1-1-1987

Water use by some crops and pastures in the southern agricultural areas of Western Australia

R A. Nulsen

I N. Baxter

ISSN 0729-3135

Water use by some crops and pastures in the southern agricultural areas of Western Australia

RA. Nulsen
I.N. Baxter

Resource Management Technical Report No.32

Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Table of Contents

1. Introduction

Salinisation of agricultural land is almost invariably the result of man's interference with the landscape water balance. The resulting excess deep percolation mobilizes stored salts which then accumulate in certain parts of the landscape.

The difference between deep percolation in the native state and the disturbed state is not large. In the glaciated portion of the Great Plains of North America it is estimated that 1 - 4% of annual precipitation reaches the shallow aquifer under native sod conditions. Under the crop-fallow farming system adopted after settlement, 7 - 15% of the annual precipitation of 250 to 450 mm passes to the groundwater system (Miller *et al*, 1981). Thus the additional recharge is only 7 - 36 mm per year. In south-western Australia where eucalypt forest and woodland was typically replaced with a cereal-ley farming system it has been estimated that the additional recharge is some 20 - 50 mm per year (Peck and Hurle, 1973; George, 1978) equivalent to 5 - 10% of annual rainfall.

To restore the landscape water balance to its pristine state and thereby reduce or stop land salinisation it is necessary to use the excess percolation. Miller *et al*. (1981) have successfully done this in Montana by planting lucerne (*Medicago sativa*) on the recharge area. Nulsen and Baxter (1982) have indicated the potential of agronomic manipulation to reduce recharge in Western Australia.

Essential to any proposal to reduce recharge by changing the plant species on a catchment is a knowledge of the comparative water use of the candidate species. The aim of this project was to measure the water use of several crop and pasture species growing at various locations in the southern agricultural areas of Western Australia.

2. Method

2.1 Measuring Transpiration

Transpiration rate was calculated using the method of Baxter and Nulsen (1986) where in:

$$ET = \frac{(e_1^* - e)}{R_V(r_a + r_c)\,[T_1 + T_a)/2]} \qquad \text{..... (1)}$$

where ET is crop transpiration rate (g/cm^2/s), e_1^* is the saturation vapour pressure (nib) of water in the sub-stomatal cavity at leaf temperature T1 (K), the ambient vapour pressure (mb), R_V the specific gas constant for water vapour (erg/g/°K), r_a and r_c the aerodynamic and canopy resistances (s/cm) respectively and T_a the ambient air temperature (°K). (Note that units are expressed as c.g.s. units for ease of calculation. The conversion of calculated ET to SI units is easily performed.)

An infra-red thermometer (Telatemp AG-42 with a 4 field-of-view) was used to measure T_1 from which e_1^* was determined.

Canopy resistance was computed from:

$$r_c = \frac{\bar{r}_s}{LAI} \qquad \text{..... (2)}$$

where $\bar{r}_s$ is the mean leaf diffusive resistance of the canopy and LAI is the ratio of stomatous leaf area to ground area.

Individual leaf diffusive resistance was calculated from:

$$r_s = \frac{1}{(1 / r_{ab} + (1 / r_{ad})} \qquad \text{..... (3)}$$

where r_{ab} and r_{ad} are the diffusive resistances of the abaxial and adaxial leaf surfaces respectively which were measured with a transient diffusion porometer.

Aerodynamic resistance was calculated assuming non-neutral stability from the equation of Thom and Oliver (1977)

$$ra = \frac{4.72\,[\,1_n\,(z - d\,)\,/\,z_o\,]^2}{1 + 0.54\,u} \qquad \text{..... (4)}$$

where u is the wind speed measured at height z, d and z_o are the zero plane displacement and roughness length of the surface, d and z_o were determined from wind profiles measured over the plant canopy and expressed as a function of crop height using the method of Riou (1984).

Transpiration was measured on crops and pastures at five locations in the southern areas of Western Australia during 1985 (Figure 1).

