Paper 3

IRRIGATION RESPONSE OF POTATOES

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INTRODUCTION

To obtain maximum benefit from applied water, anyone growing a crop under irrigation needs to know answers to the following questions.

- When should the crop be irrigated?
- How much water should be put on?
- What are the consequences in terms of crop yield of not irrigating, for instance when there is a limited water supply, or water is costly?

The purpose of this paper is to give the best answers presently available to these questions. First, a description will be given of a water budgeting technique for irrigation scheduling. This will be followed by a description and analysis of an experiment designed to measure the consequences of withholding irrigation water, and the analysis of the results of a series of experiments performed by Martin (1979).

WATER REQUIREMENTS

The fortnightly water requirements each month (evapotranspiration), calculated from the Priestley and Taylor (1965) formula (Jamieson, 1982), for maximum production from potatoes in Canterbury from both rainfall and irrigation are given in Table 1.

Table 1. Fortnightly water requirements (evapotranspiration) for maximum yield for potatoes in Canterbury.

October	40 mm
November	50 mm
December	60 mm
January	60 mm
February	50 mm
March	40 mm

IRRIGATION SCHEDULING

The water requirements of a crop can be met from three sources:

- stored water in the soil;
- rainfall;
- irrigation.

The purpose of irrigation is to overcome the shortfall in stored water and rainfall. This can be done by keeping a simple water budget. Two questions must be answered:

- when to irrigate?
- how much water to apply?

Potatoes typically root to about 750 mm depth. In deep soils (e.g. Templeton or Wakanui) the root zone holds about 120 mm of plant available water at field capacity, and shallow soils (eg. Lismore or Eyre) hold about 80 mm at field capacity. Irrigation should commence once half this water (60 mm and 40 mm respectively) has been used. Enough water should be applied to bring the soil moisture deficit to between 0 and 20 mm. A small deficit may be left so that the advantage of any rain is not lost.

Water budget

To carry out a water budget it is necessary to know how much water has gone into the soil as rain or irrigation, and how much water has been lost as evapotranspiration (ET). Rainfall on the farm should be measured with a proper rain gauge. The soil moisture deficit (SMD) at any time can be calculated from the previous SMD — adding ET and subtracting rain and irrigation. ET can be obtained from Table 1 or from the figure provided daily by the Meteorological Service with the weather map in The Press, Christchurch. The SMD at planting is usually zero, but may be substantial after a dry winter.

Example calculation

Week 1. SMD = 25 mm (beginning balance)
(After most winters the SMD is 0 mm.)
Week 2. ET = 25 mm, rainfall = 0 mm,
irrigation = 0 mm
New SMD = Week 1 SMD + ET - rainfall - irrigation
= 25 + 25 − 0 − 0
= 50 mm.

At this stage the decision is made to apply 40 mm of water to reduce the SMD to 10 mm.

Week 3. ET = Week 2 SMD + ET - rainfall -irrigation
= 50 + 30 - 10 - 40
= 30 mm.

BENEFITS OF IRRIGATION

The above shows that scheduling irrigation is fairly simple. The next question is "what is the value of irrigation water in crop production, or conversely, what are the consequences in crop yield of withholding irrigation water?'' To answer this question quantitatively, experiments need to be designed and analysed in terms of a model that relates production to water used.

A SIMPLE IRRIGATION RESPONSE MODEL

The irrigation response model described in this paper is very simple. It states that the yield of a crop is proportional to the amount of water used during its growth, and that the reduction in production is directly proportional to the amount of water the crop needed but didn't get (Penman, 1971; French and Legg, 1979). This can be stated analytically — the potential yield (Y_p) of a crop (in this case potatoes) is proportional to the potential evapotranspiration (E_p) calculated from an appropriate formula (Priestley and Taylor, 1965). Potential evapotranspiration is defined as the water lost to the atmosphere from a well watered crop.

When a crop is fully irrigated:

$$Y_p = K E_p \qquad (1)$$

When less water than is required is applied then the yield is given by

$$Y = Y_p[1-k(D_p-D_c)] \qquad (2)$$

where

$$D_p = E_p - \text{rain} - \text{irrigation}$$

k is a constant with the units of kg/ha/mm, D_c is some critical deficit below which the yield is unaffected, and D_p is the maximum potential deficit experienced by the crop during its growth. The potential deficit, the difference between E_p and the water received by the crop from rain and irrigation, is a measure of the severity of drought.

To test the applicability of this model an experiment was carried out on the Crop Research Division farm at Lincoln in 1981/82. A similar experiment in 1982/83 was severely damaged by hail. The results of the 1981/82 experiment and a series of experiments by Martin (1979) are analysed in terms of the model.

