IMPLEMENTATION OF THE *IRRIECON* V2 DECISION SUPPORT TOOL TO ASSESS NET RETURNS TO IRRIGATION SYSTEMS

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Abstract

Irriecon V2 is a spreadsheet-based tool that can be used to determine detailed capital, operating and marginal costs of various irrigation scenarios. Cost implications relating to affected farming practices, including fertiliser, herbicide, planting, harvesting and haulage operations, are incorporated in the tool. In this paper, the costs of and net returns to three different irrigation systems that are being evaluated in the Empangeni area, namely big gun, dragline and drip, are described. Farm level data were obtained from interviews with local farmers. Irrigation system design parameters and investment cost data were based on detailed and representative system designs and bills of quantities. Predicted crop yield and irrigation water use information for the various irrigation systems were simulated using the *ZIMsched* 2.0 irrigation systems model. Infield performance characteristics of the various irrigation systems, for example, the distribution uniformity of applied water, which is used as an input variable in *ZIMsched* 2.0, were based on data derived from Mobile Irrigation Laboratory evaluations. The results have applicability to irrigation system selection and design, farm management decision making, and for policy makers when assessing the economic impact of changing an irrigation system to drive irrigation water use efficiency in agriculture.

Keywords: irrigation, systems, economics, model, modelling

Introduction

Sugarcane farmers are coming under increasing pressure to demonstrate that they are managing the water used for irrigation efficiently and effectively. In many catchments the bulk of the available water is diverted to irrigated agriculture, and savings in this sector are viewed as a primary source for meeting competing demands. Recommendations to change or upgrade irrigation and/or water management systems need to be assessed from both a hydrological and an economic perspective. Prior to the development of *Irriecon* V2 there was no easily available tool that could be used either to refute or demonstrate the economic consequences of existing and/or proposed irrigation scenarios at the detailed, on-farm level.

A project was thus initiated at the South African Sugarcane Research Institute (SASRI) to develop a detailed economic analysis tool to assess farm specific scenarios related to irrigation, such as system design specifications, repairing/upgrading irrigation systems, comparing various Eskom tariff structure options, and/or changing farm and water management approaches relating to irrigation. The tool developed, *Irriecon* V2, is complementary to the original *Irriecon* decision support programme (DSP). *Irriecon* was designed for the 'broad-brush' assessment of irrigation feasibility, whereas *Irriecon* V2 is a much more detailed cost calculator. *Irriecon* V2 is based on the integration of:

- rigorous farm specific irrigation costing procedures developed at the University of the Free State during a Water Research Commission funded project (Oosthuizen *et al.*, 2005),
- procedures to assess related farming costs which were developed for the Economics of Trashing (EOT) DSP (Wynne and van Antwerpen, 2004).

The outcome is a spreadsheet-based tool which can be used to determine detailed capital, operating and marginal costs of various irrigation scenarios. Cost implications relating to associated/affected farming practices, including fertiliser, herbicide, planting, harvesting and haulage operations are incorporated in the tool. In this paper, application of *Irriecon* V2 to assess various irrigation strategies and systems for potential irrigation development in the Empangeni area is reported.

Methodology

Yield simulations

A combination of field-derived information on irrigation systems performance and simulations with an irrigation system/crop yield simulation model, were used to predict crop response to various irrigation systems, system constraints, soils, seasonal climates and watering strategies. The *ZIMsched* 2.0 irrigation system/crop yield simulation model was used for the study. ZIMsched 2.0 can be used to evaluate the impact on crop production of different irrigation strategies by taking into account the effects of different water application targets, scheduling practices, irrigation systems and irrigation system performance measures, using commonly available data and information (Lecler, 2004).

The irrigation systems scenarios that have been simulated were selected based on information derived from, amongst others, Mobile Irrigation Laboratory evaluations in the Empangeni area and are described in Table 1.

Table 1. Summary of assumptions used in the big gun, dragline and drip irrigation systems with different irrigation strategies.

