POTENTIAL EVAPOTRANSPIRATION AND PASTURE GROWTH IN CANTERBURY

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ABSTRACT

A simple model using potential evapotranspiration, rainfall and irrigation dates was used to calculate the yield reduction of pasture and lucerne caused by water deficit under flood irrigation on two soil types in Canterbury.

The model predicted that growth would be restricted by water deficit on a Templeton silt loam when the cumulative potential deficit, calculated using the Penman formula, exceeded about 200 mm for pasture and 320 mm for lucerne. For a Lismore stony silt loam, the corresponding values were 110 mm for pasture and 190 mm for lucerne. When PET was calculated using the Priestley-Taylor formula, these values had to be multiplied by a factor of about 0.65. In most cases, using the Penman formula gave a better prediction than the Priestley-Taylor formula.

The model accurately predicted both pasture and lucerne yield reductions due to water deficit at Templeton. At Winchmore, predictions were less accurate but likely reasons for this were usually identified. The model appeared to be unsatisfactory where yields of the fully irrigated control were below average and where the botanical composition or rooting depth was different between the fully irrigated and unirrigated treatments.

Apart from one trial, where rooting depth may have been restricted, the ratio of limiting deficits for the two crops on the two soil types was similar to the ratio of extractable soil water.

Additional Key Words: lucerne, irrigation, soil type, models, Penman, Priestley-Taylor

INTRODUCTION

In previous irrigation trials at the Templeton Research Station, responses to irrigation have been interpreted in terms of the moisture status of the top 150 mm of soil (e.g. Stoker, 1977). This approach is of limited value for predicting irrigation requirements due to the need for continual soil moisture measurements and gives little indication about how much water should be applied.

An alternative approach is to relate irrigation response to water deficit estimated from a water budget based on rainfall and measured or potential evapotranspiration (PET). The latter is now published regularly in some daily newspapers. Early work in New Zealand used the Thornthwaite formula (Thornthwaite, 1948) to estimate PET for pasture and lucerne growth (Rickard and Fitzgerald, 1970), but now the PET formulae of Penman (1948) and Priestley and Taylor (1972) are preferred.

A model developed by Penman (1952) has been used successfully to quantify the relative effect of water deficit on annual crops in terms of PET, and rainfall and irrigation dates and amounts (French and Legg, 1979; Gallagher *et al.*, 1983). This approach appears suitable for interpreting many irrigation trials where the data available are restricted to irrigation dates, yield, rainfall and surface soil moisture.

However, pasture and lucerne trials differ from those with annual crops in that several harvests are taken during the season. Also, pastures usually consist of a mixture of species with different growth patterns. Therefore, a simplified version of the Penman model was investigated to see if it would accurately estimate pasture and lucerne yields as a first step to assessing its applicability to pastoral crops in Canterbury.

If applicable, this model could be used by farmers, advisors and irrigation planners to determine when to irrigate pasture and lucerne if the soil type, rainfall and amount of irrigation water applied is known, and if current PET data for the district are available, e.g. in the local newspaper. Farmers using sprinkler irrigation could also estimate how much water to apply when they irrigate in order to prevent over or under watering.

In this paper, the simplified version of the Penman model is applied in detail to a pasture trial at Templeton and extended to an adjacent lucerne trial and to pasture and lucerne trials at Winchmore Irrigation Research Station.

MATERIALS AND METHODS

Experiment 1

A perennial ryegrass-white clover trial was sown in April 1978 on a Templeton silt loam at the Templeton Research Station, 13 km west of Christchurch. The design was completely randomized with 3 replicates of 3 irrigation treatments: not irrigated, and irrigated when the soil moisture content (s.m.c.) in the top 150 mm of soil had fallen to either 11% or 16% by weight (equivalent to wilting point or to 25% available soil moisture). The trial was on border dyked land and the flood irrigation was designed to apply 100 mm each time. The plots were 44 m x 10 m, fenced separately and cuts were taken every 4 weeks using the rate of growth technique with pasture frames (Lynch, 1966). The plots were grazed heavily and simultaneously immediately after cutting.

