DEVELOPMENT OF A DECISION SUPPORT TOOL FOR ASSESSING ECONOMICS OF IRRIGATION IN SUGARCANE

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Abstract

In 1997, the Swaziland Sugar Association Technical Services initiated a programme to improve water use efficiency by providing information on appropriate irrigation methods, crop water use, irrigation scheduling, system design, water measurement and irrigation system performance. Maximizing irrigation efficiency was considered to be a first step towards the goal of increasing sucrose yield per unit of water. Results from the programme, highlighted the need for assessing economics of irrigation to ensure that technical efficiency was not pursued at the expense of economic efficiency. This paper reports on the development of a decision support tool to help growers make economically sound decisions in an irrigated sugarcane production system.

Irrigation decisions are becoming more complex with changes in markets, water legislation, wider choice of irrigation systems and development of more marginal water supply sites. Historically, growers often made irrigation decisions based on minimizing capital costs without taking in to account the long-term nature of irrigation investments. This approach often results in selection of systems that do not maximize profits and may not meet other production system requirements. The framework developed helps to evaluate the relative trade-offs between water, capital and running costs over the life of the system. Sugarcane production costs and economic data from Swaziland are used to demonstrate the utility of the principles used in the model.

Keywords: irrigation economics, economic efficiency, technical efficiency, profit maximization

Introduction

Several researchers have recommended an economic approach to irrigation system selection and management. Keller (1965) compared irrigation systems and concluded that an irrigation system should be selected on the basis of costs and its effect on water conservation. Hill and Keller (1980) reported a methodology for selection of irrigation systems in sugarcane based on economic analysis and uniformity of water application. Hamilton and Schrunk quoted by Holzapfel *et al.* (1985) recommended that initial investment, operation and maintenance costs should be considered when selecting an irrigation system. Other recent developments that support an economic approach to irrigation management include the growing recognition that water is a scarce resource which should be managed as an economic good to improve water use efficiency (Briscoe, 1996; Perry *et al.*, 1997). In addition, the stochastic nature of rainfall and drought and the high opportunity cost of water in Southern Africa estimated by Merry (1997) at USD133 per mega litre, call for strategies to manage water economically. For example, growers need to make best use of good rainfall years whilst a long-term strategy is needed for managing drought. These factors coupled with recent increases in irrigation costs and proposed changes to water laws, highlighted the need for a decision support tool to help growers maximize economic return from irrigation investments as well as support long-term strategic irrigation management decisions.

In irrigated sugarcane production systems, the irrigation system interacts with agronomic inputs to produce sucrose from which farm income is derived (Figure 1). There are many technical opportunities for using water more efficiently and others are being developed. However, much less is known at present about the circumstances and conditions under which the different irrigation systems can maximise profit. Economic analysis is especially relevant for the Swaziland sugar industry because it is currently expanding into areas that are often at a greater distance from the mill and the gap between price and costs is closing. Furthermore, inexperienced smallholder farmers will manage most of the new irrigation projects thus, adding to the economic risks. In an industry where most of the sugar produced is exported, economic analysis is important to ensure global competitiveness and economic sustainability of the new and existing systems (Fry, 1998). The objectives of the paper are: (1) to develop a framework for assessing irrigation economics in sugarcane, (2) to determine how irrigation engineering and agronomic aspects affect production costs and profitability and (3) to demonstrate the utility of the approach using economic and research data from Swaziland. The paper first develops a framework for economic analysis and then describes the irrigation economics model being developed to use the framework. An example was then given to demonstrate application of the model to irrigation system selection.