Parameter	Big gun		Dragline		Drip	
Gross application (mm)	53	27	42	42	3.5	5.83
Minimum cycle (days)	10	10	10	15	1	1
Soil texture	SaLm*	SaLm	SaLm	SaLm	SaLm	SaLm
Soil drainage	Good	Good	Good	Good	Good	Good
Soil depth (m)	1.5	1.5	1.5	1.5	1.5	1.5
Soil TAM** (mm)	144	144	144	144	144	144
Evaporation losses	15%	15%	15%	15%	0%	0%
% TAM at which an irrigation application was initiated[4]	50%	50%	50%	50%	50%	50%
Uniformity index	CU[1] 55	CU[1] 55	CU[2] 80	CU[2] 80	SU[3] 88	SU[3] 88

*SaLm = sandy loam, **TAM = total available moisture

[1]Coefficient of Uniformity (CU) – values based on infield evaluations conducted by some of the authors.

[2]Coefficient of Uniformity (CU) – values assumed are for top performing systems (Reinders, 2001).

[3]Statistical Uniformity (SU) – values assumed are for top performing systems (Reinders, 2001).

[4]Irrigation applications only took place provided the accumulate time since the previous irrigation application exceeded the minimum cycle time.

A high potential, deep and well drained sandy loam soil representative of the Empangeni east area was used in the different irrigation system simulations. Ten years (1997 to 2006) of weather data from the Felixton automatic weather station were used in the simulations. Water applications were simulated to take place when 50% of the total available moisture (TAM) had been depleted for all of the different systems provided the minimum irrigation cycle time constraints were satisfied. This is a more aggressive deficit system than is generally employed for drip irrigation systems. For the purpose of this research a deficit of 50% was used for the drip systems to maintain a relatively drier soil profile, reduce losses through deep percolation and runoff, and at the same time ensure that evaporative demand was met by rainfall and irrigation water.

The CU for sprinkler systems was proposed by Christiansen (1942). It is a measurement of the uniformity of the depth of water application across the irrigated area. A CU of 55 was assumed for the big gun systems, reflecting a relatively low uniformity in water application. Infield evaluations of big gun systems had shown that CUs ranged from 29 to 83 but were generally below 60. The values obtained were highly dependent on windspeed and the orientation of the system travel path in relation to the wind direction. A CU of 80 was assumed for the dragline systems representing a high uniformity in water application by a top performing system. The SU is used to describe the uniformity of a drip irrigation block, because water is not applied to the whole field area (Pitts *et al*., 1996; Koegelenberg and Breedt, 2002). For the sub-surface drip systems a SU of 88 was assumed for a top performing system.

Irrigation system designs

In order to determine the costs of the various irrigation system options for the economic analysis, representative irrigation designs for the various irrigation systems were undertaken by Zululand Irrigation (Pty) Ltd. The irrigation designs for the various irrigation systems and irrigation strategies were based upon the optimisation of irrigation system performance and irrigated area. Although this resulted in different irrigation areas between the various systems, it permits comparisons between the irrigation systems to be undertaken on the basis that the irrigation system fixed costs are allocated over the optimum cane area matched to the system design specifications. The designs included a detailed bill of quantities and associated costs, and were undertaken assuming the Suid-Afrikaanse Besproeiings Instituut (South African Irrigation Institute) (SABI) design norms. A summary of the various system design parameters is presented in Tables 2, 3 and 4.

Analysis of irrigation system economic margins

The *Irriecon* V2 model was applied to the yield simulation results obtained from *ZIMsched* 2.0 in order to assess the economic margins associated with the various options. *Irriecon* V2 is a program developed by SASRI and SA Cane Growers' Association. It is based on irrigation costing methods reported in Water Research Commission Report No. 974/1/05 (Oosthuizen *et al*., 2005), but also includes utilities to account for other farming costs (e.g. crop establishment, ratoon maintenance, harvesting and transport) that may be impacted on by various irrigation strategies. It must be noted that the economic margins reported in this paper reflect only partial cane margins after rewarding all production factors that may be directly impacted on by changes in irrigation systems or irrigation strategies. Other fixed and variable costs not directly affected by irrigation are ignored in this paper, as are foreign factor costs such as management, rent, leases and interest on capital for land acquisition.