Experiment 2

A lucerne trial was sown in November 1978, adjacent to Experiment 1. It was a split plot design with 5 replicates. The main plots were not irrigated or flood irrigated when the s.m.c. in the top 150 mm had fallen to 16% by weight. Sub plots were 6 cultivars but only main plot data are considered in this paper. Sub plot size was 15 m x 2 m. The plots were cut with a sickle bar mower when approximately 10% of plants were in flower. The harvest area was 5 m x 0.9 m, and a subsample was taken for herbage dissection. The rest of the trial was then mown for lucerne hay. The trial was harvested from 1979-80 to 1982-83 by which time most of the lucerne had disappeared.

Experiment 3

This was a pasture irrigation frequency trial carried out on a shallow Lismore stony silt loam at the Winchmore Irrigation Research Station, 15 km north of Ashburton. The experiment has been described by Rickard (1972), and was sown in March 1969 with a mixture of 5 grasses and 3 clovers. There were 4 replicates of 5 irrigation treatments but only 3 treatments are examined here. They were: not irrigated, and irrigated when 0-100 mm depth of soil reached either 10% or 20% soil moisture content by weight (approximately wilting point and 50% available soil moisture). The plot size was 100 m x 10 m and the cutting interval and method were the same as Experiment 1. Each treatment was grazed by its own flock of sheep and grazing was not synchronized with cutting as in the Templeton trial. The yields were analysed on a seasonal basis rather than a per cut basis. When the season changed during a cutting interval, the yield from that cut was apportioned to the seasons on the basis of yields from another pasture trial cut at fortnightly intervals. The data used in this paper cover the 11 year period from 1970-71 to 1980-81.

Experiment 4

This lucerne irrigation experiment at Winchmore has been described by Fitzgerald *et al.* (1977). The cultivar Wairau was sown in spring 1970 in 7 m x 8 m basin checks. There were 4 irrigation treatments, of which 3, the same as in Experiment 3, are considered here. 100 mm water was applied at each irrigation. The plots were harvested with a sickle bar mower when approximately 10% of plants were in flower. A 3 m x 1 m cut was taken with a sickle bar mower and the trial was grazed to mower height immediately after cutting. Data were published from only the first two seasons after which the trial was severely affected by bacterial wilt.

Experiment 5

This was a successor to Experiment 4 using the cultivar Saranac. It was sown in October 1974 with the same plot sizes and management. Data up to 1978-79 have been used. After that season, yields of the frequently irrigated treatment declined severely.

Meteorological and Irrigation Data

For the Templeton experiments, data were used from the Lincoln College meteorological station, 10 km south of Templeton, except for rainfall which was recorded at Templeton. For the Winchmore experiments, data from the Winchmore meteorological station were used, except for sunshine hours which were taken from Ashburton.

Solar radiation was calculated from extraterrestrial radiation using Angstrom's equation (de Lisle, 1966) and net radiation was calculated from solar radiation using a simple linear regression equation.

The amount of water applied at each irrigation was assumed to be 100 mm.

Potential Evapotranspiration

PET was calculated using a meteorological package developed at Lincoln College (Lincoln College Computer Centre On Line Documentation), in which the formulae of Penman (1948), as given by French and Legg (1979), and Priestley and Taylor (1972) are used. The Penman formula is:

$$\mathrm{PET} = \frac{s(Rn - G) + yf(u)VPD}{s + y}$$

A simplified version, known as the Priestley-Taylor formula, is:

$$\mathrm{PET} = \frac{as(Rn - G)}{s + y}$$

where:

a = constant (taken as 1.26)
s = slope of the saturated vapour pressure curve
y = psycometric constant
Rn = net radiation
G = soil heat flux
f(u) = some function of wind speed
VPD = vapour pressure deficit

THE MODEL

The model calculates the yield of a partially irrigated or unirrigated crop relative to the yield of a crop assumed to be never so short of water that growth is restricted. The latter 'fully irrigated' crop was taken to be the one with the most frequent irrigation regime in each experiment.

Cumulative potential deficit (D) was calculated iteratively for each day. July 1 was taken as the start of the year, and D was set to 0 on that date. The value of D for each successive day was then calculated from that of the previous day by adding the PET and subtracting the rainfall or irrigation. If D was negative, it was set to zero.

The limiting cumulative potential deficit (DL) was defined as the maximum permitted value D could reach during a growth period, i.e. between cuts or over a season or year. If D exceeded DL it was set back to DL but if rainfall and/or irrigation exceeded PET then the deficit fell below DL.