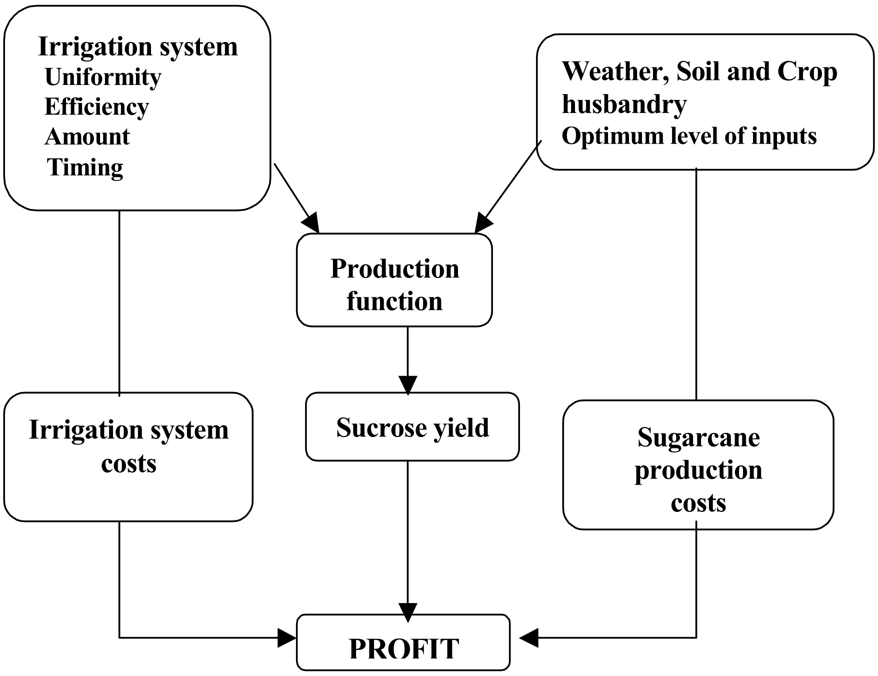

Figure 1. Irrigated sugarcane production system.

Economic decision framework

Irrigation decision-making consists of three components: (1) a business objective (e.g. maximization of profit) (2) a set of alternative choices and (3) a set of costs and constraints that limit the choices (Boggess *et al*., 1980). Carruthers and Clark (1983), underscored the need to base economic analysis on a sound understanding of irrigation and agronomic principles. Accordingly, this economic framework is based on irrigation research in Swaziland and output from the locally validated CANEGRO model (McGlinchey, 1999). The framework describes technical and economic factors that should be considered by sugarcane growers who wish to maximise net returns from irrigation in Swaziland. The approach recognises that sugarcane irrigators have an economic demand for water and operate their own water supply with the associated investment and operating costs. The framework is divided into yield, irrigation water demand and supply and profit-maximization components. It also highlights the role played by management in achieving high economic efficiency.

Sugarcane yield

Sugarcane and sucrose yields in Swaziland vary widely even under similar irrigation systems, soils and sugarcane variety (SSAES, 2001). This highlights the importance of management, climate and the uncertainty surrounding any yield predictions. Crop yield is inherently uncertain due to biological and climatic factors. In Swaziland, climate accounts for approximately 15% of the variation in potential yield from year to year and there was an almost linear decline in potential yield from 1992 to 1998 (McGlinchey, 1999). This decline has important economic implications given that potential yield sets the upper limit for actual yield attained in a given field. This is particularly important where investments have been made in capital-intensive irrigation systems in anticipation of high potential yield. Given the variability of weather, rainfall, soils, irrigation uniformity, management and other factors, the actual yield produced by a given level of water supplied (gross irrigation plus total rainfall) is quite unpredictable. Figure 2, shows yield response to different amounts of effective water (net irrigation plus effective rainfall).

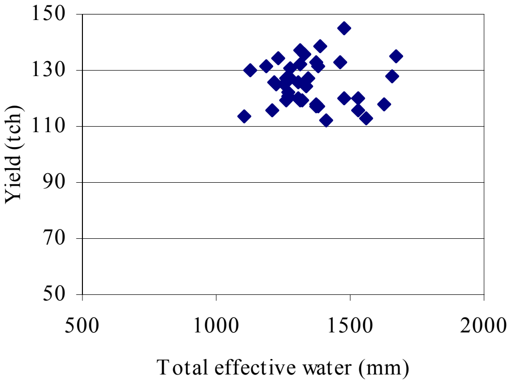

Figure 2. Yield vs total effective water (SSAES, 1999).