The *Irriecon* V2 model is designed to capture detailed fixed and variable irrigation input costs and fixed and variable agronomic input costs that may be impacted upon by changing irrigation practices. A summary of the main irrigation inputs used in the model is presented in Table 5.

Table 2. Summary of the costs of the various big gun irrigation system options.

Component	Big gun 53 mm/10 (54 ha) (R)	Big gun 27 mm/10 (72 ha) (R)	Insurance (%)[1]	Main-tenance (%)[2]	Salvage value (%)[3]	Expected life (yrs)
Mainline and hydrants	176 584	97 581		0.2	30	20
Trench costs	10 147	12 247				20
Travellers	[4]417 000	[5]310 500		2	10	10
Pump unit	75 992	72 175	0.83	2	15	15
Delivery and field work	2 000	2 000				
Subtotal	681 723	494 503				
Total per ha	**12 625**	**6 868**				

[1,3]% of purchase price [2]% of purchase price/1 000 hours per year
[4]Travellers (Model 90/300 × 3) [5]Travellers (Model 100/300 × 2)

Table 3. Summary of the costs of the various dragline irrigation system options.

Component	Dragline 42 mm/10 (63.63 ha) (R)	Dragline 42 mm/15 (95.45 ha) (R)	Insurance (%)[1]	Main-tenance (%)[2]	Salvage value (%)[3]	Expected life (yrs)
Mains and sub-mains	275 796	362 979		0.2	30	20
Trench costs	61 210	89 894				20
Flexible risers	11 864	17 680		2		10
Tripod assembly	44 639	44 639		2		10
Pump station	84 785	84 785	0.83	2	15	15
Subtotal	478 294	599 977				
Total per ha	**7 517**	**6 286**				

[1,3]% of purchase price [2]% of purchase price/1 000 hours per year

Table 4. Summary of the costs of the various drip irrigation system options.

Component	Drip 3.5 mm/1 (R)	Drip 5.8 mm/1 (R)	Insurance (%)[1]	Main-tenance (%)[2]	Salvage value (%)[3]	Expected life (yrs)
Mains and sub-mains	167 941	219 892		0.2	30	20
Trench costs	40 076	42 148				20
Micro distribution equipment:	505 982	507 263		1.5		7
Filter bank:	64 383	83 633	0.6	5		10
Pump station:	44 252	48 047	0.83	2	15	15
Sub total:	822 634	900 983				
Total per ha	**16 453**	**18 020**				

[1,3]% of purchase price [2]% of purchase price/1 000 hours per year

Table 5. Summary of irrigation system inputs for the different irrigation systems and irrigation strategies used in *Irriecon* V2.

Parameter	Big gun 53 mm/10	Big gun 27 mm/10	Dragline 42 mm/10	Dragline 42 mm/15	Drip 5.83 mm/1	Drip 3.5 mm/1
Electricity						
Landrate	100%	100%	100%	100%	100%	100%
Landrate option	2	2	2	2	2	1
Basic charge (R/month)	192.30	192.30	192.30	192.30	192.30	192.30
Network charge (R/month)	310.80	310.80	310.80	310.80	310.80	202.20
Energy charge (R/kWh)	0.3028	0.3028	0.3028	0.3028	0.3028	0.3028
Absorbed power (kW)	41.63	25.83	50.89	50.89	26.56	18.56
Power factor of the motor (h)	0.9	0.9	0.9	0.9	0.9	0.9
Pump rate design value (m^3/h)	165	86	160	160	120	74
Water						
Water charge (cents/m^3)	3.44	3.44	3.44	3.44	3.44	3.44
WRM* charge (cents/m^3)	0.62	0.62	0.62	0.62	0.62	0.62
Research levy (R/ha)	3.68	3.68	3.68	3.68	3.68	3.68
Other						
Irrigated area (ha)	54.0	72.0	63.6	95.5	50.0	50.0
Labour hours/1 000 m^3 **	0.68	0.68	1.65	1.65	0.40	0.40

*WRM = water resource management, **Hoffman *et al.* (2007).

