COMPONENTS OF THE WATER BALANCE OF AN IRRIGATED SUGARCANE CROP IN SWAZILAND

MG McGLINCHEY

Swaziland Sugar Association Extension Services, PO Box 367, Simunye, Swaziland

Irrigation has recently been highlighted as one of the most important and costly agricultural inputs in the Swaziland sugar industry. This has always been the case, but several drought years, the need for industry expansion with limited water resources, and the likely introduction of new water laws, have all served as powerful reminders that water must be managed with greater efficiency. This has prompted renewed effort in the fields of irrigation research and extension, to improve our understanding of the mechanisms of water supply and demand, and introduce techniques aimed at fine-tuning water management.

The components of the water balance of an irrigated sugarcane crop can easily be identified. Rainfall and irrigation can be termed the principal supply components, while evaporation and transpiration are considered the primary demand components. The remaining components, soil surface run-off and deep percolation or drainage, are largely soil determined. Canopy interception, although a loss in terms of water reaching the soil surface, does contribute to the demand component and cannot strictly be termed a loss to the system. However, there is evidence to suggest that intercepted water is used less efficiently than transpired water and should be minimised wherever possible (Thompson *et al.*, 1996).

Irrigation systems are designed to meet the deficit between water demand and supply. Principal design parameters are: (i) average peak monthly daily crop water use (CWU); and (ii) effective rainfall (total rainfall minus run-off and deep drainage). Irrigation scheduling, on the other hand, can be defined as the day to day water management process within the constraints of the irrigation system. The same components, daily CWU and effective rainfall, are critical inputs for any scheduling system.

Thompson proposed current water balance concepts in 1977. He proposed a model based on a balance between supply and demand within the constraints of a reservoir, the size of which was determined by soil properties. The components of this water balance were estimated from simple measurements and calculations. CWU was estimated using Class A pan evaporation and canopy factors to cope with partial canopy conditions. Water supply was estimated from effective rainfall (assumed to be 70% of total rainfall), net irrigation and the available storage capacity of the reservoir at the time of precipitation. These concepts were subsequently included in a computer program developed by Thompson and Harding (1986) in which a daily water balance was maintained, allowing comparisons between irrigation strategies.

Advances in the modelling of the processes of water supply and demand have led to the development of a detailed simulation model, CANEGRO, capable of estimating the components of the water balance more accurately (Inman-Bamber, 1991; Inman-Bamber *et al.*, 1993; McGlinchey *et al.*, 1995; McGlinchey and Inman-Bamber, 1996a). In this model water demand is estimated using a Penman-Monteith (PM) approach to estimate potential evapotranspiration (PET). PET is partitioned between soil and plant, using leaf area index (LAI) estimated by the model and soil surface moisture conditions. Water supply components are dealt with mechanistically: canopy interception is estimated as a function of LAI, soil water run-off as a function of soil surface wetness and run-off curve number, and deep drainage as the amount of water draining below a dynamic root system in a well described, layered soil profile.

This short communication reports the results of a simulation exercise to investigate the magnitude of the components of the water balance using irrigation system design and scheduling scenarios as examples. These examples aim to highlight the impact of irrigation design and scheduling choice on water use efficiency. Comparisons were made between components estimated by the two models (Thompson and CANEGRO) and the differences, and their implications on irrigation design and scheduling practices, are discussed.

Method

The CANEGRO model was used to simulate four irrigation system/soil type scenarios for the Mhlume area in Northern Swaziland (Table 1). Physical properties of a deep (120 cm) Rondspring series soil type (Shortlands form) were used as model inputs for the 'R' set soil. Inputs for the shallow (55 cm) 'S' set soil were obtained from measurements made on a Somerling series soil type (Glenrosa form). Two common irrigation systems/scheduling strategies were selected for the simulation exercise: (i) a system capable of delivering 48 mm gross (34 mm net, assuming 70% application efficiency) during a 12 hour stand time in a minimum cycle time of six days, and (ii) a system capable of delivering 24 mm gross (17 mm net at 70% efficiency) during a six hour stand time in a minimum cycle time of three days. An allowable irrigation deficit equal to the application amount was allowed to accumulate in the soil prior to irrigation being scheduled by the model. This ensured that water was not over-applied during periods of adequate rainfall. Daily meteorological data from the Mhlume weather station (26°02'S, 31°48'E) for the period 1970 to 1996 were used as meteorological inputs. To account for seasonal variation in water supply and demand, annual crops were simulated to be harvested three times during each season (mid-May, mid-August and mid-December) for each scenario. Further analysis was conducted on mean seasonal output for the 26 years under consideration. Assumptions in the simulations were that: (i) the crop was grown on level land; (ii) soils were well drained with no contribution from a water table or lateral flow; (iii) water intercepted by the canopy was evaporated at the potential rate contributing to the plant evaporation component; and (iv) irrigation was applied using an overhead system. Note that all irrigation figures quoted in the simulation results are net amounts delivered directly above the crop canopy. Application and delivery losses are ignored.