For an irrigated field annual yield can be expressed as:

$$Y = f\,(W, I, L, M, O, R_e) \qquad (1)$$

Where:

Y = Yield in tonnes cane per hectare (tch)
W = Weather variables (e.g. radiation, temperature etc.)
R_e = Effective rainfall
I = Effective Irrigation (amount, adequacy, uniformity and timing)
M = Management (e.g. P&D, fertilizer, other cultural operations)
L = Land quality (total available moisture (TAM), fertility, drainage and slope)
O = Other (e.g. crop age, variety, sodicity, compaction, salinity)

Equation 1 shows that, despite its importance, the irrigation system is only one factor affecting yield. The other important factors include weather, rainfall, soil quality and management. Water applied translates into evapotranspiration (ET) and yield through the interaction of soil-water-plant relationships, irrigation efficiency, application uniformity and the irrigation scheduling strategy. For a given irrigation system, well drained soils with a high TAM make better use of rainfall and simplify irrigation management. Consequently, economic returns are often higher and more consistent on good soils irrespective of irrigation system used. Agronomic studies have shown that reducing the amount of water applied results in yield loss (Thompson, 1976). From an economic point of view, the problem becomes one of balancing yield loss with cost savings from lower running costs. In Swaziland, the value of the crop is often greater than any cost savings from irrigation running costs emphasizing the importance of minimizing yield losses due to inefficient water application. Given that all irrigation systems apply water non-uniformly, the choice of correct amount to apply is affected by irrigation method, design application, availability of water measurement devices and the ease with which depth applied can be controlled by that system. In economic terms, it is important to recognize that each irrigation event is an input, which should be applied at the correct time to maximize return from that input. For a given soil type, seasonal yield depends more on how well the entire production system is managed than on the type of irrigation system assuming it is suitable for the soil.

Demand for water

Estimation of crop water demand is concerned with decisions on how much water to use and when to apply it. In economics, the concept of demand always refers to the quantity demanded taking in to account the cost of water and sucrose price (Martin, 1968). This is because the water required is a *derived demand,* which is dependent on the value of the crop (Seckler, 1999). For a given sucrose price and cost of water, seasonal water demand in Swaziland depends on crop ET, irrigation efficiency, scheduling and effective rainfall. ET is the primary demand variable and depends largely on climatic factors in particular radiation, wind speed, humidity and temperature (Carruthers and Clark, 1983). This has important economic implications because all fully canopied fields will have approximately similar water requirements. In other words, all things being equal, a fully canopied field with a yield potential of 150tch will more or less cost the same to irrigate as a field with a potential of 100tch. Therefore, to maximise economic return, new irrigation projects should be developed on the best quality land with higher yield potential. ET is fairly consistent from year to year with a coefficient of variation of 4% over a period of 26 years (Figure 3). In contrast irrigation requirement over the same period had a coefficient of variation of 11% showing greater variation in effective rainfall from year to year (Figure 4).

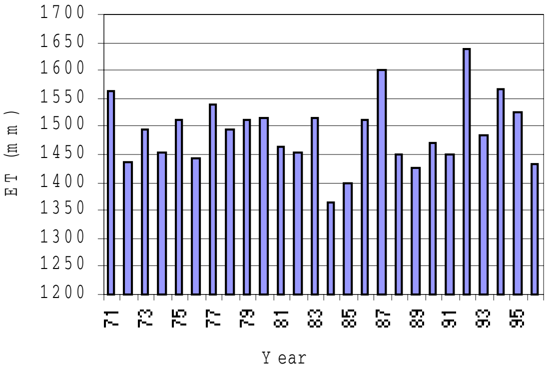

Figure 3. Sugarcane ET in Swaziland 1971-1996.

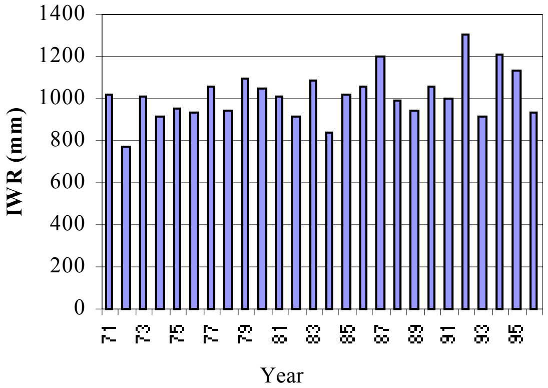

Figure 4. Irrigation water requirement (IWR) 1971-1996.