It was assumed that the crop under test grew at its maximum rate right up to DL but then growth stopped completely. Therefore, the predicted yield for a growth period was the yield of the 'fully irrigated' crop multiplied by the ratio of the number of days the test crop was growing to the total number of days in that growth period.

If the 'fully irrigated' crop had D values exceeding DL, its yield was adjusted upwards by multiplying by total number of days divided by days of growth.

The predicted yield for the year was calculated as the sum of the predictions for the individual growth periods.

The model was run with a range of DL values. The optimum DL value for a year was the value which gave the same yield as the test crop. The mean DL for each experiment was the mean of the optimum DL for each year. Predicted yields were calculated for each year using this mean value.

Tests of the Model

The performance of the model was measured by

(a) % error in loss of yield =

$$\frac{\text{actual yield} - \text{predicted yield}}{\text{fully irrigated yield} - \text{actual yield}}$$

(b) the regression of (fully irrigated yield — predicted yield) against (fully irrigated yield — actual yield), both expressed as a percentage of the fully irrigated yield.

The fully irrigated yield in both cases was the yield without adjustment for days when D exceeded DL.

RESULTS

Experiment 1

Actual pasture yield responses to irrigation at Templeton over the 5 years varied from 11% to 81% depending on the amount of rainfall (Table 1).

The DL values which correspond to the actual yields are also given in Table 1, together with the yields estimated using the mean DL value for those years where a fitted value of DL was possible. There was no significant difference in mean DL between the unirrigated and irrigated at 11% s.m.c. treatments for both PET formulae.

A DL value which would give the actual yield could not be determined for either treatment in the 1982-83 season when the experiment was badly affected by grass grub. The same problem occurred, with the Penman formula only, for the 11% s.m.c. treatment data in the very wet 1979-80 season.

TABLE 1: Rainfall (mm) with numbers of irrigations in brackets; pasture yield; the limiting deficits (DL) which correspond with the actual yields; estimated yields using the mean DL for each treatment; and the percentage difference from actual yield loss (% error in loss) for Templeton pasture in Experiment 1.

Year	Rainfall (no. of irri.)	Actual yield (kg/ha)	Penman			Priestley-Taylor		
			DL	Predicted yield	% error in loss	DL	Predicted yield	% error in loss
1978-79								
Not irrigated	834	8440	208	8460	—1.0	135	8140	+19.1
Irri at 11% w/w	(2)	9310	204	9330	—1.9	142	8750	+81.4
Irri at 16% w/w	(4)	10010						
L.S.D. (5%)		1290						
1979-80								
Not irrigated	983	10440	145	10790	—29.8	106	10750	—26.8
Irri at 11% w/w	(0)	10910	*	10790	+17.4	124	10750	—22.5
Irri at 16% w/w	(2)	11610						
L.S.D. (5%)		1210						
1980-81								
Not irrigated	369	7120	222	6950	+3.0	108	7300	—3.2
Irri at 11% w/w	(3)	9920	198	10010	—3.2	91	10880	—32.7
Irri at 16% w/w	(6)	12860						
L.S.D. (5%)		1680						
1981-82								
Not irrigated	445	7070	223	6890	+3.9	145	6890	+3.8
Irri at 11% w/w	(3)	9730	208	9720	+0.5	91	10160	—21.9
Irri at 16% w/w	(6)	11710						
L.S.D. (5%)		860						
1982-83								
Not irrigated	522	7320	*	7800	—6.5	*	7960	—10.9
Irri at 11% w/w	(3)	9190	*	11550	—58.1	*	11800	—64.3
Irri at 16% w/w	(7)	13250						
L.S.D. (5%)		1180						
Mean (± S.E.M.)								
Not irrigated			200 (18.5)		12.5	124 (9.5)		28.5
Irri at 11% w/w			203 (2.9)			112 (12.7)		

TABLE 2: Number of irrigations; actual yields (kg/ha); limiting deficit (DL) which corresponded to the actual yield; predicted yields using the mean DL; and the % error in loss for Templeton lucerne in Experiment 2.

