THE EFFECTS OF PUMPING RESTRICTIONS ON IRRIGATION EFFICIENCY: IMPLICATIONS FOR ESKOM'S TIME-OF-USE ELECTRICITY SUPPLY TO RURAL AREAS

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Irrigation farmers and Eskom are unsure about the amount of incentive required (saving in the cost of electricity) by irrigation farmers to prevent net returns from falling under load management. The adoption of Eskom's proposed Ruraflex load management programme will be affected by the risk preference of the irrigation farmer, the application capacity of the irrigation system, the plant extractable soil water (PESW) of the soil and the efficiency with which irrigation management can adapt to load management. Load management programmes can potentially increase the economic efficiency of some irrigation farms because the amount of incentive required by irrigation farmers varies between R6/ha and R282/ha. An increase in the application capacity of an irrigation system dramatically diminishes the risk of income losses when insufficient irrigation water is applied due to reduced pumping capacity caused by load management. Further research should be focused on the tradeoffs between the reduced risk of income losses and the capital outlay needed for increasing the application capacity of irrigation systems.

1. Introduction

The scheduling of irrigation water has long been seen as the most likely way irrigation efficiency can be increased. However, savings in the cost of electricity, can potentially also make a large contribution to increasing irrigation efficiency (Botes and Oosthuizen, 1991). Eskom is engaged in developing and introducing a load management programme (Ruraflex) that will supply electricity to irrigation farmers at a reduced rate. In return, however, it is expected that irrigation farmers must restrict pumping time so that Eskom can even out demand on their generating capacity.

Both the irrigation farmers and Eskom are, however, unsure about the amount of incentive (cheaper electricity rates) which must be offered to irrigation farmers so that pumping restrictions caused by load management do not leave them worse off. The problem is further complicated by the fact that the minimum amount of incentive required will most likely depend on factors such as the soils plant extractable soil water (PESW), the pumping capacity of the irrigation system and characteristics of the irrigation farmer such as risk aversion and the amount of attention devoted to scheduling management (Bosch and Eidman, 1988).

The objectives of this article are to determine:

i. how pumping restrictions affect the expected net returns, yields, the amount of irrigation water applied and the irrigation management of maize produced in the Winterton area;
ii. the amount of incentive required by irrigation farmers with non-neutral risk preferences to prevent them from being left worse off by pumping restrictions; and
iii. how factors such as the soil's PESW and the application capacity of the irrigation system influence the amount of incentive required by decision makers with non-neutral risk preferences.

2. Conceptual Model

The effect that load management has on irrigation efficiency will depend on how pumping restrictions affect economic decisions (Bosch and Eidman, 1988). Irrigation management should therefore be adjusted so that the expected utility for each load management scenario is maximized. The net income distributions that maximize expected utility before and after introducing pumping restrictions, can then be compared to determine the amount of incentive required in order not to leave decision makers with different risk preferences worse off when restricting pumping hours.

Botes (1994) developed a simulation optimization model (SIMCOM) which combines a crop growth simulation model with an efficient search optimizer. The SIMCOM model was used to maximize the expected utility of six different irrigation information scenarios over a 20 year period by searching for the optimal triggering levels in each of three growth stages. A risk efficiency criterion such as generalized stochastic dominance (GSD) (King and Robison, 1981) was used to determine the amount by which each value in cumulative distribution function of net returns (CDF-NR) obtained from one load management scenario must be lowered (or increased) so that it no longer dominates (or is dominated by) the CDF-NR obtained from another load management scenario.

The risk preferences of irrigation farmers in the Winterton area were elicited by Botes, Bosch and Oosthuizen (1994). Absolute risk aversion coefficients (RACs) of between -0,0003 and -0,00003 were identified for risk-seeking decision makers. RACs of between 0,00003 and 0,0003 were identified for risk-averse decision makers.

3. Empirical Model

The procedure used to calculate the amount of incentive required when pumping time is restricted for irrigation farmers with different risk preferences on two soil types, using irrigation systems with two application capacities in the Winterton area, require firstly, adjustment of the SIMCOM model; secondly, selection of absolute risk aversion coefficients; thirdly, budgeting of irrigated maize; fourthly, construction of alternative load management scenarios; and, finally, calculation of the amount of subsidy required under all anticipated production conditions.