The economic importance of irrigation in Swaziland is underlined by the fact that rainfall meets approximately 30% of the crop water requirement, the remaining 70% being supplied from irrigation. Seasonal irrigation water demand can be represented by the following function:

$$I_d = g(ET, C_w, E_i, T_i, P, R_e) \qquad (2)$$

Where:

I_d = Seasonal irrigation water demand (mm or m^3)
ET = Seasonal crop water requirement (mm or m^3)
C_w = Marginal cost of water (capital, labour, power, maintenance)
R_e = Effective rainfall
P = Sucrose price
E_i = Irrigation efficiency
T_i = A factor representing irrigation scheduling

Equation 2 supports the view that irrigators have an economic demand rather than a purely physical demand for water. This means water savings are likely to occur as a result of an increase in the price of water indicating demand elasticity. It follows that there must be some price so high that irrigation becomes unprofitable. The theoretical ideal of equating supply with demand is influenced by irrigation system and scheduling. Irrigation systems that consistently apply water uniformly and efficiently whilst providing maximum control of depth applied, improve the chances of accurately matching supply with demand. Having looked at demand, the next step is to look at irrigation water supply.

Irrigation water supply

Irrigation water supply decisions are concerned with selecting the water source, irrigation system, appropriate design and installation and system operation. The objective of an irrigation system is to supply sufficient water to meet the optimal ET requirements of the sugarcane crop minus effective rainfall. If the economics is favourable, adoption of irrigation systems with high application efficiency (e.g. drip and centre pivots) is encouraged because of their lower water demand, high uniformity and improved control of depth applied. The water source is also an important factor in irrigation economics. For the renewable run-of-river water source dominant in Swaziland, a grower uses one year's supply of water and then on average the same amount becomes available the following year. Therefore, amount available varies from year to year and may fail to meet requirements in some years. With a given irrigation system, the management objective is to maximize profit on an annual basis. If a dam is the water source, the objective then should be to maximize the present value of benefits over the life of the irrigation system (Mjelde *et al.*, 1990). The irrigation supply function for a grower wishing to maximize profit is:

$$I_s = h(A, L, I_d, C_w, R_i, Q, M) \qquad (3)$$

Where:

I_s = Irrigation water supply (mm or m^3)
A = Fraction of water available (equal to one if there is no shortage)
L = Represents limitations, conditions or other restrictions imposed by regulators on private irrigation decisions
R_i = Cost of capital (rate of interest)
Q = Peak gross crop water requirement in mm/day
M = A factor to represent management of the water supply system

Under the Water Act of 1967, growers in the lowveld were allocated a flow rate of 0.875 l/s/ha, which made water readily available provided there was adequate water in the river and the irrigation system had sufficient capacity. Reliable run-of-river water supply diverted by gravity also meant low water supply costs for sugarcane irrigation. This contributed significantly to the comparative advantage of irrigating sugarcane in Swaziland. Government water allocation policy is part of the variable L in equation 3 and is likely to be important in the future with the imminent introduction of a new Water Act and volumetric allocation.

All the readily available run-of-river water in Swaziland is now fully committed resulting in a substantial increase in the marginal cost of supplying irrigation water in the future. For example, Swaziland's share of 83 million cubic metres from Maguga dam cost the government approximately USD32 million. This translates to a cost of 38 US cents per cubic metre (ZAR 4.39/ m^3) at the 2002 exchange rate. This cost is high enough to make sugarcane irrigation unprofitable. In river basins without storage, serious shortages during droughts significantly threaten profitability of irrigation because of fixed irrigation costs. Although water supply is reliable in Swaziland, long-term strategies for managing droughts are required. Options include investing in storage and using deficit irrigation strategies under water-limited situations. Lecler (2000) concluded that under water limiting conditions in Zimbabwe, significant extra income could be attained by irrigating about 1.37 ha with 1450mm for every hectare irrigated with 1800mm.

Profit maximization and economic efficiency

The final step in this formulation is to integrate the components of the framework to determine how they interact to affect net income and economic efficiency. For the individual grower, the distinction between technical and economic efficiency is important. Technical efficiency is a measure of the physical output per unit of input whether land or water (tch or tc/m^3 are measures of technical efficiency). Economic efficiency is attained through managing irrigation and agronomic inputs to maximise profit and is closely related to the ratio of input and production costs to output price (Martin, 1968). It follows that economic efficiency depends on being a low cost producer relative to sucrose price. Economic theory assumes that the irrigation manager maximises profit in a risk free environment. However, research shows that under risk and uncertainty, a manager sacrifices some amount of expected profit in order to reduce risk as measured by variability of income (Lynne *et al.*, 1987). The risks and uncertainty emanate from climate, instability in sugar and input markets and new water laws. Thus, economic efficiency also depends on the behavioural attributes of the irrigator and institutional factors.