3. Sites and Species

3.1 Cuballing

On Falls' farm catchment, oats (cv West) and lupins (cv Yandee) were sown by the farmer as part of the experimental catchment management programme. Transpiration measurement sites were selected on two different soil types for each crop . a sand and a loam for oats and a sand and a gravelly surfaced duplex soil for lupins.

3.3 Bedford Harbour

The hay oat (cv Saia) was sown on July 31, 1985 and transpiration measurement sites selected in a sandy soil and a gravelly duplex soil. The oats were cut for hay on October 30, 1985.

3.4 Cairdner River

Transpiration of wheat (cv Osprey) and lucerne (cv Trifecta) was measured over 12 months beginning on December 1, 1984. The species were in adjacent paddocks growing in a sandy surfaced duplex soil. The lucerne was sown in July 1984 and was rotationally grazed during the measurement period. The wheat was sown on May 10, 1985 and for six months prior to seeding the paddock was almost devoid of green vegetation while weed control procedures were carried out.

3.5 Mallee Road Sump

Measurements were done on experimental plots (40 m x 5 m) of wheat (cv Aroona) barley (cv Stirling) and peas (cv Derrimut) growing in a medium, grey clay.

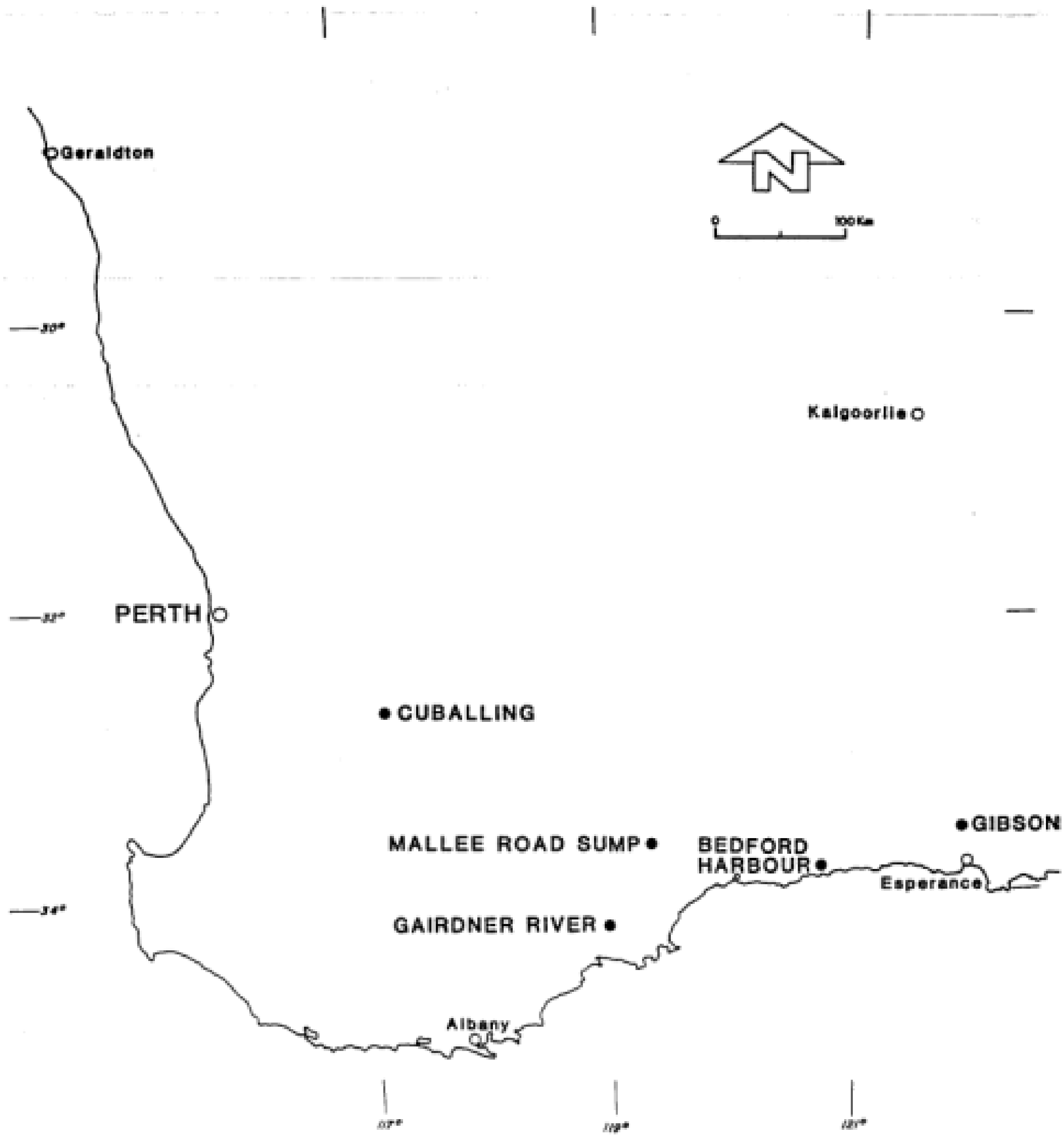

Figure 1 Location of measurement sites at Cuballing, Gairdner River, Mallee Road Sump, Bedford Harbour and Gibson

3.6 Gibson

Plots of a number of lucerne cultivars had been established on deep sand at Ireland Farm, Gibson by the Esperance District Office of the Department of Agriculture in 198-. Transpiration measurement were done on the cultivars Springfield, Siriver, Sheffield and Hunter River. These plots were grazed twice during the measurement period.

4. Field Method

Transpiration was measured on each species at each location for at least one full day every two weeks during the measurement period. During the measurement day a determination of transpiration rate was done about every hour - a single determination took some 15 minutes.

Measurements were made on the grazed lucerne at Gairdner River and Gibson on the scheduled day regardless of the state of the stands.