Year	No. of of irrigations	Irrigated yield	Unirrigated yield	DL	Predicted unirrigated yield	% error in loss
1979-80	2	5140	4930	*	5140	+100.0
1980-81 (1)	4	5070	2530	334	2450	+3.0
1981-82 (1)	5	4580	2460	322	2350	+5.0
1982-83 (2)	6	2020	590	303	690	—7.0
Mean (±S.E.M.)				320 (9.0)		5.0 (3)

(1) first cut omitted
(2) first cut omitted and no growth on not irrigated plots at third and fourth cuts
(3) 1979-80 omitted

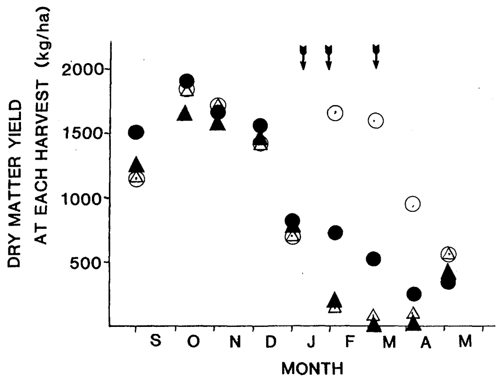

Figure 1: Actual and predicted yields for unirrigated and irrigated at 11% s.m.c. treatments for 1982-83 Templeton pasture in Experiment 1 using the mean limiting cumulative potential deficit (DL) calculated using the Penman formula. ▲—▲ unirrigated actual yield, △—△ unirrigated predicted yield, ●—● irrigated actual yield, ○—○ irrigated predicted yield (where different to unirrigated predicted yield). Vertical arrows indicate irrigation dates.

When the mean DL for the other years was used to predict the yields in 1982-83, there was good agreement with actual yields for the unirrigated treatment (Figure 1). However, the predicted yields for the 11% s.m.c. irrigation treatment were considerably higher in the autumn than the actual yields which responded poorly to irrigation. The mean % error in loss was considerably smaller for the Penman formula than for the Priestley-Taylor formula (Table 1).

The regression of the estimated against actual reduction in yield below the "fully irrigated" control is shown in Figure 2(a) for the Penman formula. The Priestley-Taylor formula gave a similar result. The one point off the regression line is the 11% s.m.c. irrigation treatment in 1982-83, as was discussed above. Excluding this point, the regression equations are:

$\mathrm{PY(Penman)} = -0.57\,(1.10) + 1.009\,(0.0400)\,\mathrm{AY} \quad R^2 = 98.9^{**}$

$\mathrm{PY(P-T)} = 1.18\,(2.56) + 0.906\,(0.0928)\,\mathrm{AY} \quad R^2 = 93.2^{**}$

where PY is estimated yield reduction and AY is actual yield reduction, R^2 is % reduction in sums of squares, and numbers in brackets are standard errors of the coefficient.

The Penman formula estimated yield reductions accurately over the whole range whereas the Priestley-Taylor formula tended to underestimate the larger yield reductions.

Since the Penman formula generally gave a better fit to the data than the Priestley-Taylor formula, only data for the Penman formula is presented in subsequent tables.

Experiment 2

The lucerne at Templeton was a very poor crop which produced low yields and suffered from severe weed competition.

The estimated and actual yields from this crop agreed well, although some data had to be omitted when unirrigated yields exceeded irrigated yields, including the very wet first season and the first cut in subsequent seasons when excessive weed growth occurred in the irrigated plots.

Despite the limited data, the estimated and actual yields agreed well. The regression of estimated against actual yield reduction below the control for the Penman formula is given in Figure 2(b). The regression equation is:

$\mathrm{PY} = -1.98\,(4.57) + 1.01\,(0.093)\,\mathrm{AY} \quad R^2 = 98.4^{**}$

Experiment 3

Not irrigated

For the unirrigated pasture treatment at Winchmore, the model generally overestimated actual yield by a factor of up to 2.1 (Penman) or 2.4 (Priestley-Taylor) during dry summers and autumn. This treatment is not reported in detail.

Irrigated at 10% s.m.c.

In 6 of the 11 years examined, DL values were very similar for both Penman (Table 3) and Priestley-Taylor (Mean 64, s.e.m. 3.2). This was the only trial where the Priestley-Taylor formula appeared to fit the data better than the Penman formula.