Principles of economic optimisation in irrigated agriculture are well researched and show that profit maximization occurs where marginal cost equates to marginal value (English, 1990). However, such optimisation cannot be carried out precisely in practice because yield is influenced by many factors making it virtually impossible to know precisely what level of water use will maximise profit. Furthermore the optimum level of water use is likely to change as input and crop prices change. The analysis presented here is limited to aspects of economic optimisation considered applicable in Swaziland and assumes the grower's objective is to maximise profit without taking risk in to account. Accordingly, the analysis stops before delving in to the calculus of economic optimisation. If risk is ignored, the grower is said to maximise his annual expected profit per hectare within his constraints according to the following equation:

$$\prod = PS_cY-C_wI_{dg}-C_i-C_v \qquad (4)$$

Where:

$\prod$ = Profit
P = Sucrose price per tonne
S_c = Sucrose % in cane measured at the mill
Y = Cane yield per hectare in tonnes (tc/ha)
C_w = Cost of water (power, maintenance, labour)
I_{dg} = Gross irrigation demand
C_i = Fixed irrigation costs (investment and interest)
C_v = Other production costs (fertilizers, chemicals, fuel, machinery, administration costs)

Both yield and cost efficiency are implicit in Equation 4, which also shows that significant gains in profits could result from high yield varieties or efficiency gains in other agronomic operations. The economic impact of the decline in potential yields referred to earlier can be inferred from Equation 4. One of the main aims of this paper was to determine how irrigation engineering and agronomic aspects affect production costs and profitability. Equations 2 to 4 show the close interaction between technical and economic efficiency. Maximizing yield per unit of water gives technical yield efficiency whilst minimising the cost per unit area results in technical cost efficiency. Connecting these to irrigation engineering and agronomy, technical efficiency is controlled by irrigation system type, irrigation scheduling and uniformity of application. Economic efficiency on the other hand depends on sucrose yield, cost of inputs and sucrose price and technical efficiency. The possibility of trading-off one input for another is evident in Equation 4.

Management

Management is a key variable in Equations 1 to 4 and plays an important part in achieving high economic efficiency. It is necessary for the farm to operate as a business maximizing profits in the short and long-term. To maximise profits, farmers should manage the sugarcane production system's inputs and risks in an integrated manner. Success depends on the grower's ability to produce sucrose at a cost lower than the sucrose price with sufficient margin to cover risks. Typically, low cost producers integrate management of their irrigation systems with other important operations. These include, land preparation to facilitate surface water drainage and provide a good growing medium for the crop, varieties, nutrition, pests and diseases, weather, financing, labour, ripening, harvesting and transportation. Proper management of these operations should be complemented by good knowledge of soils and water resources. Management priorities must be weighed against one another as measured by their impact on profits and should be adaptable to changing conditions. Research conducted in Swaziland has led to development of tools that integrate soils, weather and economic conditions to help growers make sound agronomic and irrigation decisions. These tools include the Sugarcane Production Manual, CANESCHED, IREM and other technical services.

Management of the irrigation component of the production system involves selection of the most economical irrigation system and ensuring that the system is matched to soils, well-designed and correctly installed. In the past, the cost of irrigation could easily be absorbed because of a high sucrose price. More recently, the cost of irrigation has increased due to rising water supply, capital, energy and labour costs. This has increased the need for greater management effort to control the irrigation costs as much as possible. Furthermore, the cost of more intensive management is less than the value of the crop lost due to poor management or the cost of investing in alternative irrigation systems. On-farm evaluations of irrigation systems in Swaziland are showing that, good management maximizes the efficiency of any given irrigation system, traditional or modern. Good management here refers to correct scheduling of irrigation, water measurement, periodic checking of system performance and timely maintenance.

Irrigation economics model

An irrigation economics model (IREM) is being developed to use the economic framework above to conduct economic evaluation of investments in new irrigation systems, adjustments to irrigation systems and evaluating management strategies that improve water use efficiency. IREM is designed to utilize user-supplied data to calculate investment costs, operating costs and determine economic viability of different irrigation systems used in sugarcane. The model can assist growers to determine which type of irrigation system is most economical to own and operate. It can also be used to evaluate irrigation system changes such as pump efficiency decline, operating costs for different levels of water application, changes in economic conditions (e.g. water cost) and the economic benefits of switching from one irrigation system to another. Important design variables that affect economics of irrigation include peak crop water requirement, static pumping height, distance from water and power sources, soil type and irrigation efficiency.