Duplicate 1.0 m^2 quadrats of crops and pastures were cut at each measurement date (with the exception of Gibson where a single 0.5 m^2 quadrat was used) for determination of fresh weight and dry weight. Leaf area index (LAI) was measured four times during the season and the dry weight-LAI relationship used to determine the LAI on those days when LAI was not measured.

The grain yield of crops was determined where applicable from duplicate 1.0 m^2 quadrats. Due to circumstances yields were not measured at Cuballing.

5. Results

5.1 Cuballing

During the cropping period (June 6 . November 15)- there was 258 mm of rainfall at the - Cuballing site. The crops growing on the heavier textured soils transpired more water than the crops on the light textured soils (Table 1). Oats growing on loam were the best performers in term of water use.

Table 1. Transpiration of lupins and oats grown on different soils at Cuballing

	Lupins (cv Yandee)		Oats (cv West)	
	Sand	Gravel	Sand	Loam
Transpiration (mm)	94	145	111	244
Rain less Transpiration (mm)	164	113	147	14

The daily transpiration rates of the four sites throughout the growing season are shown in Figure 2. Crops growing on the heavier soils had higher transpiration rate throughout the season than their counterparts in the lighter soils. The bigger difference was between the two oat sites but these sites also had the larger soil textural contrast.

Leaf area indices and above ground dry matter are given for four sampling dates in Table 2.

Table 2. Leaf area index (LAI) (m^2/m^2) and above ground dry matter (DM) (t/ha) for lupins and oats grown on different soils at Cuballing

Species	Lupins				Oats			
Soil	Sand		Gravel		Sand		Loam	
Sample Date	LAI	DM	LAI	DM	LAI	DM	LAI	DM
3.09.85	0.5	0.74	0.9	1.07	1.7	1.40	4.7	2.55
25.09.85	1.2	1.92	2.1	3.20	2.5	3.50	4.7	6.50
10.10.85	1.0	2.3	1.6	3.97	1.2	5.03	5.4	11.40
23.10.85	0.8	2.08	1.0	4.26	0.9	4.73	2.0	9.92

Again, the oats growing in the loam soil were the best performers and produced about twice the dry matter of oats growing in sand. Similarly, lupins growing in the gravelly duplex soil produced about twice the dry matter of the lupins growing in the sand.