The SIMCOM model was adjusted to optimize expected utility as the principal performance measure for each load management scenario, risk preference, application capacity and soil type using 20 years' weather data from the Winterton area. More specifically, the maximum expected utility for a risk-averse decision maker was calculated as follows:

$$\text{MAX EU(BTNI)} = \sum_{i=1}^{20} [- \text{EXP} (NR_{im}*\text{-RAC})*\text{Pr}] \qquad (1)$$

The BTNI for any given weather year was calculated by summing net returns received from 50 ha of irrigation maize (NR_{im}). The negative exponent of the BTNI value, multiplied by the selected RAC, was then calculated. This was multiplied by its probability (Pr) and summed to similar values calculated from using all 20 the weather years. RACs identified by Botes, Bosch and Oosthuizen for risk-seeking and risk-averse decision makers were used.

Net returns received from the irrigated maize enterprises for a specific year were calculated as follows:

$$NR_{im} = \sum_{i=1}^{20} [\{(IY_i * P_i) - PC_i - IC_i - YC_i\} * A_i] \qquad (2)$$

where the variables represent the irrigated maize yields (IY), the producer price for maize (P), production cost (PC), irrigation variable cost (IC), yield variable cost (YC) and the area under production (A) in a specific year (i).

The CERES maize (IBSNAT, 1986) crop growth simulation model, which was built into the SIMCOM model, was used to simulate irrigated maize yields for each of the 20 years. The maize price scenario developed by Meiring (1994) was used to obtain stochastic maize prices. The @RISK program was used to generate 20 random maize prices. Each maize price was randomly assigned to different weather years.

An enterprise budget for irrigated maize was constructed with the help of farmers and farm advisers in the area. Production cost (PC) for irrigation maize was calculated at R1 198/ha. Yield variable cost (YC) was calculated at R54,78 per harvesting hour and R0,154/ton/km over a distance of 30 km from the farm to the market.

AGRICO Machinery (PTY.) LTD. supplied the specifications for a 50 ha centre pivot irrigation system with an application capacity of 135 m^3/h. The analyses were repeated for an irrigation system with a higher application capacity. For this purpose, the pumps and design specifications of the irrigation system were changed to allow it to apply 200 m^3/h. The variable cost of applying irrigation water was calculated by using the IRRCOST computer program (Meiring and Oosthuizen, 1992). The variable cost of applying one millimeter of water per hectare for the centre pivot irrigation systems is 64 cent per millimeter.

A 1 050 mm deep Hutton/Deverton soil and a 800 mm deep Avalon/Bergville soil were identified by the Grain Crops Research Institute at Cedara as two fairly representative soil types in the Winterton area. The plant available water capacity for the two soils was 77 mm and 138 mm respectively.

Two load management scenarios were constructed. The first scenario assumes no interruptions; e.g., the irrigation farmer can apply irrigation water 24 hours every day of the week (168 hours per week). The second scenario assumes that irrigation farmers limit pumping to 81 hours per week. This scenario is closely related to Eskom's Ruraflex load management programme. Ruraflex enables irrigation farmers to obtain cheaper electricity if pumping is restricted to the off-peak periods. In Ruraflex the total off-peak periods per week amount to 81 hours.[1] (about 12 hrs per day).

The SIMCOM model was used to search over alternative combinations of depletion levels to find an irrigation management strategy that maximizes the expected utility for each load management scenario, risk preference, application capacity and soil type. The optimized CDFs-NR, with and without pumping restrictions, were used in the comparisons. The GSD program of Cochran and Raskin (1988) was used to calculate the amount of incentive required by each type of decision maker under all the anticipated management and production conditions.

4. Results

The effects of pumping restrictions on the profitability of irrigation

The average per hectare reductions in the net returns from irrigated maize produced in the Winterton area, and the soil water depletion levels at which irrigation was initiated for the two load management scenarios on the Hutton and Avalon soils when pumping capacities were 135 m^3/h and 200 m^3/h respectively, are presented in Table 1.