The economic logic for the model was developed and tested using an Excel spreadsheet that will be converted to a flexible computer program in the Windows environment in 2002. The annual cost component of IREM uses a capital recovery factor to calculate annual costs (Keller and Bliesner, 1990). The investment appraisal component uses discounted cash-flow analysis, a standard tool used by economists and accountants to evaluate investment in capital items (Knapp, 1993). Table 1, summarises the inputs for the model. Profit is calculated using Equation 4. Limitations of the model include its failure to accommodate the farmer's risk attitudes, use of average water demand to calculate costs and the assumption that inflation will affect costs and benefits equally. The model also assumes that rainfall effectiveness is the same for all the different irrigation systems. These limitations will be overcome in time through further development.

Table 1. Irrigation economics model inputs.

System inputs	Cost component	Revenue component
Irrigation system	Initial equipment (E*)	Yield (tch)
Area (ha)	Land development (E)	Sucrose (%)
Gross rainfall (mm)	Civil works (E)	Sucrose price (E/ts)
Total head (m)	Energy cost (E/kWh)	
Irrigation efficiency (%)	KVA cost (E/KVA)	
Pumping efficiency (%)	Production (E/ha)	
Flow rate (m^3/h)	Harvesting and transport (E/tc)	
Seasonal crop ET (mm)	Maintenance (%)	
Amount applied (mm)	Water charges (E/m^3)	
Soil TAM (mm)	Interest rate (%)	
Power factor	Cost per irrigation (E)	
	Loan period (years)	

*1 Emalangeni (E) = 1 South African Rand

Application to irrigation system selection

Both existing and new growers are faced with the need to select viable irrigation systems. For existing growers, alternative irrigation systems may become more profitable as costs and prices or their objectives change over time. New technology is constantly being developed and growers need a quick method to assess economic benefits of technology as it becomes available. Without this capability poorly planned systems and inefficient water application could reduce profits through lower yields and higher operating costs. Under any given set of conditions, the choice of irrigation technology should be based on costs and returns. The relevant variables are:

- Investment costs which assume an incremental value if the system is changed.
- Running costs over the life cycle of the irrigation system.
- Yield variable costs brought about because of the system (e.g. increased harvesting and transport costs).
- Additional benefits accruing from irrigation.
- Grower's financial situation.

Growers with capital shortages or high indebtedness will be at more financial risk if they adopt capital-intensive systems than those with a strong financial base. In Swaziland, an irrigation system should be selected based on its ability to earn a profit at export prices with a significant margin for risk. In order to take advantage of economies of scale, growers should where possible develop the largest area possible for a given investment. This is because of the indivisibility of equipment such as pumps, transformers and pipelines. On smallholder projects this means small landholdings should be consolidated to an economically viable size before an irrigation scheme is designed to maximise economic returns.

Empirical example

The model application will be illustrated with an example of a planned 250ha expansion on a sugar estate with a capital constraint. This example was selected because input data for the model and designs for the four irrigation systems were available. However, the model can be applied to any specific situation giving different results and conclusions depending on economic conditions and soils on a particular farm. The results reported here are specific to this particular situation and are not to be interpreted as generally applicable or recommendations. The soils were shallow well-drained soils with TAM less than 65mm. It was established that the major limitations on these soils was low TAM and relatively low fertility. These limitations could be overcome by any of the solid set irrigation systems considered coupled with a sound agronomic management programme. This was evident on similar soils on the estate, which had averaged 123tch over six years under centre pivot irrigation.

The systems considered were dragline, centre pivot, subsurface drip and floppy. A professional irrigation designer prepared an optimal design for each system after a detailed feasibility analysis. Interest rate of 14% was used with a sucrose price of E1100 per tonne and 13.8% sucrose which is the estate average. Production, harvesting and transport costs were based on estate actual figures. For centre pivot and dragline systems, yield was estimated using estate historical yields adjusted for differences in soils. For subsurface and floppy, industry average data was used taking in to account soil type. Sensitivity analysis was used to determine the effect of changes in yield and other key variables. All costs are based on 2001 prices and standard estate management practices. Irrigation system data used in the analysis are given in Table 2 whilst Table 3 illustrates selected results from the model. When designing centre pivot systems, it is important to limit the size of each unit to range between 50-70ha in order to minimise problems with run-off and soil erosion. The pivots in this project were designed according to this criterion.