5.2 Bedford Harbour

Armyworm (*Mythimna convecta*) severely damaged the Saia oats at Beford Harbour 91 days after seeding. During the 91 day growing season there was 197 mm of rainfall and the oats growing in-sand transpired 94 mm of water while those in the gravelly duplex soil transpired 157 mm.

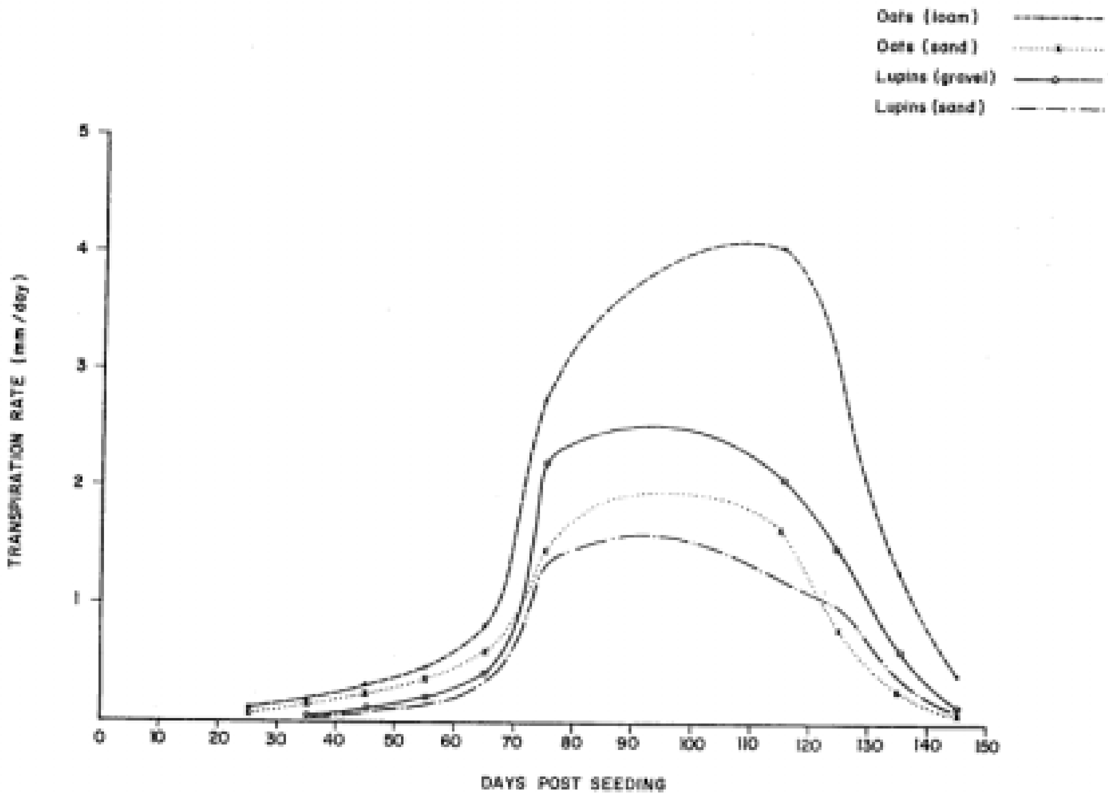

Figure 2 Seasonal transpiration rate of oats and lupins grow on different soil types at Cuballing.

The transpiration rate$_3$ above ground dry matter and LAI for both sites are given for three days on which all were measured in Table 3.

Table 3. Daily transpiration rate (mm/day), dry matter (DM (t/ha) and LAI (m^2/m^2) of oats (cv Saia) grown on two soil types at Beford Harbour

	Sand			Gravel		
	Transpiration	**DM**	**LAI**	**Transpiraton**	**DM**	**LAI**
20.09.85	2.0	0.80	1.2	3.2	0.50	1.2
4.10.85	1.4	0.87	1.4	2.1	1.17	2.1
30.10.85	0.9	1.39	0.6	2.5	2.26	1.6

The seasonal daily transpiration rates are shown in Figure 3. As at Cuballing, the oats on the heavier textured soil maintained a higher transpiration rate throughout the season than those growing in light textured soil. Differences in total water transpired may have been greater had it been possible to extend the measurements beyond 91 days.

