ADVANCES IN THE SCIENCE AND ECONOMICS OF SUPPLEMENTARY IRRIGATION OF SUGARCANE

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Abstract

Irrigation science in recent years has been driven largely by the technology requirements of large schemes where production would be impossible without irrigation. In these schemes the aim is often to remove water as a constraint to production, whereas in many sugar producing areas of Australia there is insufficient irrigation water to supplement rainfall fully and yields are often limited by water. Irrigation strategies developed for full irrigation systems may not always apply to supplementary systems with limited water. Drawn together in this paper are the results of replicated field trials, crop simulations and investment analysis to consider the long term benefits of installing and implementing supplementary irrigation in the Mackay and Atherton regions of Queensland, Australia. Large yield responses were obtained from relatively small but well-timed applications of water in two field experiments. Some of these responses were nearly as high as the theoretical maximum for the areas concerned. Mean response to irrigation simulated with the APSIM-Sugarcane model was similar to mean measured response. Simulations were then conducted to predict yearly fluctuations in yield response to supplementary irrigation applied in a variety of ways including winch, centre pivot and trickle irrigation systems, different scheduling options, different water allocations, different crop classes and different soils. Many of these options affected yield response probability and some had a profound effect on the financial investment feasibility of supplementary irrigation. Change in net present value over a 20-year term due to irrigation was as high as +$120 000 for a trickle system on a sandy soil at Mackay and as low as -$196 000 for a winch system on a clay soil at Atherton.

Introduction

Water remains one of the most serious constraints to increased productivity and profitability in the Australian sugar industry. Supplementary irrigation has increased in traditionally rainfed areas such as the Herbert, Mackay and Bundaberg regions particularly after dry years in the late 1980s early 1990s. A survey conducted in 1998 among growers in the Herbert region who irrigate, showed that about half these growers intend to invest in more water resources or to upgrade their systems, despite 1998 being a very wet season in that area. Recent experience of water shortages in the Bundaberg region indicate that growers require urgent support for decision making related to maximising the return from limited irrigation water supplies in dry years, as well as support, for strategic decisions about supplementary irrigation investments over the longer term.

Irrigation science in recent years has been driven largely by the technology requirements of large schemes where production would be impossible without irrigation. In these schemes the aim is often to remove water as a constraint to production. While full irrigation schemes exist in the Ord, Mareeba, Dimbula and Burdekin regions, sugar production in many other regions depends on rainfall and some supplementary irrigation. However, water supplies in these regions of relatively high rainfall are often insufficient to supplement rainfall fully. Irrigation strategies developed for full irrigation systems may not apply to supplementary systems with limited water. A major factor that growers in rainfed areas have to contend with, is rainfall variability. The variability of rainfall and of irrigation supplies in these areas calls for a new approach to research. Replicated field trials are inadequate without a sound biophysical framework because of the large number of irrigation options available to growers and because of the varied nature of soil and climate. Irrigation research also needs to be directly linked to the economics of production and to sustainability issues so that the correct priority is given to irrigation options that impact most on profitable and sustainable production.

Several assessments of return on investment in supplementary irrigation have been conducted in the past. Chapman and Chardon (1979) concluded from a field experiment and a simple water balance that installation of their experimental irrigation system in Mackay could not be justified over the long term because of the high cost of installation and low responses to irrigation (0 to 11 t cane per Ml irrigation). This work was done during a period of high rainfall and conclusions may have been different for different irrigation strategies and for a dry period such as the early 1980s or 1990s. Later, Wegener (1990) interpreted the results of this experiment differently using a crop growth model and an economic framework. He found that supplementary irrigation increased farm income; but it increased rather than reduced risk which was an assumption of the earlier study. Schmidt (1996) used a simple water balance model similar that used by Chapman and Chardon (1979), to assess profitability of various capital and variable costs of irrigation in variable climates. Profitability was averaged over a 20-year period and this showed that investment in supplementary irrigation in one high rainfall region would be worthwhile only if capital and variable costs were low. Wilcox *et al.* (1997) used a simple water balance model and detailed costing procedure to determine the benefit:cost ratio of upgrading or installing various irrigation systems in the Bundaberg region. Singels *et al.* (1999) used a physically based water balance and an economic framework to show that profitability of supplementary irrigation depended on a number of factors, including soil depth, irrigation strategy and rainfall conditions. This paper adds to the cited works by bringing together results of replicated field trials, a process level growth model and a detailed discounted cash flow model to demonstrate the benefit and risk of implementing supplementary irrigation.