Net returns are reduced by between R11/ha and R136/ha when a pumping restriction is introduced. The lowering of the application capacity of the irrigation system and the soil's PESW render irrigation farmers vulnerable to reductions in net returns resulting from pumping restrictions.

Net return losses due to pumping restrictions increase from R95/ha to R136/ha if the PESW is lowered from 138 mm (Hutton) to 77 mm (Avalon). Farmers irrigating a soil with a low PESW (Avalon soil) will thus lose an additional R41/ha, because the soil is not able to store enough water to offset pumping restrictions.

The application capacity of the irrigation system is another important factor affecting the potential impact of pumping restrictions on the net returns generated from irrigated maize. For example, the average reduction in net returns on the Avalon soil decreases by R113/ha from R136/ha to R23/ha if the application capacity of the irrigation system increases from 135 m^3/h to 200 m^3/h.

From the results it is clear that the increase in application capacity can partially substitute for income losses resulting from pumping restrictions and the irrigation of soils with low PESW.

The soil water depletion levels (expressed in percentage points) where irrigation is triggered to maximize the expected net returns for maize, vary between 71% and 85% of PESW. Irrigation water is applied sooner (higher depletion levels) if pumping restrictions are introduced or the soil's PESW is lower. For example, with the 138 mm PESW soil, the 135 m^3/h application capacity and no interruption load management scenario, the optimal irrigation strategy calls for the irrigation of maize when 85% of the plant extractable soil water is depleted. The trigger level increases to 71% of PESW if pumping time is restricted.

Table 1: The average per hectare reductions in net returns from irrigation maize and the soil water depletion levels for two load management scenarios on two soil types with two pumping capacities in the Winterton area

Load management scenarios		135 m^3/h		200 m^3/h	
		Hutton	Avalon	Hutton	Avalon
No interruptions (168 hrs/week)	Net income loss (R/ha)	0	0	0	0
	Trigger level (%)	85	81	85	78
Pumping restrictions (81 hrs/week)	Net income loss (R/ha)	95	136	11	23
	Trigger level (%)	71	68	82	76

Table 2: he average maize yields (ton/ha) and the amount of irrigation water applied (mm/ha) with the two load management scenarios on two soil types and two pumping capacities in the Winterton area

Load Management Scenarios	135 m^3/h Hutton	Avalon	200 m^3/h Hutton	Avalon
No interruptions (168 hrs/week)				
Yield (ton/ha)	9,72	9,66	9,71	9,68
Water (mm/ha)	146	179	147	191
Pumping restriction (81 hrs/week)				
Yield (ton/ha)	9,48	9,33	9,69	9,68
Water (mm/ha)	158	190	153	220

Similarly, the depletion level increases from 85% for the high PESW soil (Hutton soils) to 81% if the soil's PESW is lowered (Avalon soil).

Irrigation is however triggered at lower soil water levels if the application capacity of the irrigation system increases. On the low application capacity system, for example, irrigation water is applied when 71% of the Hutton soil's PESW is depleted. In comparison, the trigger level decreases to 82% when the application capacity of the irrigation system increases to 200 m^3/h.

The average per hectare maize yields and the amount of irrigation water applied with the two load management scenarios on soils with PESW of 138 mm and 77 mm and application capacities of 135 m^3/h and 200 m^3/h respectively are presented in Table 2.

The average maize yield declines when a pumping restriction is introduced. However, the decline in maize yield is substantially reduced if the application capacity of the irrigation system is increased from 135 m^3/h to 200 m^3/h. For example, the pumping restriction only reduces maize yields by 20 g/ha on the Hutton soil if the application capacity of the irrigation system is 200 m^3/h, compared to the 240 g/ha reduction in maize yield when the application capacity is 135 m^3/h.