5.3 Mallee Road Sump

At Mallee Road Sump there was 241 mm of rain during the growing season. Total transpiration and yield data are summarised in Table 4.

Table 4. Total transpiration and grain yield data for wheat (cv Aroona), barley (cv Stirling) and peas (cv Derrimut) grown at Mallee Road Sump

	Wheat	**Barley**	**Peas**
Total transpiration (mm)	120	123	143
Grain yield (t/ha)	2.16	2.19	1.82
Dry matter at harvest (t/ha)	2.82	3.15	3.44
Transpiration efficiency (kg/ha/mm)	18.0	17.8	12.7

The peas used slightly more water than either the wheat or barley but all crops used only about half of the rain that fell during the growing season.

Note that the transpiration efficiencies cited in Table 4 are calculated from the amount of water transpired and are therefore apparently higher than other figures cited in the literature, usually referred to as water use efficiencies, which are calculated either from evapotranspiration (soil evaporation plus transpiration) or from rainfall received during the growing season plus a change in soil moisture content from the beginning to the end of the growing season.

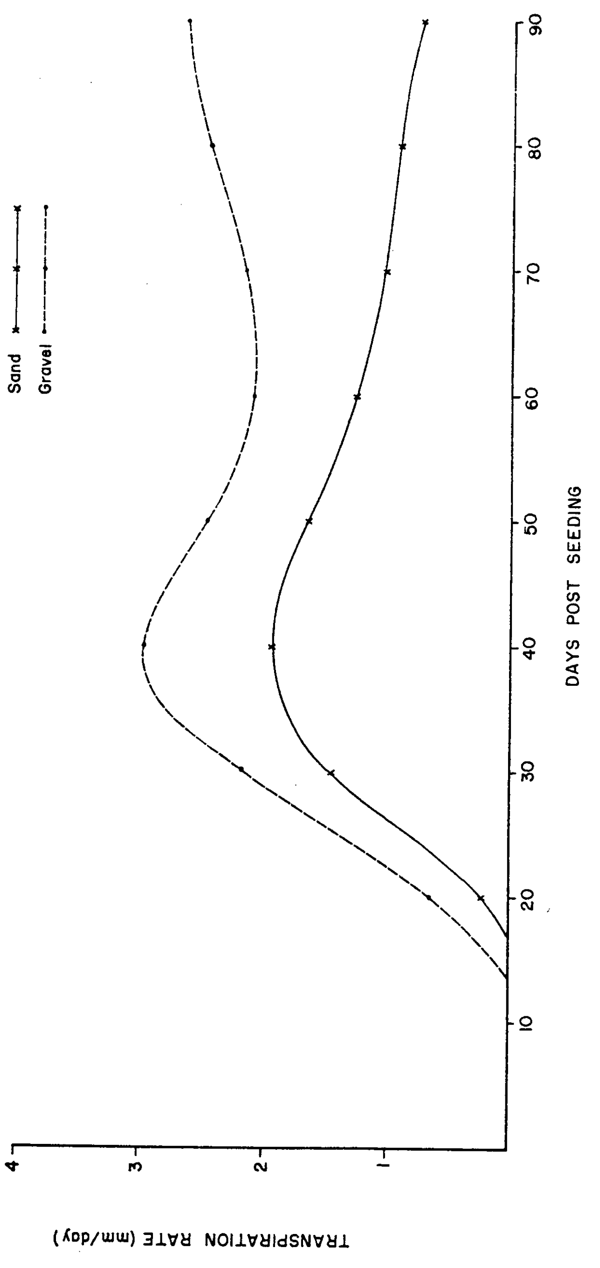

Figure 3 Seasonal transpiration rate of oats grown on two soil types at Bedford Harbour.

The seasonal daily transpiration rates for the three species are shown in Figure 4. All follow a similar pattern peaking about 130 days after seeding and then rapidly declining to near zero by day 152.