The high capital and variable costs of irrigation and the large increases in yield possible with supplementary irrigation make it essential that all possible agronomic, economic and risk factors are considered before advocating or discarding irrigation as a viable option for growers in medium to high rainfall areas. The objectives of this paper are to consider a theoretical framework for possible responses to supplementary irrigation and then to assess published and unpublished experimental evidence to substantiate the theory. The theory embodied in the APSIM-Sugarcane model is then used to predict long term responses to limited irrigation and, finally, these crop by crop responses are assessed in an investment analysis model to demonstrate the value of the modelling tools in assessing sensitivity of irrigation investment options to climate, soil and some economic factors. The economic analysis does not apply to situations where irrigation infrastructure is already in place.

Theoretical maximum response to irrigation

Tanner and Sinclair (1983) proposed that a simple association between water transpired by the canopy (ΔT) and dry matter accumulation (ΔY) could be a useful way of determining crop water use. The theory showed that ΔY/ΔT was approximated by the quotient of a constant (k) and vapour pressure deficit (VPD) which is a measure of the dryness of the air (eqn 1). Water evaporating from the soil does not contribute directly to biomass accumulation and cannot be avoided, but can be reduced by getting the crop or crop residues to shade the ground as much as possible. The fraction of transpiration in evapotranspiration (ET) is a function of leaf area index (LAI) which is the ratio of leaf area to ground area (eqn 2). The cane yield component (ΔY_C) of biomass accumulation depends on the fraction of biomass in cane (F) and the dry matter content of cane (DMC) (eqn 3). Irrigation water use efficiency (IWUE) can be defined as the cane yield response to irrigation water applied (Chapman, 1997; Inman-Bamber *et al.*, 1999). If it is assumed that all irrigation is used for evapotranspiration (ET), then IWUE is the increase in cane yield occurring while this water is being used for ET (eqn 4).

$$\frac{\Delta Y}{\Delta T} = \frac{k}{VPD} \tag{1}$$

$$\frac{\Delta T}{\Delta ET} = f(LAI) \tag{2}$$

$$\Delta Y_c = \frac{\Delta Y.F}{DMC} \tag{3}$$

$$IWUE = \frac{\Delta Y_c}{\Delta ET} \tag{4}$$

Robertson *et al.* (1997) used this simple theory embodied in the APSIM-Sugarcane model (Keating *et al.*, 1999) to show that responses to irrigation could be as high as 22 t cane per 100 mm at Mackay and up to 10 t per 100 mm at Pongola. Robertson (personal communication) estimated VPD using saturation vapour pressure (SVP) at maximum (T_{max}) and minimum (T_{min}) daily temperature such that VPD= 0,75(SVP(T_{max})-SVP(T_{min})). Recent VPD for a region in the Burdekin measured with a dew point hygrometer showed that mean VPD for daylight hours over a 75 d period in spring and summer was 1,15 kPa. VPD estimated from maximum and minimum temperature for the same period was 1,67 kPa. Using the correct VPD could increase Y/T by 45% (eqns 1 to 4) so it is possible that theoretical responses to irrigation at Mackay could be as high as 32 t cane/Ml if water is applied when VPD is low and when soil evaporation is low under a complete canopy of leaves.

Other components of IWUE such as LAI, F and DMC could also be important. Robertson *et al.* (1999) showed that stress imposed early in the development of the crop reduced F later in the crop after stress had been relieved. From these considerations Inman-Bamber *et al.* (1999) suggested that benchmark water use efficiencies for full irrigation production (Thompson, 1976; Kingston, 1994) are not appropriate for supplementary irrigation.

Field experimentation

Responses of up to 27 t cane/Ml were measured recently in a supplementary irrigation experiment at Bambaroo near Ingham, North Queensland, where application efficiency was assumed to be 100% (Inman-Bamber *et al.*, 1999). Some data from this experiment are provided in Table 1 along with some new results from a supplementary irrigation experiment in Mackay. Of the 15 measured responses to irrigation treatments in Bambaroo and Mackay trials, 13 were statistically significant (Table 1). Statistically significant responses to irrigation varied from 6 to 28 t cane/Ml. Thus the maximum IWUEs determined experimentally at Bambaroo and Mackay are similar to the maximum IWUE shown by theory.