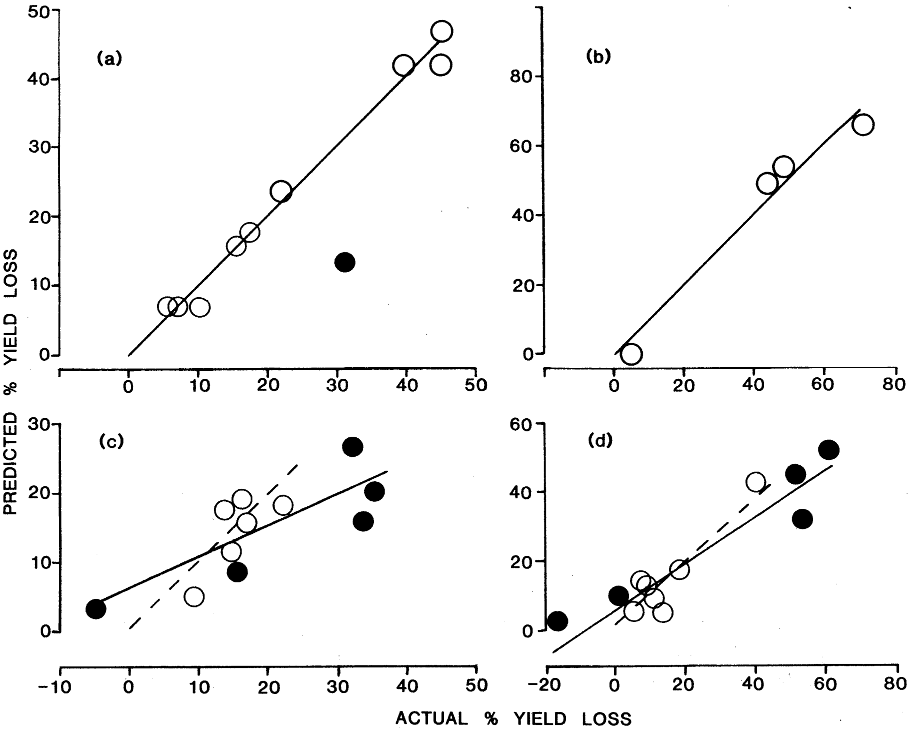

Figure 2: **Regression of yield loss predicted using the Penman formula against actual yield loss for (a) Templeton pasture (● = point not used in the regression), (b) Templeton lucerne, (c) Winchmore pasture (solid regression line is all points, dashed line through ○ points, which are the years when an optimum DL value could be calculated), and (d) Winchmore lucerne (solid regression line is through all points, dashed line through ○ points, which are the years when an optimum DL value could be calculated). Regression equations are given in the text.**

TABLE 3: **Rainfall; yields (kg/ha), with number of irrigations in brackets for the irrigated at 20% and 10% s.m.c. treatments; limiting deficits (DL) which corresponded to the actual yield; predicted 10% s.m.c. treatment yields using the mean DL; and the % error in loss for Winchmore pasture in Experiment 3.**

Year	Rainfall (mm)	20% Yield	10% Yield	DL	Predicted 10% yield	% error in loss
1970-71	591	13390 (8)	11530 (5)	141	11000	+28.8
1971-72	580	12520 (10)	9820 (5)	85	10280	—16.9
1972-73	502	11620 (9)	9760 (6)	146	9370	+21.1
1973-74	932	12790 (6)	10590 (4)	94	10880	—13.1
1974-75	756	10640 (6)	9640 (4)	84	10120	—48.0
1975-76	722	8470 (8)	5460 (4)	H	6780	—43.7
1976-77	697	9010 (4)	7620 (3)	H	8200	—42.0
1977-78	863	10930 (9)	7310 (4)	H	9190	—52.0
1978-79	1140	12020 (5)	10280 (4)	86	10560	—16.3
1979-80	884	11640 (3)	12080 (2)	L	11150	—210.5
1980-81	565	8350 (7)	5620 (5)	H	6120	—18.5
Mean (± S.E.M.)				106 (12.0) (1)		30.0 (2)

H and L mean model predictions were higher or lower respectively than actual measurements over whole range of deficits
(1) mean for 6 years when optimum DL could be determined
(2) mean excludes 1979-80

TABLE 4: **Actual yields (kg/ha), with number of irrigations in brackets, for the irrigated at 20% s.m.c., unirrigated and irrigated at 10% s.m.c. treatments; limiting deficit (DL) which corresponded with the actual yield; predicted yields for the unirrigated and irrigated at 10% s.m.c. treatments using the mean DL for each experiment; and the % error in loss for Winchmore lucerne in Experiments 4 and 5.**