The estimation of repairs and maintenance costs of the differing systems were based on a percentage of purchase per 1 000 hours irrigation, as suggested by Oosthuizen *et al*. (2005). The capital recovery method for estimating depreciation and interest costs was employed in this study.

The costing of other farming activities was based on information obtained from local growers and prices published in July 2007. A summary of the costings is presented in Table 6.

Table 6. Summary of agronomic costs for the different irrigation systems and irrigation strategies used in *Irriecon* V2.

Cost	Measure	Big gun	Dragline	Drip
Planting costs	R/ha	9 429	9 429	9 724
Ratoon maintenance costs		3 155	3 155	2 509
Harvesting costs	R/ton	12.02	12.02	12.02
Transport costs		47.69	47.69	47.69

Irriecon V2 is designed to provide an estimate of the total farm margin after accounting for all costs that may be affected by changes in irrigation systems or combinations of irrigation systems. However, for the purpose of this paper the *Irriecon* V2 model was used to evaluate the economic performance of each irrigation system separately. As explained above, the irrigated area of the different irrigation systems varied according to the optimisation of the system design for a given capacity, and for this reason it was possible to apply only a set cost per ton for the harvesting and transport cost components of the analysis, as these would otherwise be affected by economies of scale and capacity utilisation.

Results

Results obtained include simulations of irrigation water applied, runoff and deep percolation losses, crop yields and economic margins of the associated irrigation systems and management strategies.

Irrigation water applied

The amounts of irrigation water applied simulated for the Big gun, dragline and Drip systems for the different scenarios are shown in Figure 1.