Table 1. Cane and sucrose yield and irrigation water use efficiency (IWUE) achieved from responses to irrigation at Bambaroo (Inman-Bamber *et al.*, 1999) and at Mackay. Simulated IWUE is also provided.

Sample date	Age (months)	Irrigation treatment	Cane yield (t/ha)	Irrigation (mm)	IWUE	
					Meas.	Simul.
					(t cane/Ml)	
Bambaroo plant crop						
21/01/96	7	High	71	170	19,4*	24,3
07/05/96	10	Medium	130	198	6,9	2,2
07/05/96	10	High	132	338	4,3	11,6
25/08/96	14	Medium	147	379	5,6*	6,2
25/08/96	14	High	155	511	5,7*	10,9
Bambaroo 1st ratoon						
7/5/97	8	Medium	130	179	21,1*	15,5
7/5/97	8	High	145	195	27,9*	17,2
20/08/97	12	Medium	143	179	27,4*	16,2
20/08/97	12	High	148	273	18,6*	15,5
Mackay plant crop (shallow soil)						
18/03/97	9	Full	96	179	27,3*	18,8
18/03/97	9	Half	58	94 †	7,4*	24,8
20/06/97	12	Full	143	328	15,2*	13,2
20/06/97	12	Half	122	177 †	16,9*	22,7
20/09/97	15	Full	165	379	12,0*	15,5
20/09/97	15	Half	148	200	16,0*	24,1

* Significant at $p<0,05$
† Irrigation differed less than 100 mm from control

Model validation and limitations

The validity of the APSIM-Sugarcane model for predicting yields of a large range of crops in Australia, South Africa and Mauritius has been established (Keating *et al.*, 1999). The data from the Bambaroo and Mackay experiments provided an independent test of the model's validity for the specific purpose of predicting response to irrigation. The standard error (SE_y) for cane yield predictions for 1995 to 1997 was 11 t/ha and coefficients of regression (b) and determination (r^2) were 0,76 and 0,85 respectively (Figure 1). Simulation of IWUE by the model is more demanding than yield simulation because one is attempting predict a yield difference rather than an absolute yield. Mean measured and simulated IWUE were similar (16,1 ± 1,7 t cane/Ml and 15,4 ± 2,1 t cane/Ml respectively). The model underestimated responses to irrigation at Bambaroo, particularly when measured IWUE was greater than 20 t cane/Ml (Table 1). It is possible that a carry-over effect from the plant crop of the Bambaroo experiment was responsible for large IWUE measured in the ratoon crop (Inman-Bamber *et al.*, 1999). Other sources of error were estimates of VPD, LAI, F and DMC. Regression coefficients (no constant) for simulated on measured cane yield, LAI, F and DMC were 1,00, 1,06, 1,02 and 0,97 respectively. There was therefore little bias in the simulation of these components. Bias was most in LAI, and an over-estimate of LAI increased rather than decreased the estimate of IWUE (eqns 1 to 4). Further work is required to determine sources of errors in the prediction of IWUE.

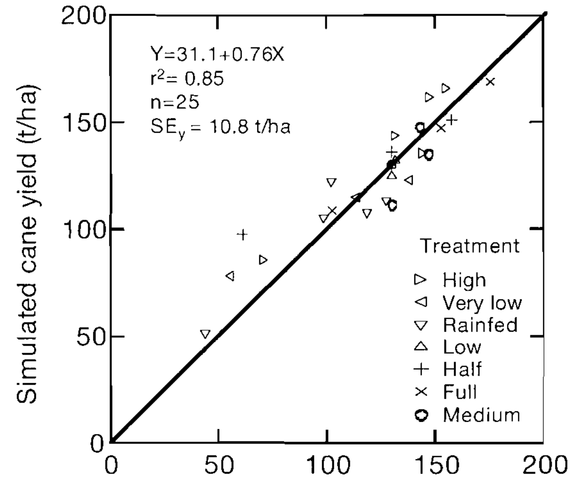

Figure 1. Measured and simulated cane yields for irrigation experiments at Bambaroo and Mackay from 1995 to 1997.

Yield accumulation is sometimes reduced or curtailed when lodging occurs (Muchow *et al.* (1995); Singh *et al.* (1999)) and APSIM-Sugarcane has no mechanistic way of dealing with this at present. It is possible that some simulated responses may not be achieved in practice if irrigation hastens lodging. In recent samplings of the Bambaroo trial a response to irrigation was detected at eight months but, when the crop was sampled again at 12 months, irrigated plots yielded significantly less than rainfed plots (data not shown). This was because the larger irrigated crop had lodged earlier than rainfed plots, resulting in more stalk damage, measured as loss of live stalks.