Table 2. Irrigation system data.

System	Investment cost (E/ha)	Efficiency (%)	Area (ha)
Dragline	31922	75	245
Subsurface drip	37847	90	248
Floppy	40205	85	243
Centre pivot	36999	85	234

Table 3. Irrigation economics model results.

System	Area (ha)	Yield (tch)	NPV (E)	IRR (%)	Payback (yrs)
Pivot	234	123	5055253	25	4
	234	107	1844106	18	6
Floppy	216	123	4013745	23	4
	243	123	4512546	23	4
	243	110	1769253	18	5
	216	110	617976	16	6
Subsurface	230	123	5136645	26	6
	248	123	5534053	26	6
	230	110	2569957	20	7
	248	110	2768677	20	7
Dragline	245	105	1800476	19	7
	245	100	749821	15	9

Economic viability of each irrigation system was analysed by calculating the internal rate of return (IRR), net present value (NPV) and payback period. Payback period forecasts how long it will take for the expected net cash income to pay back the investment outlay. The analysis assumed inflation will affect the costs and benefits equally and is therefore not included in the calculations. The net present value approach is preferred because comparisons are made on a common time scale. Taking time into consideration recognizes that a Rand today is worth more than a Rand next year.

The analysis showed that all the four systems are viable under the given physical and economic situation. The dragline system met the lowest capital criterion but had the lowest economic return over 20 years due mainly to the low yields projected on the shallow soils. It was felt that the optimum frequency required on these soils would be very difficult to achieve with a dragline system. The centre pivot system was the least flexible in maximising area irrigated particularly utilisation of the best soils but yielded the second best and most robust return on investment. The subsurface drip system yielded the highest return on investment if consistently high yields of 123 tc/ha could be achieved. Because of their high initial capital cost in this project, subsurface drip and floppy systems were more sensitive to low yields than centre pivot and dragline systems, both yielding a negative net present value at 107 tc/ha if sucrose dropped to 13%. This indicates that despite the high rate of return, subsurface drip irrigation has a higher risk than centre pivot, which yields a positive net present value at 107 tc/ha. Similarly floppy had a higher risk than both subsurface drip and pivot because it had the highest capital cost. With a depreciating currency, the need to replace subsurface drip laterals after 10 years or earlier if the crop were to be ploughed out for any other reasons would tend to expose the grower to exchange risks. This would tend to favour centre pivot and floppy which were assumed to last 15 and 20 years respectively and do not need to be replaced should the field be ploughed out for any reason.

This exercise highlighted the importance of site-specific economic analysis when selecting an irrigation method. In particular, it demonstrates the importance of soil quality on system selection. On well-drained soils with a high TAM, the situation would most likely be different tending to favour the dragline system because of its low capital cost. This is because on high quality land, the increase in yield from solid set systems (pivot, drip and floppy) would be less relative to their fixed investment cost. However, this would have to be proved by an economic analysis. The best choice rests on physical, biological and economic conditions, which vary greatly from farm to farm. For smallholder farmers, dragline systems are preferred because they minimise the initial amount borrowed by the farmers, the schemes are limited to high quality land wherever possible and the need to create jobs for the local communities. These assumptions need to be examined critically to ensure that they are economically sound.

Conclusions

This paper developed a decision framework that integrates economics, irrigation engineering and agronomy and showed that the three are closely linked. Application of economic principles should be based on fundamental physical principles governing the use of water by crops and the engineering aspects of irrigation systems. The major benefit of the framework is to help growers to quickly assess economic consequences of irrigation decisions. At sugar industry level, it will be useful as a tool for analysing cost competitiveness and ensuring that our technical recommendations are grounded in crop production economics. The framework is a sound basis for identifying the main factors that affect irrigation economics in Swaziland and for demonstrating how irrigation engineering and agronomy affect profitability. These factors are water availability, climate, institutional factors, size of scheme, soil quality, cost of capital, crop price, production costs, transport costs and the irrigation system. Given that most of these factors are given for a particular situation, good management of all inputs of the production system ultimately determines profitability.