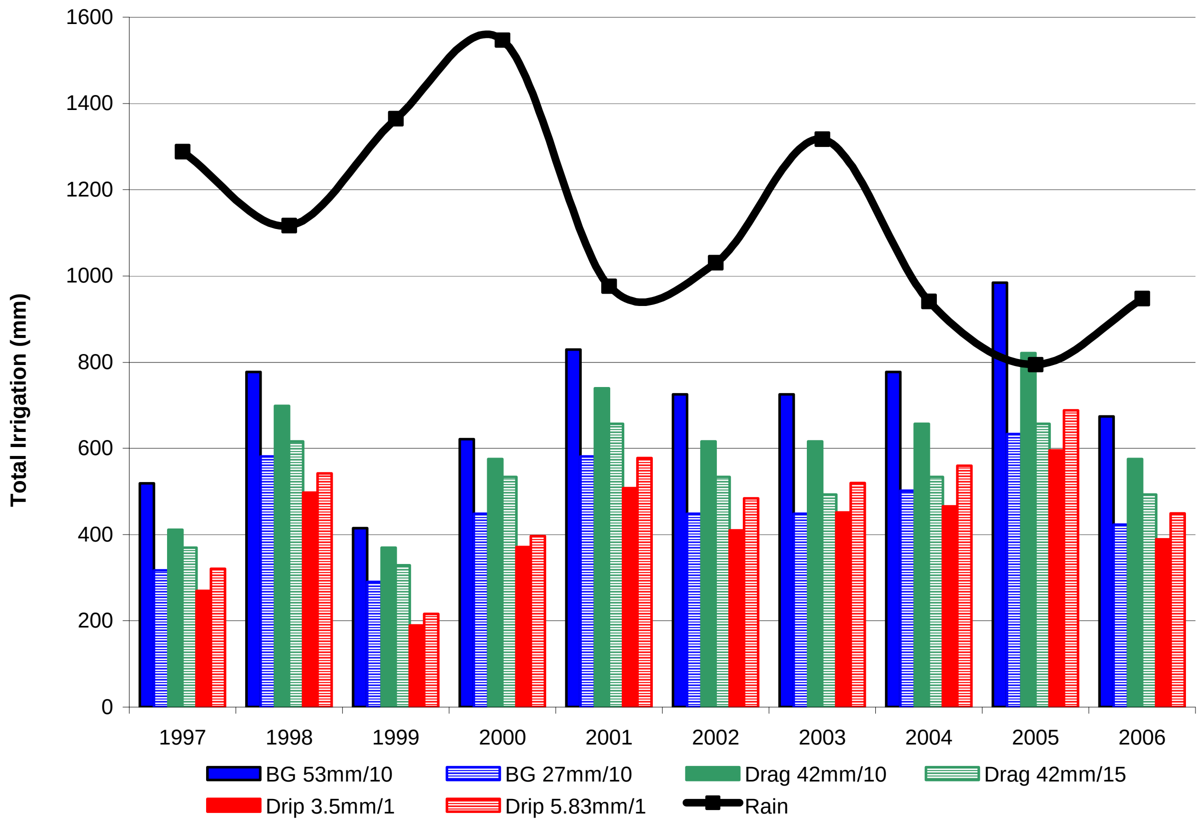

Figure 1. Simulated irrigation water applied by big gun (BG), dragline (Drag) and drip irrigation systems with different irrigation strategies, over the period 1997 to 2006.

It can be seen in Figure 1 that there was wide variation in required water application rates between the various irrigation systems according to their design capacity. The big gun system applying 53 mm in 10 days and the dragline systems required the highest water application rates, while the drip irrigation systems were the most effective water saving technology of the three systems, and also exhibited the lowest variation between water application requirements.

Runoff and deep percolation losses

The runoff and deep percolation losses simulated for the big gun, dragline and drip systems for the different scenarios are shown in Figure 2.

The choice of irrigation system and irrigation strategy was shown to have a substantial influence on runoff and deep percolation. These were particularly high for the big gun system capable of applying 53 mm in 10 days, while the losses in the big gun system applying 27 mm in 10 days were also high relative to the total amount of irrigation water applied. The high range in these losses highlights the importance of selecting an appropriate management strategy with big gun systems. Overall, the losses simulated under the drip systems were least sensitive to the system design capacity.