Simulations with APSIM-Sugarcane tended to underestimate measured responses to irrigation, although there will be cases when the reverse is true. Simulations will also underestimate the benefit of irrigation in situations where stalk death occurs as a result of water stress. It is nevertheless reasonable to proceed with assessments of variability in yield response to irrigation using this model, provided these limitations are kept in mind.

Long term predictions of crop responses

Growers in Bundaberg, Mackay, Proserpine, Herbert and Atherton regions generally have between 1 and 5 Ml irrigation per hectare either through on-farm bores, on-farm dams or off-farm storage and reticulation systems owned by syndicates or local, state or federal authorities. There are numerous options for growers who have access to these limited quantities of water including an option not to irrigate at all. This paper explores only a small set of options that growers have in the Mackay and Atherton regions to show the variability of yield responses to various components of these options. Daily climate data from 1957 to 1993 was measured or generated for these regions following the procedures outlined by Muchow *et al.* (1997). Median, 10- and 90-percentile rainfall for Mackay was 1 604, 865 and 2 309 mm, and for Atherton was 1 322, 915 and 1 760 mm respectively. It is interesting to compare these two regions, which differ markedly in amount and variability of rainfall.

For Mackay, irrigation options with water winch, centre pivot and trickle (drip) were compared. Application efficiencies assumed for these systems were 75, 85 and 90% respectively, and net irrigation per application was 37,5, 42,5 and 15,0 mm respectively. Allocations of 1 or 3 Ml/ha were compared for a sand, loam and clay with 63, 114 and 162 mm plant available water capacity (PAWC). Irrigation in the simulations was triggered when available water content fell to 50% of PAWC for all soils. A simple cropping system of a 12-month crop harvested green and ratooning in June each year was simulated.

To deal easily with the range of IWUE and responses to irrigation over the many years and conditions of the simulations, the data was ordered from minimum to maximum and then divided into four equal lots. The values that divide these lots are called quartiles, Q1, Q2 (or median) and Q3.

The mean mid-range (Q1 to Q3) simulated IWUE for Mackay was 7,5 to 18,3 t/Ml (Table 2). In general very high IWUE's (>20 t cane/Ml) occurred in less than 25% of all simulated treatments and years. IWUE and irrigation response were greatest in the loam and least in the clay for Q1, Q2 and Q3. Maximim IWUE and response was greatest in the sand (Table 2) because of low rainfed yields in the soil in dry years (data not shown).

Median (Q2) and Q1 IWUE, was greater with 3 than with 1 Ml allocation but maximum IWUE was greatest with the 1 Ml allocation (Table 2) also because of large responses to limited water in dry years. Median and Q1 responses to irrigation were therefore more than three times greater for the 3 Ml than for the 1 Ml allocation. There were no consistent IWUE differences between irrigation systems. Irrigation responses were higher for pivot and trickle systems than for the winch system because of the higher application efficiencies assumed for pivot and trickle systems (Table 2). The comparison of these systems would be different if different application efficiencies and irrigation strategies were assumed.

Water winch was the only system considered in the Atherton simulations. Soils in this area are derived from igneous rock and are generally as deep or deeper than those in coastal regions. A red earth and a kraznozem were compared with PAWCs of 162 and 290 mm respectively.

Allocations of 0, 1, 2, 3 and 4 Ml/ha net irrigation were simulated and irrigation was triggered when available soil water had declined to 70, 50 or 20% of PAWC, provided 10 days had elapsed since the last irrigation. A realistic cropping sequence for this region was simulated. Planting was done in early July after a 6-month fallow. A plant crop and four ratoon crops were harvested on 1 July, 1 August, 1 September, 1 October and 1 November respectively. All crop classes were represented in each year of the simulation. The APSIM-Sugarcane model makes a distinction between plant and ratoon crops but not between ratoon crops themselves so the simulated effects of ratoon class (or ratoon age) are therefore entirely due to cropping cycle.

Table 2. Simulated irrigation water use efficiency (IWUE) and response to irrigation for various treatments (factors and levels) at Mackay. Quartiles show 25% (Q1), 50% (Q2 or median), 75% (Q3) probability of not exceeding values in table. Minimum values in all cases were zero.