Peas, produced -more than twice the leaf area and about 1. 5 times the dry matter of either wheat or barley (Table 5) and this vegetative production must have been a key factor in their higher transpiration.

Table 5. Transpiration (mm/day), dry matter yield (t/ha) and LAI (m^2/m^2) of wheat (cv Aroona), barley (cv Stirling) and peas (cv Derrimut) grown at Mallee Road Sump

Species	Date	Transpiration Rate	Dry Matter	LAI
Wheat	5.09.85	1.1	0.95	1.3
	3.10.85	1.6	2.92	2.0
	16.10.85	2.2	4.58	1.5
Barley	5.09.85	1.2	0.91	1.5
	3.10.85	1.7	1.88	2.0
	16.10.85	2.1	4.52	1.5
Peas	5.09.85	1.1	1.32	2.3
	3.10.85	1.6	3.66	4.9
	16.10.85	2.7	6.33	4.3
	31.10.85	1.4	5.63	2.9

5.4 Gairdner River

Lucerne transpired more water in the 12 month period of measurement than rain that fell (Table 6). However, during the wheat growing season the wheat transpired about 50% more water than the lucerne and its transpiration accounted for all but 10 mm of the rainfall during the period.

It is notable that at Gairdner River, during the year of measurements, 143 mm or 37% of the rain fell outside the wheat growing period.

Daily transpiration rates of the wheat and lucerne are shown in Figure 5. The lucerne transpiration was quickly reduced by the short periods of intensive grazing at the ends of December, January and February. However, the transpiration rate recovered quickly after the sheep were removed. The lower intensity grazing imposed on April 9 slowly reduced transpiration rate over the ensuing month and maintained it at a low rate until the animals were removed in July. Recovery was slow during this cool period of the year. The daily transpiration rate of lucerne peaked in late October just before it was cut for hay.

The peak transpiration rate for lucerne was lower than for wheat but the high total transpiration for lucerne was a result of the long period over which transpiration occurred.

