SHORT COMMUNICATION

APPLICATION OF A CATCHMENT-SCALE IRRIGATION SYSTEMS MODEL

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Abstract

ACRUcane is a computer simulation modelling tool developed to manage and assess catchment water supply and demand interactions and the associated impacts on the profitability of irrigated sugarcane. The model was configured to represent a catchment in northern KwaZulu-Natal (Pongola) with runoff feeding into a dam which supplied water for a dragline irrigation system. Various 'what if' scenarios representing potential changes to the irrigation system or management practice were assessed. Analysis of the simulated scenarios showed the interdependencies between irrigation application uniformity and irrigation scheduling. Improved application uniformities needed to be combined with improved scheduling to obtain maximum benefit, estimated to be approximately R3000/ha. Improved scheduling resulted in fewer seasons with water shortages and crop yield reductions. Replacing the dragline system with subsurface drip (SSD) resulted in gains in the proportion of applied water used beneficially and a small increase in crop yields. However, the amount of water applied using both types of irrigation system and the impacts on the dam storage levels were very similar. The increased capital cost of the SSD system relative to the dragline system resulted in marginally lower profits.

Keywords: sugarcane, hydrology, economics, irrigation, irrigation systems, modelling, irrigation scheduling

Introduction

ACRUcane (Moult *et al*, 2005; Moult, 2006) is a computer simulation model developed to manage and assess catchment water supply and demand interactions and the associated impacts on the profitability of irrigated sugarcane. It was developed because farmers in South Africa are facing increasing pressure to use water more effectively, to justify existing water allocations, and to budget and plan with growing uncertainty regarding water availability. In this communication example applications showing the potential utility and value of the ACRUcane model are given.

Methodology

The ACRUcane model was configured to represent a catchment in northern KwaZulu-Natal (Pongola), with runoff feeding into in a dam which supplied water for a dragline irrigation system. Various 'what if' scenarios representing potentially beneficial changes to the irrigation system were assessed from an economic perspective. The scenarios assessed included:

- an improvement to the irrigation application uniformity, as could be attained, for example, by replacing worn sprinkler nozzles
- an improvement to irrigation scheduling
- replacing the dragline (DL) system with a subsurface drip (SSD) irrigation system. SSD was selected for comparison with DL because the SSD system is often perceived as very efficient, which could have a positive impact on water supplies.

The scenarios were assessed in terms of cumulative frequency distributions of crop yield, seasonal irrigation efficiency (*SIE*) and net return per hectare (*NRH*) using 30 years of historical data from Pongola. *SIE* is defined in Equation 1.

$$SIE = \frac{\Sigma T}{\Sigma I + \Sigma R} \times 100 \quad (1)$$

where

ΣT	=	transpiration accumulated over the course of the season (mm)
ΣI	=	irrigation accumulated over the course of the season (mm)
ΣR	=	rainfall accumulated over the course of the season (mm)

NRH is defined in Equation 2:

$$NRH = R - BPC - IWC - EC - HC - LC - CapC - MC \quad (2)$$

where

NRH	=	Net return per hectare (R/ha)
R	=	Revenue (R/ha)
BPC	=	Base Production Cost (R/ha)
IWC	=	Irrigation Water Cost (R/ha)
EC	=	Electricity Cost (R/ha)
HC	=	Haulage Cost (R/ha)
LC	=	Labour Cost (R/ha)
CapC	=	Capital Cost (R/ha)
MC	=	Maintenance Cost (R/ha)

R was computed as the product of sucrose yield in t/ha and its price, assumed to be R1350/t. *BPC* was assumed to be equal for all scenarios at R4000/ha. *IWC* was assumed to be comprised of a constant water price of R0.123/m^3 and a constant Catchment Management Agency (CMA) levy of R0.01/m^3. *EC* represents the cost of pumping, and a constant electricity cost of R0.30/kWh was assumed. The power used was calculated from the total volume of water pumped, the required operating head and the pump efficiency, assumed to be 70% in all cases. The required operating head was determined assuming a static head of 5 m, a 500 m length of pipe, and a friction loss of 1.5 m per 100 m, i.e. 1.5% (Ascough and Lecler, 2004). *HC* was determined from the product of sugarcane yield and a harvest and haulage cost of R45/t. *LC* was determined using system specific values of ha/person obtained from Koegelenberg and Breedt (2003), and a fixed labour salary of R8803/year (personal communication[1]). *CapC* was computed according to Koegelenberg and Breedt (2003) assuming an interest rate of 10.5%. *MC* was estimated by the product of total capital costs and a system specific maintenance percentage obtained from Koegelenberg and Breedt (2003). The assumed costs for the dragline and drip irrigation systems are shown in Table 1.