Factor	Level	IWUE (t/Ml)				Response to irrigation (t/ha)			
		Q1	Q2	Q3	Max	Q1	Q2	Q3	Max
Soil	Clay	7,0	12,0	17,1	27,0	8,1	13,5	32,5	60,8
	Loam	8,0	14,0	20,4	37,0	10,6	18,2	35,9	63,5
	Sand	7,3	13,0	18,0	59,5	9,8	16,6	37,4	84,2
Allocation	1 Ml/ha	7,0	12,6	18,0	59,5	5,8	10,5	15,0	47,6
	3 Ml/ha	8,3	13,6	18,1	34,1	20,3	34,0	45,8	84,2
System	Winch	7,3	13,0	18,5	59,5	8,1	14,7	33,1	76,7
	Pivot	6,8	13,4	18,1	56,0	9,8	16,5	35,9	84,2
	Trickle	8,1	12,8	17,8	45,0	10,3	16,5	38,9	83,3
Mean		7,5	13,1	18,3	47,2	10,4	17,6	34,3	73,1

Simulations with the red earth produced considerably higher IWUE than simulations with the kraznozem. Differences in irrigation response were accentuated because more irrigation was required for the crop on the red earth than on the kraznozem (Table 3). IWUE decreased with increasing allocation. Irrigation response increased less than four-fold between 1 and 4 Ml/ha allocation for this reason and because high allocations were not always needed. Irrigating when soil water content was low (20% PAWC) resulted in the most efficient use of irrigation water (IWUE) and irrigating at 70% PAWC resulted in the lowest IWUE (Table 3). However because less water was applied at high allocations with the 20% PAWC than the other strategies, response to irrigation was similar with 20% and 50% PAWC strategies and slightly less with the 70% PAWC strategy (Table 3). IWUE and cane yield response to irrigation were considerably higher in first ratoon than in plant crops (Table 3), presumably because the 6-month fallow prior to planting allowed soil water to be replenished. Median monthly rainfall for July to September at Atherton is less than 20 mm. Ratoon crops develop more rapidly than plant crops demanding more water in the early stages. The first ratoon crop was particularly vulnerable because it had the longest dry period before the wet season, which usually begins in December. No physiological differences between ratoon crops are acknowledged in the model. Differences in Table 3 are due only to different growth periods assumed for these ratoon crops.

Investment analysis

A spreadsheet model was developed to incorporate the capital and operating costs associated with a number of irrigation systems. The model accepts simulated yields and total irrigation of individual crops and then conducts discounted cash flow (DCF) analyses on after-tax income. The Australian Income Tax Assessment Act contains certain provisions to encourage the development of water resources and investment in irrigation infrastructure. These provisions are made by government to help stabilise income from primary production and to facilitate self reliance and hence reduce the need and cost of government support during drought. Pertinent aspects of the act incorporated in this model include: marginal income tax rates/company tax income splitting, section 51(1) provisions which allow primary producers to write off irrigation investigation and planning costs and all irrigation operating costs in the year of expenditure, and Drought Investment Allowance which allows primary producers to claim an additional deduction of 10% of the capital costs (up to a maximum deduction of $5 000) associated with irrigation reticulation in the year of expenditure.

The results of APSIM-Sugarcane simulations for Mackay and Atherton were transferred to the investment model. DCFs were then conducted over a 20-year time frame to reflect what is considered to be a reasonable investment horizon for a grower considering installation of supplementary irrigation equipment and to coincide with the expected life of much of this equipment. A farm business on 50 ha with two partners paying the marginal tax rate was considered. Capital investments derived from the cost of various components plus installation costs were $1 648, $2 365 and $3 335 for water winch ('Big gun'), centre pivot and trickle (drip) systems respectively.

CF analysis showed that a positive return on investment in supplementary irrigation is by no means a foregone conclusion despite the favourable response estimates already discussed. Of the 18 options analysed for Mackay (three soils, three systems and two allocations) only four showed positive net present value (NPV). An allocation of 1 Ml/ha was not economic with any system or soil (Table 4) and no options were economic for the clay soil (not shown). The most profitable option was the use of a trickle system on a sandy soil with a 3 Ml/ha allocation (Table 4). This showed an internal rate of return of 11% and an increase in NPV over rainfed of $120 000. The robustness of this investment is shown in the breakeven costs and sugar price. The sugar price, for example, could decrease to $252/t before this option became non-viable. Centre pivot and trickle systems would both be viable on sands and loams provided water allocation was 3 rather than 1 Ml/ha. The economics of the three systems

Table 3. Simulated irrigation water use efficiency (IWUE) and response to irrigation for various treatments (factors and levels) at Atherton.