MATERIALS AND METHODS

Crop management

A potato crop (*Solanum tuberosum* L., cv. Rua) was grown in a Templeton sandy loam soil on the Crop Research Division farm at Lincoln, Canterbury. A small buffer strip was planted around the plots. The crop was planted on 23 October 1981 according to standard agricultural practice and a balanced NPK fertiliser applied with the seed tubers. No special weed control measures were necessary. The plants had emerged by 23 November and were moulded on 26 November. The plant population was approximately 40 000 per ha. There were three replicates of three irrigation treatments in a randomized complete block design, giving 9 plots of 10 metres square. Trickle irrigation was used to supply precise quantities of water. The irrigation treatments were:

I1 — no irrigation.
I2 — half the water applied to I3.
I3 — complete replacement of ET every week.

Plant sampling

Final yield was obtained from a 3 m² sample on each plot. Samples were divided into tops and tubers and dry matter percentage obtained by oven drying subsamples.

Evapotranspiration

Evapotranspiration was measured at weekly intervals by the water balance method using a neutron probe to measure soil moisture to a depth of 1 m. Moisture in the top 20 cm was measured by weighing and drying. Soil water extracted by the crop was separated from that lost by drainage using the method of Gregory *et al.* (1978) based on the profiles obtained from the nil irrigation treatment. This probably led to an overestimate of ET from the irrigated treatments since in frequently recharged profiles rapid drainage is difficult to detect. The measurements of ET were compared with estimates based on the Priestley and Taylor (1965) formula.

RESULTS AND DISCUSSION

Weather

A summary of the weather conditions during the experiment and corresponding 7-year means are given in Table 2. The main feature of the season was that there was less than 40% of the mean rainfall for the previous 7 years. It was a summer of drought.

Table 2. Average monthly climate parameters at Lincoln for November through March 1981/82 and 7 year means for the same months.

Month	Rain mm	Temperature Max Deg C	Min Deg C	Solar Irrad MJ/m²/d
1981/82				
Nov	32.6	13.3	5.0	19.2
Dec	18.1	18.6	8.2	20.5
Jan	26.8	19.3	6.8	21.4
Feb	20.8	19.7	6.4	18.7
Mar	14.7	15.4	4.6	13.9
7 year means				
Nov	53.9	16.3	7.1	19.3
Dec	63.0	19.4	9.4	20.9
Jan	68.5	21.7	12.0	20.6
Feb	46.1	21.3	11.2	18.3
Mar	61.9	19.6	10.4	12.7

Yield and Water Use

Final yield and total ET are presented in Table 3. The yield of the fully irrigated treatment was 63% greater than the non-irrigated treatment, significant at $p<0.01$.

Table 3. Crop development, final dry matter yield and water use.

Treatment	50% emerged	Final harvest	Tuber yield T/ha	Water used (ET) mm	E_p mm	Max pot deficit mm
I1	23 Nov	20 Apr	6.5	241	459	376
I2	23 Nov	20 Apr	8.5	352	459	208
I3	23 Nov	20 Apr	10.6	511	459	40

Included in the table are the maximum potential deficits experienced by each treatment, and the potential ET from the Priestley and Taylor (1965) formula (E_p). Note that the water use by treatment I3, the fully irrigated treatment, exceeds the calculated potential ET. This is most probably due to the over-estimate of ET by the water balance calculation, which did not account sufficiently for drainage.

Comparison with the results of Martin's experiments.

R.J. Martin of the MAF Research Division performed three irrigation experiments at Templeton Research Station in 1976/77 and 1978/79. These experiments were reported in Martin (1979). From his irrigation dates and amounts (R.J. Martin, personal communication) it is possible to carry out the same analysis. His experiments 2 and 3 were performed in adjacent paddocks in the same year so here they have been combined. The results of Martin's experiments and the above experiment are presented as a plot of final tuber dry matter yield against maximum potential deficit in Figure 1. Several things are clear from the figure.

- In any year the yield loss is a linear function of the maximum potential deficit.
- The yield loss per mm of potential deficit is the same in different years (i.e. the slopes are the same).
- The potential yield in different years is not the same (the intercepts are different).