		Not irrigated				irrigated at 10% s.m.c.			
	20% Yield	Actual Yield	DL	Predicted Yield	% error in loss	Actual Yield	DL	Predicted Yield	% error in loss
Experiment 4									
1972-73	13590 (12)	5130	*	6530	—16.5	11000 (5)	95	10940	+2.5
1973-74	14470 (11)	6750	*	7960	—15.7	12900 (3)	89	13010	—6.8
Experiment 5									
1975-76	17740 (11)	8140	*	12000	—40.2	15290 (3)	130	16790	—61.0
1976-77	12630 (5)	11430	224	11000	+35.8	12030 (1)	213	11740	+48.5
1977-78	10000 (8)	5670	167	5730	—1.5	9030 (3)	222	8500	+54.2
1978-79	12430 (5)	12200	x	1170	+448.3	14670 (2)	x	12240	—108.7
Not irrigated and 10% combined mean (± S.E.M.)							191 (18.5) (1)		40.2

* = predicted yield considerably lower than actual yields
x = actual yields exceeded fully irrigated yields at some harvests resulting in predicted yields being lower than actual.
(1) 1975-78 only

In the other 5 years, values of DL corresponding to the actual yields could not be determined. The model underpredicted in 1979-80 because the 10% s.m.c. irrigation treatment yielded higher than the 20% one in the relatively wet season. In the other 4 years, the model overpredicted by 8 to 26%.

Differences in % error in loss (Table 3) were higher than in Experiments 1 and 2, especially when the 10% s.m.c. treatment yielded higher than the fully irrigated control. The regression of predicted against actual yield loss is given in Figure 2(c). The regression equation is:

$PY = 6.36\ (2.68) + 0.452\ (0.123)\ AY \qquad R^2 = 60.0^{**}$

The estimated yield loss was only about half the actual loss due mainly to the large yield underestimation in 1975-76, 1977-78 and 1980-81.

If the analysis was restricted to those years in which an optimum DL value could be obtained (Table 4), the dashed line regression in Figure 2(c) was obtained, the equation is:

$PY = -0.61\ (7.22) + 0.981\ (0.479)\ AY \qquad R^2 = 53.7$ N.S.

The slope is now much closer to 1, although the fit is poor.

Experiments 4 and 5

For the Winchmore lucerne, the model calculations agreed well with the actual irrigated at 10% s.m.c. treatment yields, apart from 1975-76 and 1978-79. In the latter case, yields of the 10% s.m.c. treatment were 18% higher than those of the 'fully irrigated' control. However, the model generally underestimated unirrigated yield reductions.

TABLE 5: **Ratios of limiting deficit (DL) between the two methods of calculating PET and the two crops and the two sites.**

Ratio P-T : Penman	**Treatment**	**Templeton**	**Winchmore**
pasture	not irrigated	.62	
	irri. at 10%	.55	.60
lucerne	not irrigated	.68	
	irri. at 10%		.68 (exp 4) .68 (exp 5)
Ratio Pastures : Lucerne	Penman	.60	1.15 (exp 4) .56 (exp 5)
	Priestley-Taylor	.54	1.02 (exp 4) .58 (exp 5)
Ratio Winchmore : Templeton		**Pasture**	**Lucerne**
	Penman	.52	.29 (exp 4) .60 (exp 5)
	Priestley-Taylor	.54	.29 (exp 4) .51 (exp 5)

The two trials gave quite different results, Experiment 4 having a much lower mean DL than Experiment 5. Also, the % errors in loss were reasonable for Experiment 4 but generally high for Experiment 5 when yield reductions due to water stress were generally small.

A combined regression for both treatments in Experiments 4 and 5 is given in Figure 2 (d). The regression equation is:

$PY = 6.78\ (2.37) + 0.651\ (0.073)\ AY \qquad R^2 = 89.5^{**}$

Excluding those data sets where estimated yield reductions were considerably less than actual yields, i.e. for the unirrigated plots for Experiment 4 and the first year of Experiment 5, and for both treatments in the final year, the dashed regression line was obtained, with the equation:

$PY = 1.41\ (2.96) + 0.926\ (0.149)\ AY \qquad R^2 = 88.5^{**}$

This regression has a slope considerably closer to one.

Combined results

Table 5 shows that the ratio of the mean DL values was consistent between the two PET formulae, the two crops and the two sites, with the exception of Experiment 4 which had DL values similar to Experiment 3.