Factor	Level	IWUE (t/Ml)				Response to irrigation (t/ha)			
		Q1	Q2	Q3	Max	Q1	Q2	Q3	Max
Soil	Clay	10,6	13,6	16,7	68,9	17,7	30,6	45,4	109,1
	Kraznozem	7,0	10,9	14,3	40,6	11,1	21,0	33,9	104,1
Allocation	1 Ml/ha	9,1	12,8	16,3	68,9	9,0	12,7	16,3	68,9
	2 Ml/ha	9,1	12,4	15,8	45,8	17,3	24,6	31,5	91,6
	3 Ml/ha	8,5	12,0	15,4	35,5	22,5	34,6	45,5	106,5
	4 Ml/ha	8,5	11,8	15,2	35,5	26,3	41,6	58,7	109,1
Strategy	50% PAWC	8,8	12,0	15,4	68,8	14,3	26,8	40,9	108,8
	20% PAWC	11,0	14,0	16,8	68,9	14,6	26,3	41,2	106,5
	70% PAWC	6,8	10,7	14,2	68,7	12,5	23,5	36,7	109,1
Crop	Plant	8,3	11,7	14,1	21,7	12,7	21,8	35,4	74,6
	Ratoon 1	10,7	14,6	18,5	68,9	16,1	29,7	47,9	109,1
	Ratoon 2	8,0	12,0	15,4	40,5	12,8	22,8	38,9	84,4
	Ratoon 3	9,3	12,0	15,4	47,2	14,5	26,3	40,4	80,3
	Ratoon 4	8,2	11,7	15,1	41,6	14,0	25,6	39,4	97,9
Mean		8,9	12,3	15,6	51,5	15,4	26,3	39,4	97,1

Table 4. Discounted cash flow analysis of selected irrigation options at Mackay with assumptions of sugar price = $320/t, water price = $40/Ml and irrigation scheduled at 50% PAWC. Irrigated area = 50 hectares. CCS = 13.5%.

Irrigation system	None	Winch		Pivot		Trickle	
Water allocation (Ml/ha)	-	1	3	1	3	1	3
Effective irrigation (Ml/ha)	-	0,75	2,25	0,85	2,55	0,90	2,70
Operating costs ($/Ml)	-	96	96	28	28	27	27
Soil type	Sand - plant available water content of 63 mm						
Average yield (t/ha)	87	99	120	100	123	100	126
Breakeven operating costs ($/Ml)	-	71	83	-	64	-	70
Breakeven water cost ($/Ml)	-	-	15	-	109	-	123
Breakeven sugar price ($/t)	-	840	375	794	257	861	252
Internal rate of return (%)	-	-	-	1	9	-	11
NPV ($1 000)	-	-25	-41	-33	104	-61	120
Soil type	Loam - plant available water content of 114 mm						
Average yield (t/ha)	111	122	141	124	145	124	148
Breakeven operating costs ($/Ml)	-	38	67	50	50	-	57
Breakeven water cost ($/Ml)	-	-	-	-	81	-	98
Breakeven sugar price ($/t)	-	-	-	839	271	847	260
Internal rate of return (%)	-	-	-	-	7	-	9
NPV ($1 000)	-	-53	-77	-59	52	-75	72

could change with different application efficiencies and operation costs.

None of the irrigation options considered for the kraznozem soil at Atherton were economically viable. The worst case was a negative cash flow of $196 000 with a winch installation and an allocation of 4 Ml/ha scheduled at 50% PAWC on a kraznozem. For the red earth, NPV was positive for both allocations considered, provided irrigation was scheduled at 20 or 50% PAWC and not 70% PAWC, and provided the investment was made in a dry rather than in a wet period (Table 5). While mean annual rainfall for 20 year periods starting in 1961 or 1971 was similar (1 448 and 1 409 mm respectively), mean annual rainfall for the first five years of these periods differed substantially (1 372 and 1 751 mm respectively). This resulted in greater responses to irrigation and greater NPVs for 1961 to 1980 than for 1971 to 1990. The most rewarding option of those considered was a 4 Ml/ha allocation applied when soil water content decreased to 20% PAWC. In this case NPV was similar in both 20-year periods.