[1] Chris Gillitt, South African Cane Growers' Association, 10 October 2005.

Table 1. Cost input variables for the dragline and drip irrigation systems.

Variable	Input value	
	Dragline system	Subsurface drip system
Labour requirement (ha/person)	25	30
Total capital cost (R/ha)	12 000	22 000
System life (years)	10	10
Maintenance cost (%)	4	3

Results

Improved uniformity

Assuming a fixed summer and winter cycle (FSWC), *viz*. 48 mm irrigation applied each week in summer, and 48 mm every two weeks in winter, an increase in distribution uniformity, DU, from 50-75% resulted in:

- an increase in yield of 3.1%
- an increase in *SIE* of 2.2%
- an increase in the *NRH* of 10.5%, on average.

There was no impact on the dam storage levels.

Improved irrigation scheduling

Improved irrigation scheduling was represented by scheduling water applications such that 40 mm of water was applied when the soil water had reached a depletion of 45 mm below field capacity. This resulted in considerable differences in the amounts of water applied per season compared with the FSWC. With the FSWC, 1638 mm was applied per season where water supply was not restricted; however, restrictions occurred 40% of the time because of shortages in the dam. Thus, an average of 1428 mm was applied per season. With the improved scheduling only 816 mm water was applied per season, on average. Thus, a much larger area could have been irrigated without severe water shortages. Higher yields were obtained with improved scheduling for 60% of the years simulated. The main reason for this was that, with the FSWC, there were often water shortages as a result of the dam running low or emptying. On average, however, the increase in yields was marginal (2.5%) compared with FSWC, because the relative benefits of improved scheduling were somewhat negated in years when there was sufficient water, i.e. 40% of the time, due to the poor DU of 50%. With the improved scheduling but poor DU, relatively larger portions of the field were under-irrigated resulting in stress and a reduced yield relative to the FSWC. However, the improved scheduling resulted in a much higher *SIE* (40% on average), and a *NRH* that was on average R1850/ha higher per season, due mainly to a reduction in water and energy costs.

Improved uniformity and irrigation scheduling

In the previous scenarios, the benefits of the well-scheduled system were somewhat negated by poor uniformity and the improvements to uniformity were masked by the over-irrigation of FSWC. Combining improved irrigation scheduling with an improved DU resulted in a substantial improvement in yields and returns for all seasons. The *SIE* increased by 48% on average, and the *NRH* increased by R3067/ha on average.

Changing to a subsurface drip irrigation system (SSD)

Simulations showed that a well scheduled SSD system with a DU of 85% used only marginally less water than an ideal dragline system, i.e. well scheduled and with a DU of 75%. Intuitively, one would have expected there to have been a greater difference in water use, as SSD has the advantage of minimising evaporation of water from the soil surface and there are no spray evaporation and wind-drift losses (assumed to be 10% for the DL system). However, the SSD system was scheduled to refill the soil profile at a much lower depletion than the dragline system. Consequently, crops grown under SSD were not subjected to soil water stress and consistently transpired at potential rates. With the dragline system, the crop was occasionally subjected to mild stress to meet the specified depletion level. Slightly less water was used during these 'stress' periods and, with the profile generally drier, a lower proportion of rainfall was lost to runoff.

Simulated yields with the SSD system were slightly higher than yields simulated with the dragline system, *viz*. an average of 16.92 t/ha vs 16.08 t/ha. The average *SIE* for SSD was 80% compared with 77% for the ideal dragline system. The increased capital costs associated with the SSD system resulted in the system being marginally less profitable than the ideal dragline system. The average *NRH* obtained using the SSD system was R7562/ha, slightly lower than the R7841/ha obtained using an ideal dragline system.

Conclusions

Analysis of the simulated scenarios showed the interdependencies between irrigation application uniformity and irrigation scheduling. Improved application uniformities needed to be combined with improved scheduling to obtain maximum benefit, estimated to be approximately R3000/ha. Improved scheduling resulted in increased storage levels for the dam and fewer seasons with water shortages and crop yield reductions.

Replacing the dragline system with SSD resulted in gains in the proportion of applied water used beneficially, i.e. for transpiration and small gains in crop yields. However, the amount of water applied using both types of irrigation system and the impacts on the dam storage levels were very similar. Despite the simulated increase in crop yields, the increased capital cost of the SSD system relative to the dragline system resulted in marginally lower profits.

Ultimately, the scenarios investigated have shown that ACRUcane can be used to provide an indication of the potential returns associated with various changes to an irrigation system and/or management practice in a catchment context, i.e. where the integrated relationship between irrigation water supply and demand is represented.

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