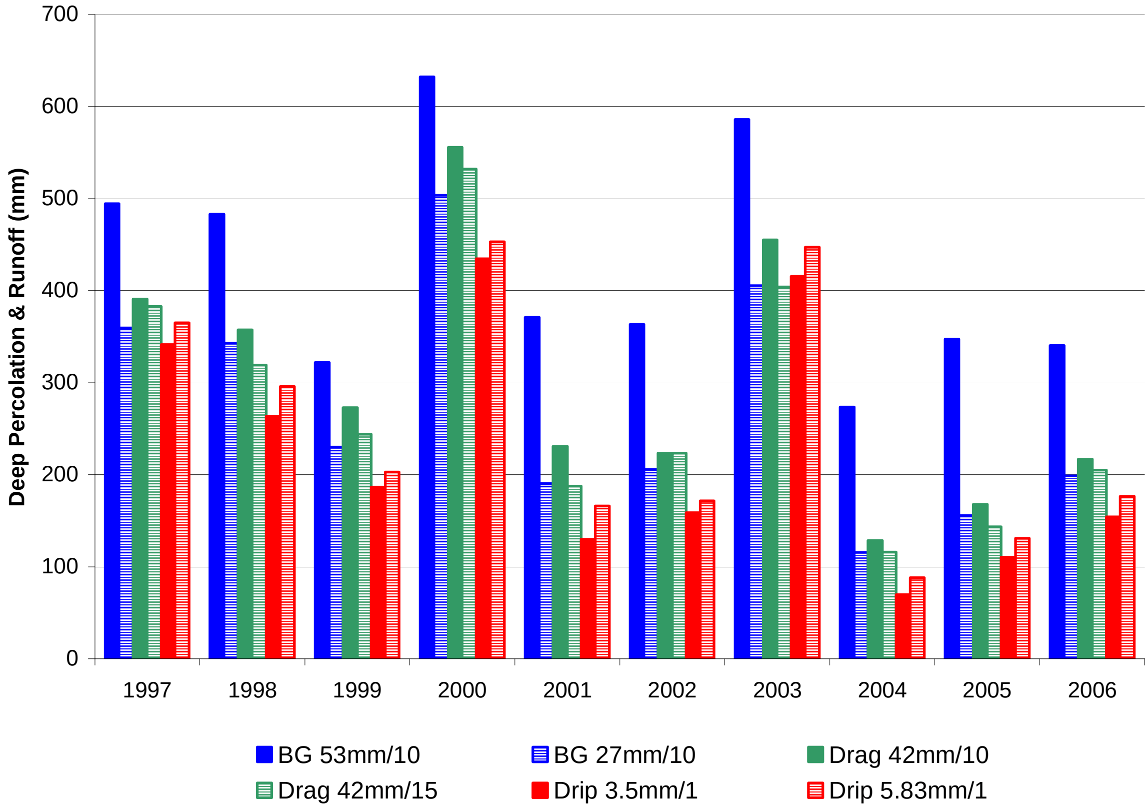

Figure 2. Simulated runoff and deep percolation losses for the big gun (BG), dragline (Drag) and drip irrigation systems with different irrigation strategies, over the period 1997 to 2006.

Crop yields

The cane yields simulated for the big gun, dragline and drip systems for the different scenarios are shown in Figure 3.

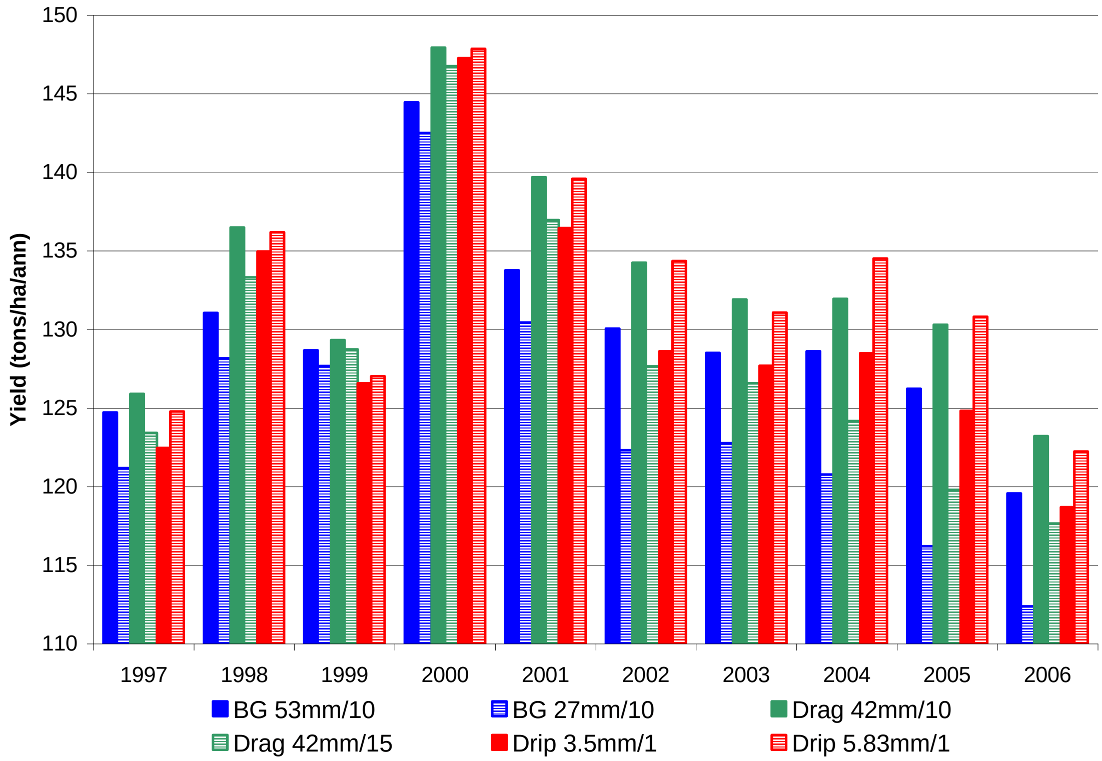

Figure 3. Simulated cane yields for the big gun (BG), dragline (Drag) and drip irrigation systems with different irrigation strategies, over the period 1997 to 2006.