DISCUSSION

The model estimated that growth will be restricted by water deficit on a Templeton silt loam when the cumulative potential deficit (D), calculated using the Penman formula, exceeds about 200 mm for pasture and 320 mm for lucerne. For a Lismore stony silt loam the corresponding values are 110 mm for pasture and 190 mm for lucerne. If PET is calculated using the Priestley-Taylor formula, these values have to be multiplied by a factor of 0.6 to 0.7.

The model has quantified the higher tolerance to water deficit of lucerne. With the exception of Experiment 4, where root growth was probably restricted by bacterial wilt (Fitzgerald *et al.* 1977), lucerne continued to grow at both sites until water deficits were about 1.6 times that at which pasture growth stopped.

The ratio of DL at Winchmore to Templeton was a little over 0.5 for both pasture and lucerne, except for Experiment 4. The maximum amount of water extracted under pasture to a depth of 0.9 m was 92 mm at Winchmore (Stoker, 1982). At Templeton, unpublished data show a maxmimum extraction of about 180-190 mm to 1.05 m depth. This gives a ratio of maximum extractable water between the two soils of around 0.5, similar to the DL ratio. French and Legg (1979) found that the ratio of limiting deficits above which irrigation increased yields between a sandy soil and a silty clay loam clay also approximated the ratio of the water holding capacities of the soils to a depth of 1 m. Trial data from other soil types will be examined to determine the relationship between DL and soil moisture properties.

This very simple model worked very well at Templeton, considering the crude assumptions made. With one exception, it accurately estimated yields of pasture and lucerne even when an optimum DL value could not be determined, either due to poor growth or to very small irrigation responses in a wet season. The one exception occurred when 3 irrigations produced very little growth, possibly due to grass grub infestation or to poor infiltration on this silty soil in a relatively dry season.

Although the results of fitting the model at Winchmore were less satisfactory, omitting those seasons or treatments where DL could not be calculated resulted in a good prediction of yield reduction (Figures 2 (c) and (d)).

In Experiment 3, the large difference in botanical composition between the unirrigated and fully irrigated treatments (Rickard, 1972) probably explains the poor prediction of unirrigated plot yields. Unirrigated plots had subterranean clover, which has a winter-spring growth habit, as their main legume component, whereas irrigated plots had white clover, which grows mainly in summer and autumn. Over the long duration of this trial, there could also have developed marked differences in root distribution and soil hydraulic characteristics between unirrigated and irrigated plots.

In the case of pasture irrigated at 10% s.m.c., the agreement was good except in 1975-78 when yields of the 'fully irrigated' control were below average. This yield reduction was accompanied by a large reduction in the white clover content of the pasture (D.S. Rickard, pers.comm.). Also, reanalysis of the results using individual harvests rather than seasonal yields would probably improve the relationship between annual actual and predicted yields.

The inability to determine DL for the unirrigated lucerne in Experiment 4 and the first year of Experiment 5 may have been due to poorer rooting in this treatment, as Janson (1975) found that irrigation of lucerne greatly increased rooting depth. The model also considerably underestimated the last year's data in Experiment 5 when the stand irrigated at 20% s.m.c. was starting to deteriorate, probably due to disease.

This model could be improved in several ways:

1. use the two stage model of French and Legg (1979) in which growth slows at DL rather than stops.
2. account for delay in recovering from water deficit stress by putting a constant into the model (French and Legg, 1979).
3. use solar radiation values rather than sunshine hours.
4. adjust PET to take account of incomplete ground cover after cutting (Tanner and Jury, 1976), particularly for lucerne.
5. alter the constants in or modify the PET formula to take more account of advection (Jury and Tanner, 1975).
6. measure the amount of water applied at each irrigation.
7. account for seasonal changes in botanical composition and growth patterns in pasture (McAneney *et al.*, 1982).
8. account for carryover effects of drought from the preceding season (Rickard and Fitzgerald, 1970).
9. eliminate variation due to changes in the yield of the 'fully irrigated' control by using yields calculated from solar radiation and crop conversion efficiency as

the control (Penman, 1970).

(10) relating DL value to soil moisture properties and rooting depth (McAneney *et al.*, 1982), which would enable the model to be used predictively.

More refined model incorporating these adjustments could be checked against this simple model to quantify the improvement in yield prediction.

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