Application of the model under conditions in Swaziland showed that, on suitable soils, any of the different irrigation systems (dragline, drip, floppy and centre pivot) are profitable. However, within the range of profitable irrigation, opportunities exist through the use of IREM to select systems that maximise profit under specific economic and physical conditions, which vary from farm to farm. Where possible, irrigation systems should be developed on the best land with high TAM and yield potential to maximise economic return. The analysis showed that taking in to account capital and running costs over the life cycle of the irrigation system is better than the predominant practice of selecting irrigation systems on the basis of the lowest initial capital costs.

On the water supply side, all the easily accessible water in Swaziland is now fully committed and new supplies will only be available at a higher cost. The cost of producing a unit of water on the next project is higher because of development of more marginal sites, inflation and the need for storage. This highlights the importance of using water efficiently on existing schemes through demand management and improving the performance of irrigation systems. Furthermore, the cost of more intensive management is less than the cost of developing new water supply sources. At industry level, a strategy for managing drought is required which may require investment in storage to improve control of water and to provide incentives for more efficient water use.

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REFERENCES

Bogess, WG, Jones, JW, Swaney, DP and Lynne, GD (1981). Evaluating irrigation strategies in soyabeans: a simulation approach. In: *Irrigation Scheduling for Water Energy Conservation in the 80s*. ASAE Irrigation Scheduling Conference. pp 45-53.

Briscoe, J (1996). Water as an economic good: the idea and what it means in practice. ICID 16th Congress, Cairo.

Carruthers, I and Clark, C (1983). *The Economics of irrigation*. Liverpool University Press, Liverpool. 300 pp.

English, M (1990). Deficit irrigation I: analytical framework. *ASCE Journal of Irrigation and Drainage Engineering* Vol 116: 399-412.

Fry, J (1998). Competitiveness and benchmarking in the world sugar industry. *Proc S Afr Sug Technol Ass* 72: xiii-xix.

Hill, RW and Keller, J (1980). Irrigation system selection for maximum profit. Transactions of ASAE: 366-372.

Holzapfel, EA, Marino, MA and Morales, JC (1985). Procedure to select an optimum irrigation method. *ASCE Journal of Irrigation and Drainage Engineering* Vol III(4): 319-329.

Keller, J (1965). Effect of irrigation method on water conservation. *ASCE Journal of Irrigation and Drainage Engineering* Vol 91(IR3): 61-72.

Keller, J and Bliesner, RD (1990). Sprinkle and trickle irrigation. Van Nostrand Reinhold, New York.

Knapp, KC (1993). Economics of irrigation system investment. In: Jorgesen, GS and Norum, KN (Eds), *Subsurface Drip Irrigation: Theory, Practices and Application* CATI: 127-139.

Lecler, N (2000). Water Management Project. Research Report 1999-2000. Zimbabwe Sugar Association.

Lynne, GD, Anaman, K and Kiker, CF (1987). Irrigation efficiency: economic interpretation. *ASCE Journal of Irrigation and Drainage Engineering* Vol 113(3): 317-334.

Martin, A (1968). *Economics and Agriculture*. Routledge and Keagan Paul Ltd, London.

McGlinchey, MG (1999). Computer crop model applications: developments in Swaziland. *Proc S Afr Sug Technol Ass* 73: 35-38.

Merry, RE (1997). Case study in the conversion of dragline sprinkler to subsurface drip. In: Proceedings of International Society of Sugar Cane Technologists Irrigation Workshop, 15-19 September 1997, Brisbane, Australia.

Mijelde, JW, Lacewell, RD, Talpaz, H and Taylor, CR (1990). Economics of irrigation management. In: Hoffman, CJ, Howell, TA and Solomon, KH (Eds), *Management of Farm Irrigation Systems*. ASAE: 461-493.

Perry, CJ, Rock, M and Seckler, D (1997). Water as an economic good: a solution or a problem. Research Report 14. 16pp.

Seckler, D (1999). Revisiting the IWMI paradigm: Increasing the efficiency and productivity of water use. IWMI Water Brief 2, IWMI.

SSAES (2000). Results of field trials. Swaziland Sugar Association Extension Services.

SSAES (2001). Swaziland crop statistics. Swaziland Sugar Association Extension Services.

Thompson, GD (1977). Irrigation of sugarcane. *S Afr Sug J* 61: 126-131 and 161-174.