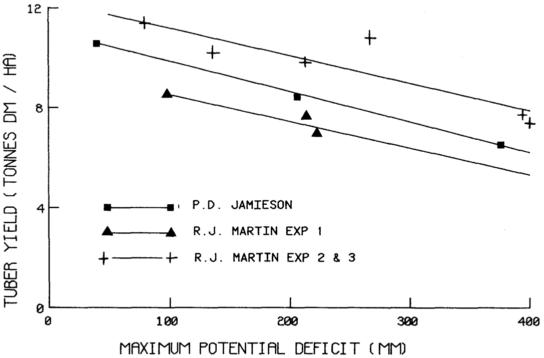

Figure 1. **Tuber dry matter yield plotted against maximum potential deficit for three different years. R.J. Martin Experiment 1, 1976/77; R.J. Martin Experiment 2, 1977/78; P.D. Jamieson, 1981/82.**

A regression of yield on maximum potential deficit for Martin's results of 1977/78 give the relationship

$$Y = 12.3 - 0.011 D_p \text{ t/ha } (r^2 = 0.79)$$

The common slope of all the experiments, allowing different intercepts, is 0.0109 ± 0.0018 t/ha/mm. This means that every mm of water applied and used by the crop will return 46 kg/ha of potatoes assuming a moisture content of 24%. In other words, if 50 mm of water is applied and used, the yield increase will be about 2.3 t/ha.

To take account of the differing potential yields in different years, it is possible to normalise the results by dividing the yield at each treatment by the intercept on the y-axis for that year. The result of this exercise is given in Figure 2. Linear regression of relative yield on maximum potential deficit, with the one wild point excluded, gives

$$Y/Y_i = 0.984 - .000984 D_p \ (r^2 = 0.97)$$

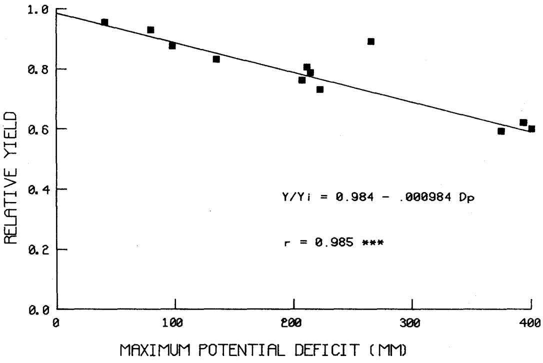

Figure 2. **Relative yield, obtained by dividing each yield by the intercept on the yield axis for its year, plotted against maximum potential deficit. With the wild point excluded, the regression explains 97% of the variation in yield in 11 out of 12 points.**

This means that each mm of water applied and used by the crop returns 0.1% of the potential yield. The form of this relationship is similar to that found by French and Legg (1979) for potatoes grown at Rothamsted, although the slope of the line is about ⅓ of theirs. This is consistent with the theory of Tanner and Sinclair (1983) which states that yield is proportional to the integral of transpiration divided by the daytime vapour pressure deficit. In the cooler, moister British climate daytime vapour pressure deficits are smaller than those in Canterbury.

There is one wild point evident in both figures. The reason the point does not fit the pattern is not clear, but may be due to irregularities in irrigation leading to application of a greater quantity of water to the harvest rows (R.J. Martin, personal communication). Nevertheless, 97% of the variation of 11 out of 12 points is explained by the model.

There is insufficient data to determine the critical deficit (D_c in equation 2). However, the data indicate that D_c is less than 40 mm. The size of the critical deficit should be affected by the rooting depth and water-holding capacity of the soil. All of the experiments reported here were carried out on Templeton silt loams which hold around 120 mm of water in the root zone of potatoes; critical deficits in lighter soils would be expected to be less than 40 mm.

Note that the irrigation response defined in the response model is not the same as water use efficiency, or yield per unit ET. This is because the water use efficiency of the crop increases as less water is used, as in the half irrigation and no irigation treatments. This comes about for two reasons. First, with frequent irrigations more water is lost as direct evaporation from the soil, and this has no physiological effect. Second, the crop under stress appears to use less water for a given unit of yield. Why this is so is at present not clear, and this effect is not exhibited by peas, wheat or barley (P.D. Jamieson and D.R. Wilson, unpublished data).

The irrigation response defined in the model gives yield loss for each mm of water not applied, and not the response to all of the water used by the crop.

CONCLUSIONS

1. The yield response of potatoes to irrigation is between 45 and 50 kg/ha of fresh tubers per mm of water applied, provided that the water is required.
2. The soil moisture deficit beyond which yield reductions can be expected is of the order of 40 mm.
3. Frequent small irrigations will give the highest yields. The longest interval between irrigations in the absence of rain should be two weeks with irrigations of the order of 50-60 mm.
4. Because the response of the crop to irrigation is linear, when water is short the best strategy is to spread the water out somewhat rather than concentrate it, so that advantage can be taken of any rain. In the absence of rain the same yield will be obtained from a given area of crop whether the water is applied to a small section to reduce the deficit to less than 40 mm, or spread over the entire area.

Although not dealt with in the model, it should also be noted that uneven water supplies cause secondary growth, which adversely affects tuber quality. Therefore frequent small irrigations are also best if good quality tubers are to be produced.

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