Simulated crop yields were highest for the dragline system with a capacity of 42 mm in 10 days, for the drip system with a capacity of 5.83 mm per day and to a lesser extent for the drip system with a capacity of 3.5 mm per day. The simulated big gun systems yields were relatively lower despite their higher irrigation water application levels, with the higher capacity big gun system having comparable yields to the lower capacity drip irrigation system. These results need to be viewed in the context of assumptions regarding the soils and climate, i.e. a deep sandy clay loam with a TAM of 144 mm and average rainfall for the seasons simulated a relatively high 1 132 mm/annum. Simulations on shallow soils and in regions of less rainfall will show markedly different trends.

Table 7 provides a summary of the average annual water application, losses and crop yields for the different irrigation systems and irrigation strategies.

Table 7. Summary average irrigation water application, losses and cane yields for the big gun, dragline and drip irrigation systems with different irrigation strategies.

System	Maximum capacity	Average annual irrigation (mm)	Average annual runoff and deep percolation losses (mm)	Average annual cane yield (tons/ha)
Big gun	53 mm in 10 days	704.6	421.2	130
Dragline	42 mm in 10 days	607.6	299.7	133
Drip	5.83 mm per day	475.1	249.4	133
Big gun	27 mm in 10 days	467.1	270.4	124
Dragline	42 mm in 15 days	521.4	275.5	128
Drip	3.5 mm per day	414.4	226.1	130

A separate simulation completed under dryland conditions indicated that estimated rainfed yields in the study area would have been on average 97 tons cane/ha/annum[1] over the 10-year period. All of the irrigation systems simulations show a considerable yield response over rainfed conditions, and the viability of these yield responses was tested using the *Irriecon* V2 model. The results are discussed in the following section.

Financial results

The financial results simulated for the big gun, dragline and drip systems for the different scenarios are shown in Table 8.

The results from Table 8 show that simulated partial cane margins for the dragline systems were higher than the big gun and drip systems. The dragline system with a capacity of 42 mm in 10 days achieved the highest cane margin of R11 278/ha, some R263/ha higher than the dragline system with a capacity of 42 mm in 15 days. The higher simulated profitability of the dragline systems is attributable to their relatively higher cane yields and lower fixed irrigation system costs compared to the other systems.

The big gun system cane margins were similar between the two different irrigation strategies. The lower capacity strategy applying 27 mm in 10 days achieved a slightly better partial cane margin than the higher capacity strategy applying 53 mm in 10 days. This underscores the importance of selecting an appropriate management strategy with this type of system.

[1]It must be noted that the study area is considered to be a high potential cane production area, and the simulated yield results reported in this paper are therefore not representative of the average industry cane producer.

Table 8. Summary of financial results for the big gun, dragline and drip irrigation systems with different irrigation strategies, and for a dryland simulation in the study area.

Revenue/Costs	Big gun		Dragline		Drip		Dryland
	53 mm/10	27 mm/10	42 mm/10	42 mm/15	5.83 mm/1	3.5 mm/1	
REVENUE	**R/ha**	**R/ha**	**R/ha**	**R/ha**	**R/ha**	**R/ha**	**R/ha**
Cane sales	23 870	22 876	24 477	23 667	24 459	23 851	17 852
IRRIGATION COSTS							
Mainline costs							
Mainline fixed costs	575	341	663	541	865	690	–
Mainline operating costs	616	514	671	581	539	563	–
Total mainline costs	1 191	855	1 333	1 122	1 404	1 252	–
System costs							
System fixed costs	963	554	121	89	1 837	1 832	–
System variable costs	680	554	367	319	512	609	–
Total system costs	1 643	1 108	488	408	2 349	2 440	–
Total irrigation costs	2 835	1 963	1 821	1 530	3 753	3 693	–
OTHER DIRECT COSTS							
Planting costs	943	943	943	943	972	972	928
Ratooning costs	2 741	2 741	2 741	2 741	2 180	2 180	2 773
Harvesting costs	1 510	1 447	1 549	1 497	1 548	1 509	1 130
Haulage costs	5 992	5 743	6 145	5 941	6 140	5 987	4 481
Total other direct costs	11 186	10 874	11 377	11 123	10 840	10 649	9 312
NET PARTIAL MARGIN	9 849	10 039	11 278	11 015	9 866	9 508	8 539
Index (Dryland = 100)	115.3	117.6	132.1	129.0	115.5	111.3	100.0

Partial cane margins were lowest for the smaller capacity drip system while the higher capacity drip system yielded a partial margin similar to the higher capacity big gun system. The relatively lower drip system returns are due largely to their significantly higher fixed irrigation costs compared to the other systems. Fixed costs in the drip systems were R1 164 to R1 627/ha higher than the big gun systems, and R1 892 to R1 918/ha higher than the dragline systems respectively, due to their higher annual ownership costs.

