportunity to realise revenues from water savings, the grower was better off having had improvements made to the technical performance of the system. This was due to the greater amounts of water that could be applied and potentially higher crop yields that could be obtained, despite the increased pumping, harvesting and haulage charges incurred. With the present institutional arrangements, potential increases in water costs were not relevant because water was paid for on a per hectare basis. Also, any water savings had limited realisable revenue earning opportunities. The system with the best technical specifications may not necessarily be the most effective system, unless the cost of achieving the high technical specifications is compensated for by increased returns. If the costs (capital and operating) are too high the system will not be optimal from a business perspective, no matter how good the technical performance.

From a technical irrigation system perspective, if a system's performance is poor because of a low pump operating pressure, overall impacts on profitability are likely to be less severe than if performance is poor due, for example, to worn nozzles. In the case study, the low pump operating pressures resulted in a substantial reduction in pumping costs and applied water, with a relatively small penalty in terms of reduced uniformities of water applied and overall profitability, assuming irrigation water was paid for on a per m^3 basis. If the poor system performance and low uniformities had been caused by worn nozzles, the grower may have unintentionally being applying relatively excessive amounts of water (dependent on the performance characteristics of the pump) per 12-hour stand time, and the water would likely have been applied in a very uneven fashion with the worn nozzles. This would result in poor sprinkler overlap patterns, a low system $DU_{lq,}$ and higher pipe friction losses. There could thus have been a large escalation rather than a large reduction in pumping costs, and a likely reduction in crop yields.

Using the service of a MIL to assist with the evaluation and maintenance of irrigation systems should be a viable and cost effective management option, provided the results of the evaluations are assessed in a wider economic context, as in this case study. For this case study analysis, the benefit or breakeven amount a grower could afford to pay for evaluations and subsequent system and management modifications ranged from R164/ha to as much as R1882/ha, depending on institutional arrangements. In South Africa, increases in water prices and reductions in water availability are very probable future scenarios, therefore the potential benefits from using MIL services are likely to escalate. What is clearly evident from the results is that irrigators need to schedule more precisely and to make better use of rainfall. In order to schedule more precisely, farmers need to know exactly how much water is being delivered to their fields. This, together with the derivation of an appropriate overall watering strategy, is possibly the greatest potential benefit from performing an irrigation evaluation.

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