Some generalisations are possible from these DCF analyses. Supplementary irrigation was generally more profitable in Mackay than in Atherton, despite the lower rainfall in Atherton than in Mackay. High allocations were more profitable than low allocations even though IWUE was greater for low than high allocations at Atherton. Irrigation was more profitable on sandy soils than on clays because of the higher rainfall efficiency and higher rainfed yields on the clays. Irrigation application efficiency was an important factor in profitability.

Table 5. Discounted cash flow analysis of selected irrigation options at Atherton for a Red Earth soil with PAWC = 162 mm, with assumptions of sugar price = $320/t, water price = $40/Ml and irrigation applied with a winch which is 75% efficient. Irrigated area = 50 hectares. CCS = 14.5%.

Irrigation schedule	None	20% PAWC		50% PAWC		70% PAWC	
Water allocation (Ml/ha)	-	1.3	4.0	1.3	4.0	1.3	4.0
Effective irrigation (Ml/ha)	-	1.0	3.0	1.0	3.0	1.0	3.0
Operating costs ($/Ml)	-	96	96	96	96	96	96
Period of investment	1961 to 1980						
Average yield (t/ha)	111	129	155	128	154	127	159
Breakeven operating costs ($/Ml)	-	59	75	45	46	23	20
Breakeven water cost ($/Ml)	-	105	114	98	99	87	85
Breakeven sugar price ($/t)	-	307	291	317	315	333	341
Internal rate of return (%)	-	6	14	4	6	2	-
NPV ($ 1000)	-	11	55	3	10	-10	-35
Period of investment	1971 to 1990						
Average yield (t/ha)	108	124	151	123	148	122	143
Breakeven operating costs ($/Ml)	-	38	76	20	34	1	0
Breakeven water cost ($/Ml)	-	95	114	85	93	75	75
Breakeven sugar price ($/t)	-	321	290	336	326	359	369
Internal rate of return (%)	-	3	16	0	-	-	-
NPV ($ 1000)	-	-1	56	-12	-10	-23	-74

Sensitivity to IWUE estimate

DCF analyses were repeated for Mackay after adjusting responses to irrigation downwards and then upwards by 20%. This made a large difference to some of the investment and operation options (Figure 2). However, only two options with originally positive NPV turned out to be unprofitable with a 20% reduction in IWUE, and only one option with an originally negative NPV became profitable with a 20% increase in IWUE. The sensitivity of NPV to estimates of IWUE highlights the importance of improving the model and the required input data for assessing responses to irrigation.

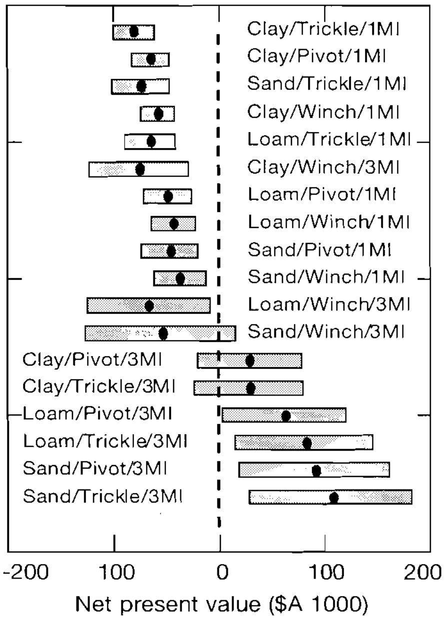

Figure 2. Net present value (NPV, ●) and NPV range of various irrigation systems and operating options. Lower limit derived from predicted irrigation water use efficiency (IWUE) x 0,8 and upper limit from IWUE x 1,2.

Conclusions

An important factor in sugarcane production is variability. Climatic variability from season to season and between locations has a major influence on irrigation requirement and response to irrigation. The close linkages now established between field research, cropping systems modelling and economic modelling provide a new basis for considering water as a means of controlling yield and farm income in a highly variable climatic and economic environment. Although the APSIM-Sugarcane model requires further refinement, probabilities of yield response to supplementary irrigation can be predicted with some degree of confidence, and for Mackay and Atherton these probabilities are high. However, for growers currently without irrigation capability, the economic viability of investments in irrigation are by no means certain. Research conducted in the Australian sugar industry in recent years has led to the development of tools which can integrate information on soils, weather, cropping system and individual financial position to help growers make rational decisions regarding irrigation.

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