In contrast to the decline in the average maize yields, the average amount of irrigation water applied increases when pumping time is restricted. The average amount of irrigation water applied on the Hutton and Avalon soils with an application capacity of 135 m^3/h, for example, increases by 12 mm/ha and 11 mm/ha respectively when a pumping restriction is introduced. This is because irrigation is triggered at higher soil water levels.

The use of pumping restrictions as a policy instrument to restrict the use of irrigation water or to increase the efficiency with which irrigation water is used, will fail. The reason is that it will have the opposite effect because irrigation farmers will be inclined to use more irrigation water.

Evaluation of pumping restrictions with non-neutral risk preferences

Both Eskom and irrigation farmers are concerned with the amount of discount on the cost of electricity that must be offered to keep expected net returns from falling when load management is imposed. The effect of risk preferences on the amount of discount needed to keep irrigation farmers from being left worse off by pumping restrictions, are shown in Table 3. The results have been obtained by calculating the amount that must be added to the net returns on irrigation maize when load management is introduced to keep the distribution of net returns obtained under restricted pumping from being stochastically dominated by the unrestricted pumping net income distribution.

The results show that the amount of compensation needed by irrigation farmers if they are not to be left worse off, increases with risk aversion. The risk-seeking decision makers using the 135 m^3/h system on the Hutton soil require a subsidy of R46/ha if a 81 hour per week pumping restriction is introduced. Risk-averse decision makers, on the other hand, require a subsidy of R220/ha. The significant increase in the required subsidy is the result of income losses in drier weather years when insufficient irrigation water is applied due to reduced pumping capacity caused by load management. Because risk-averse decision makers seek to maximize the worst outcomes and disregard the rest of the net income distribution, a much higher incentive must be offered to keep risk-averse irrigation farmers from being left worse off.

The required subsidies for the three types of decision makers irrigating the Hutton soil are significantly reduced to R6/ha, R11/ha and R25/ha respectively if the application capacity of the irrigation system is increased to 200 m^3/h. The amount of subsidy required by risk-averse decision makers, for example, declines by R195/ha from R220/ha to R25/ha because the higher application capacity limits the losses of crop yields in the drier weather years, by offsetting the reduced pumping capacity caused by load management.

5. Conclusion

From the results it is clear that financial incentives must be offered to the irrigation farmers if they are not to be left worse off when load management strategies are introduced. Irrigation farmers must therefore ensure that the per hectare savings in the cost of electricity due to the use of cheaper electricity are at least equal to the amount of subsidy required not to leave them worse off by restricting pumping hours. Clearly the economic profitability, and therefore also the adoption of the proposed Ruraflex load management programme, will be affected by the financial incentive offered (reduction in the cost of electricity), the risk preference of the irrigation farmer, the application capacity of the irrigation system and the soil's PESW, as well as the efficiency with which irrigation farmers can adjust their irrigation scheduling strategies to the load management programme.

The importance of proper irrigation scheduling will increase under load management conditions. The net returns maximizing strategy calls for initiating irrigation sooner (higher soil water levels). Failure to adjust the soil water depletion levels will increase yield losses in the drier weather years. An over-adjustment in the soil water depletion levels will result in more irrigation water being applied. This can lead to the use of more electricity (longer pumping hours), eventually offsetting the possible advantages of using the cheaper electricity offered under the load management programme.

The finding of this research is that load management programmes can potentially increase the economic efficiency of irrigation farming because there is a wide variation in the amount of subsidy required to keep irrigation farmers from being left worse off by load management programmes; especially, if it is made voluntary. Some irrigation farmers would however be better off if they do not participate in load management programmes, because of low application capacities of irrigation systems, poor quality soils, high risk aversion and/or the inability to adjust irrigation management to load management programmes.

Further research is required to determine the effect of different climates, soil types, irrigation systems and crop rotations on the amount of incentive needed to compensate irrigation farmers for restricted pumping hours.

In addition, further research should focus on the tradeoffs between the reduced risk of income losses and the capital outlay needed for increasing the application capacity of irrigation systems.

Notes

i. The off-peak periods in Ruraflex are as follows: Monday to Friday 8 hours per day, Saturday 17 hours and on Sunday 24 hours.

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