A further financial analysis was undertaken assuming that the availability of water was limited relative to availability of land, as is likely to be the case in many of the water stressed catchments. For this analysis the area which could be irrigated using the same amount of water for each system was determined. The margins shown in Table 8 were then multiplied by these area ratios to indicate what the total returns could be on a relative basis if the same quantity of water was used on different areas with each system. The results are shown in Table 9.

Analysis of the results in Table 9 indicate that in a water stressed situation the smaller capacity big gun and dragline systems irrigating a larger cane area are more profitable than the larger capacity systems using the same quantity of water but irrigating a smaller cane area, and the balance of the area being farmed as dryland cane. The extra capital costs of the larger capacity systems would not be warranted under such circumstances as the availability of water would limit the ability of a grower to use the additional irrigation system capacity and add more water. The opportunity cost of water is shown to be much greater than the direct costs of water. However, the opposite is found to be true for the drip system, where a higher total margin would be achieved by employing the higher capacity irrigation system on a smaller cane area, with the balance of the area remaining as dryland. The reason for this is that the difference between the irrigation costs for the large and small capacity drip systems was relatively small. Furthermore, the pump selected by the designers for the smaller capacity drip system operated at a lower efficiency relative to the pump used on the larger capacity drip system.

Table 9. Summary of financial results for the different irrigation systems where the area irrigated using each strategy was adjusted so that the same volume of water was used for each strategy.

Parameter	Big gun		Dragline		Drip	
	53 mm/10	27 mm/10	42 mm/10	42 mm/15	5.83 mm/1	3.5 mm/1
Net partial margin above dryland (R/ha)	1 310	1 500	2 739	2 476	1 327	969
Relative irrigable area[1]	1	1.51	1.16	1.35	1.48	1.7
Relative potential increase in margin obtained by converting dryland cane area to irrigated cane area for a given amount of water (R)	1 310	2 265	3 177	3 343	1 964	1 647

[1]For example, the 53 mm 10-day cycle big gun system uses 705 mm, so the irrigable area ratio is 705/705 = 1, whereas the 3.5 mm per day drip system uses 414 mm, so the equivalent ratio is 705/414 = 1.7 (see Table 7 for average water use of each strategy).

Conclusion

Results shown in this paper are for a specific context where different irrigation systems and strategies were compared assuming relatively good soils and high mean annual precipitation. Thus the potential differences in the performance of the systems from an agronomic perspective were largely negated and overshadowed by the economic considerations. The relatively inexpensive dragline systems resulted in the highest returns per hectare. Due to labour and theft issues with dragline irrigation, many growers are considering big gun irrigation systems as a preferred option; however, the potential margin for these systems was less than for the dragline systems.

The opportunity cost of water can, however, have a substantial influence on the selection of an appropriate irrigation strategy. Irrigation systems and strategies that use less water relative to competing systems allow a relatively larger area to be irrigated. Depending on the increase in margin over dryland margins, this may result in a low water use system being the most profitable system. For example, the low capacity big gun system resulted in similar cane margins to the high capacity Big gun system where water was unlimited. However, if availability of water limited the area that could be converted to irrigation, the lower capacity big gun system could be used to irrigate a relatively larger area and this would result in higher farm profit than the higher capacity big gun system. Selection of an irrigation system with appropriate capacity was shown to have major profitability implications under both land and water limited production constraints.

Although the drip systems had the best performance from an agronomic perspective they yielded the lowest margins, and conversion to drip irrigation in this situation would have been the least profitable option.

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