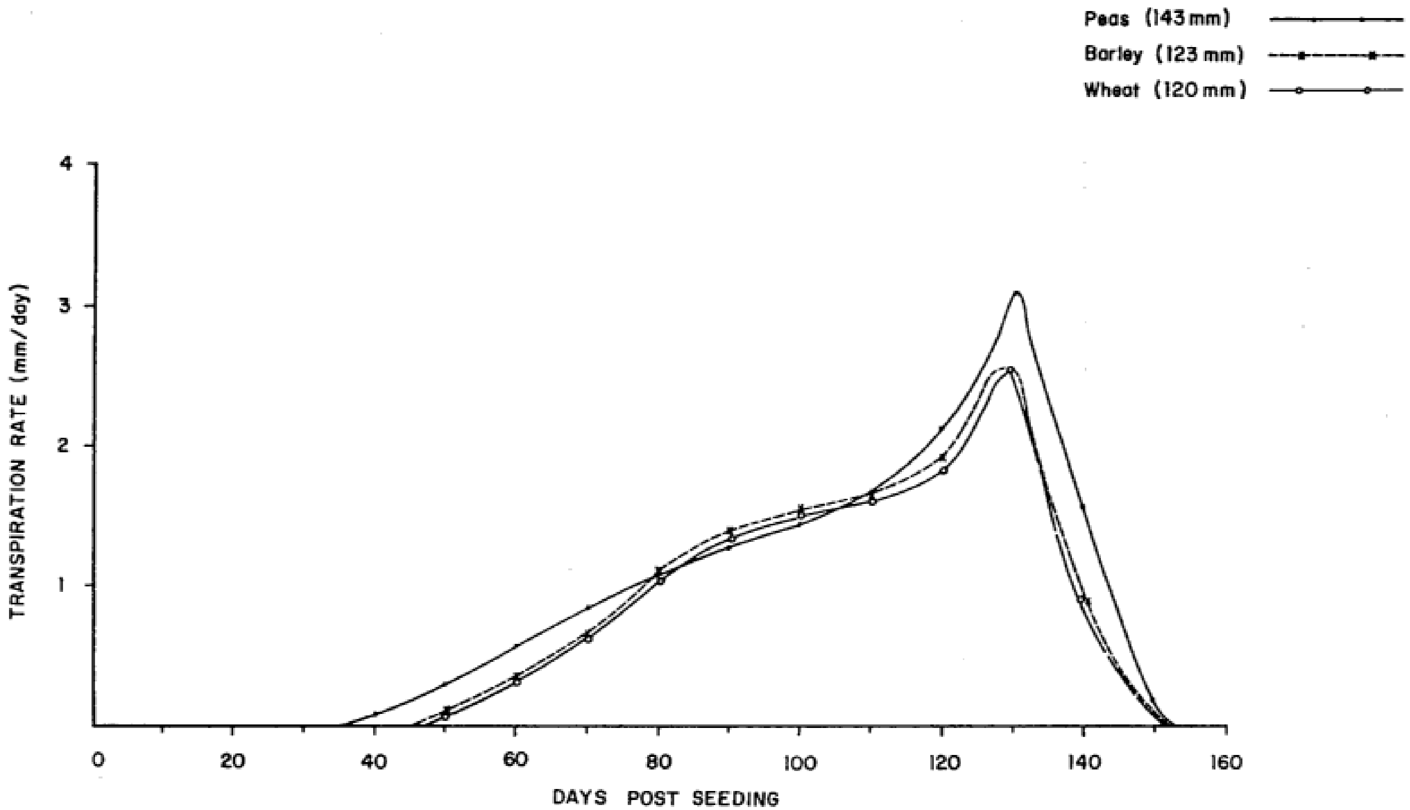

Figure 4 Seasonal transpiration rate of peas, barley and wheat at Malice Road Sump

Figure 5 Transpiration Rate (mm/day) of Wheat (cvOsprey) & Lucerne (cv Trifecta)