Table 1. Scenarios used in the simulation exercise.

Scenario	Soil type	Irrigation system
1	'R' set	34 mm net, 6 day cycle
2	'R' set	17 mm net, 3 day cycle
3	'S' set	34 mm net, 6 day cycle
4	'S' set	17 mm net, 3 day cycle

Simulation results

Total seasonal rainfall varied between 381 and 1 287 mm, with a mean of 784 mm. PET calculated using the PM approach varied little between scenarios and averaged 1 643 mm. This was 17% less than LTM Class A pan evaporation for the Mhlume area (1 989 mm). Although run-off varied by as much as 25% between soils as a result of differences in run-off curve number, it amounted to a relatively small loss in the total water balance (mean of 51 mm). Deep drainage varied between soils and irrigation strategies (Figure 1). A total of 221 mm of water was estimated to have drained below the root zone in scenario 1 compared with 266 mm for the same irrigation strategy on a shallow 'S' set soil (scenario 3). A similar order of difference was observed between the two soils under the frequent irrigation strategy (278 mm versus 351 mm). This was expected considering the restricted water holding capacity of the shallower 'S' set soil compared with that of the 'R' set soil. Halving cycle time from six to three days increased deep drainage by 20% on the 'R' set soil (221 mm versus 278 mm) and by 24% on the 'S' set soil (266 mm versus 351 mm). Soils irrigated more frequently are wetter for a greater proportion of the season, and rainfall is more likely to fall on a full profile. Differences in Et were due largely to differences in the soil evaporation component. Under frequent irrigation (scenarios 2 and 4) soil evaporation was 20% higher than that under less frequent irrigation (scenarios 1 and 3; 255 mm versus 226 mm and 328 mm versus 276 mm respectively). Soil evaporation was greater on the 'S' set soil than the 'R' set soil due to an increase in irrigation frequency to compensate for increased drainage. The plant evaporation component accounted for an average of 1 227 mm of the total balance. This included evaporation of water intercepted by the canopy, which did vary between scenarios (227 mm – 334 mm).

The net effect of the differences between these components can be observed in the amount of irrigation applied, and the effectiveness of rainfall in each scenario (Table 2). On average 944 mm of irrigation water was applied to scenario 1. By halving irrigation cycle time from six to three days (scenario II) an additional 120 mm (13%) was applied on the 'R' set soil and effective rainfall was reduced from 65% to 57%. On the shallower 'S' set soil, 1 013 mm was applied as irrigation, some 70 mm more than was applied on the 'R' set soil under the same irrigation strategy. A total of 1 173 mm of irrigation water was applied on the 'S' set soil in scenario IV (irrigation cycle halved from six to three days), 160 mm (16%) more than was applied in scenario 3. Rainfall efficiency was reduced from 61% in scenario 3 to 49% in scenario 4.

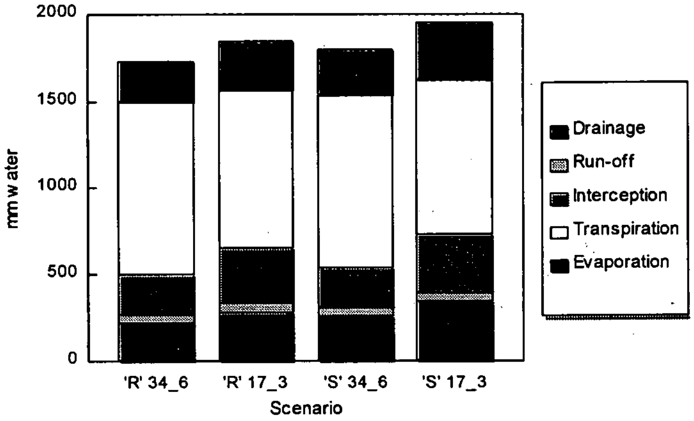

Figure 1. Components of the water balance for the four simulation scenarios ('R' and 'S' refer to the soil type, the remaining digits refer to the net application amount and irrigation cycle time).

Table 2: Net irrigation applied, and effective rainfall for each of the four scenarios ('R' and 'S' refer to the soil type, the remaining digits refer to the net application amount and irrigation cycle time).

Scenario	Net irrigation (mm)	Effective rainfall (mm and [% of total])
'R' 34_6	944	510 [65]
'R' 17_3	1 064	448 [57]
'S' 34_6	1 013	476 [61]
'S' 17_3	1 173	386 [49]

Model comparisons

In the above examples, Class A pan evaporation exceeded PET estimated using PM by 17%. There is substantial evidence to support using PM to estimate sugarcane CWU. Irrigation scheduling trials in Swaziland and South Africa have shown irrigation water savings of between 15 and 25% using PM to estimate CWU, compared with Class A pan evaporation (McGlinchey *et al.*, 1995; McGlinchey and Inman-Bamber, 1996b; McGlinchey, 1997).

Irrigation design norms are based on average peak monthly daily CWU. Using PM to estimate CWU compared with the Class A pan, resulted in a reduction in estimated peak demand from 7,1 to 6,0 mm/day at Mhlume. This would reduce design requirements significantly, resulting in substantial capital cost savings at installation.

In the four scenarios above, mean seasonal effective rainfall varied between 65 and 49%. Season to season variation was much larger (between 47 and 89% for scenario 1) and between individual rainfall events it was enormous. This suggests that using a single estimate of effectiveness is not appropriate for irrigation design and scheduling purposes. Robertson and Muchow (1997) reported variations in effective rainfall ranging from 15 to 98% between seasons at a range of sites in Australia, and came to a similar conclusion.

Conclusions

The above examples indicate clearly that incorrect irrigation system/scheduling combinations can reduce irrigation water use efficiency. It is necessary to be aware of the benefits of matching irrigation strategy with soil limitations in order to minimise losses and maximise rainfall efficiency. Differences between the components estimated by the two models were significant and did impact on irrigation design and scheduling practices. A detailed modelling approach, such as CANEGRO, offers designers and managers scope for fine tuning irrigation design practices and scheduling systems to use water more efficiently.

REFERENCES

Inman-Bamber, NG (1991). A growth model for sugarcane based on a simple carbon balance and the CERES-Maize water balance. *S Afr J Plant Soil* 8: 93-99.

Inman-Bamber, NG, Culverwell, TL and McGlinchey, MG (1993). Predicting yield responses to irrigation of sugarcane from a growth model and field records. *Proc S Afr Sug Technol Ass* 67: 66-72.

McGlinchey, MG (1997). Irrigation scheduling developments in the sugar industry. *Proc SABI 2001 Congress*.

McGlinchey, MG, Inman-Bamber, NG, Culverwell, TL and Els, M (1995). An irrigation scheduling model based on a crop model and an automatic weather station. *Proc S Afr Sug Technol Ass* 69: 69-73

McGlinchey, MG and Inman-Bamber, NG (1996a). Predicting sugarcane water use with the Penman-Monteith equation. pp 592-598 In: CR Camp, EJ Sadler and RE Yoder (eds) *Evapotranspiration and Irrigation Scheduling*. Proceedings of International Conference.

McGlinchey, MG and Inman-Bamber, NG (1996b). Effect of irrigation scheduling on water use efficiency and yield. *Proc S Afr Sug Technol Ass* 70: 55-56.

Robertson, MJ and Muchow, RC (1997). Variation in the effectiveness of rainfall meeting crop water requirements in the Australian Sugar Industry. *Proc Aust Soc Sug Cane Technol* 19: 229-236.

Thompson, AL, Martin, DL, Norman, JL and Howell, TA (1996). Scheduling effects on evapotranspiration with overhead and below canopy application. pp 182-188 In: CR Camp, EJ Sadler and RE Yoder (eds) *Evapotranspiration and Irrigation Scheduling*. Proceedings of International Conference.

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

Thompson, GD and Harding, RL (1986). A computerised model for evaluating irrigation schemes for sugarcane. *Proc S Afr Sug Technol Ass* 60: 177-183.