Gairdner River 1/12/84 – 30/11/85

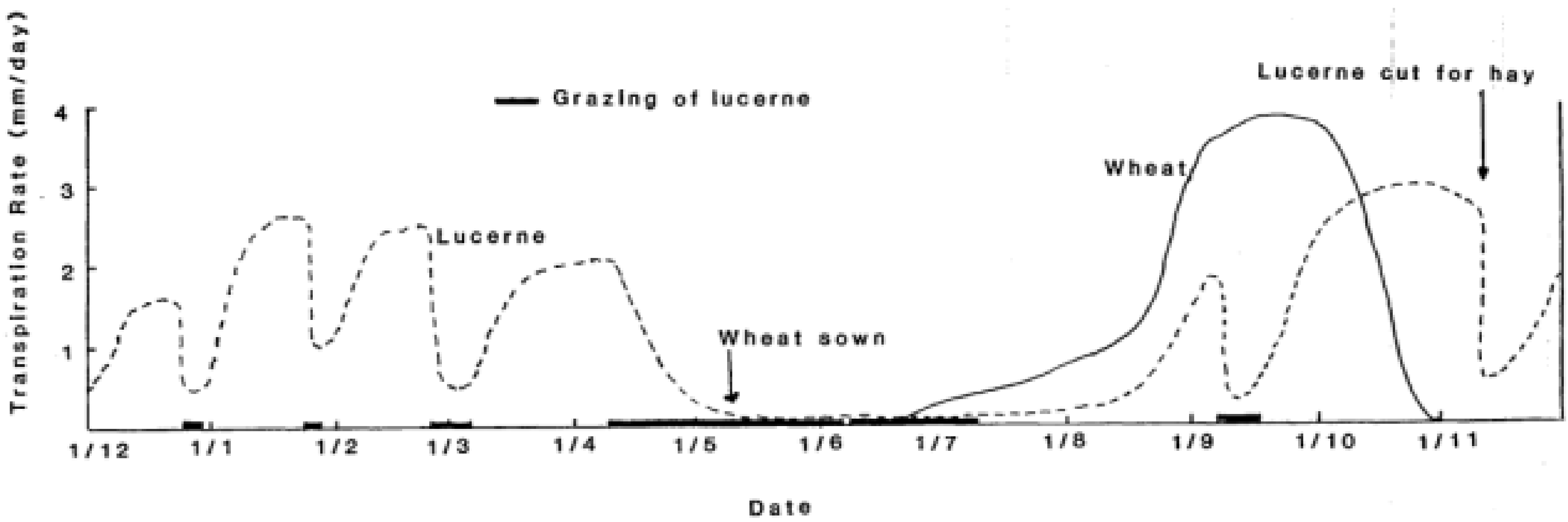

Table 6. Total transpiration of wheat (cv Osprey) and lucerne (cv Trefecta) at Gairdner River for periods December 1, 1984 to November 30, 1985[1] and during the wheat growing season[2]

	Transpiration[1] (mm)	Transpiration[2] (mm)
Wheat	231	231
Lucerne	433	155
Rainfall	384	241

Grazing data for the lucerne are given in Table 7. Dry sheep equivalents were calculated assuming a lamb = 0.7 DSE, a ewe = 1.3 DSE and a ram = 1.5 DSE (B. Beetson, pers. comm.). Total grazing for the year was equivalent to a set stocking rate of 4.8 DSE/ha, which compares very favourably with a district average grazing rate on subterranean clover based pastures of about 3 DSE/ha.

Table 7. Grazing regime of 13.75 ha of lucerne at Gairdner River during 1985

Date	Days Grazed	Stock	DSE grazing days
24/01 – 27/01	4	1100 lambs	5390
24/02 – 7/03	11	400 ewes	5720
9/04 – 4/06	56	45 rams	3780
5/06	1	500 ewes	650
6/06 – 9/07	33	45 rams	2228
7/09 – 18/09	11	800 lambs	6160
10/11	Cut for hay		

Daily transpiration, above ground dry matter and LAI for sampling days and wheat yield data are given in Table 8. It is obvious that the grazing kept the lucerne LAI lower for most of the period. The wheat produced a copious quantity of dry matter but did not produce a proportionally high grain yield.

Table 8. Transpiration rate (mm/day), dry matter (t/ha) and LAI (m^2/m^2) of lucerne (cv Trifecta) and wheat (cv Osprey) at Gairdner River.

Date	Transpiration Rate	Dry Matter	LAI
Lucerne			
12.12.84	1.5	0.44	0.4
12.02.85	2.4	0.67	0.9
2.04.85	2.1	0.90	1.5
28.05.85	0.1	0.65	0.1
21.08.85	0.6	0.80	1.0
4.09.85	1.7	1.00	1.0
2.10.85	2.3	0.70	0.9
1.11.85	2.9	1.30	1.3
Wheat			
16.07.85	0.5	1.10	2.1
21.08.85	1.4	2.80	4.4
4.09.85	3.4	5.10	4.1
2.10.85	3.7	7.10	1.8

Wheat dry matter at harvest 8.8 t/ha
Wheat grain yield 2.4 t/ha
Total transpiration by wheat 231 mm
Transpiration efficiency 10.4 kg/ha/mm

5.5 Gibson

There were differences in the total transpiration over the measurement period between the four lucerne cultivars studied (Table 9). The maximum difference was 56 mm between Siriver and Hunter River which represents 19% of the rainfall for the period. If a one-dimensional water balance is assumed then the drainage, calculated as Rainfall-Transpiration, under Hunter River was more than four times that under Siriver.

The seasonal daily transpiration rates of the four cultivars are shown in Figure 6. The periods of intense grazing are reflected in the transpiration rates but the dominant feature is the rapid drop in transpiration rate in April-May and the equally rapid rise when the weather warmed in September.

Figure 7 illustrates the differences in transpiration rates of the cultivars for the day of March 28, 1985. Siriver and Sheffield both reached a maximum rate of about 14.5 g m^{-2} min^{-1} but there is a difference in the time of the peak of two hours.

Plant production data are given in Table 10. The integrated time persistence of dry matter (tonne days) ranks the cultivars in the same order as their measured transpiration given in Table 9. (Tonne days was calculated from the five dates for which dry matter data were available for all cultivars).

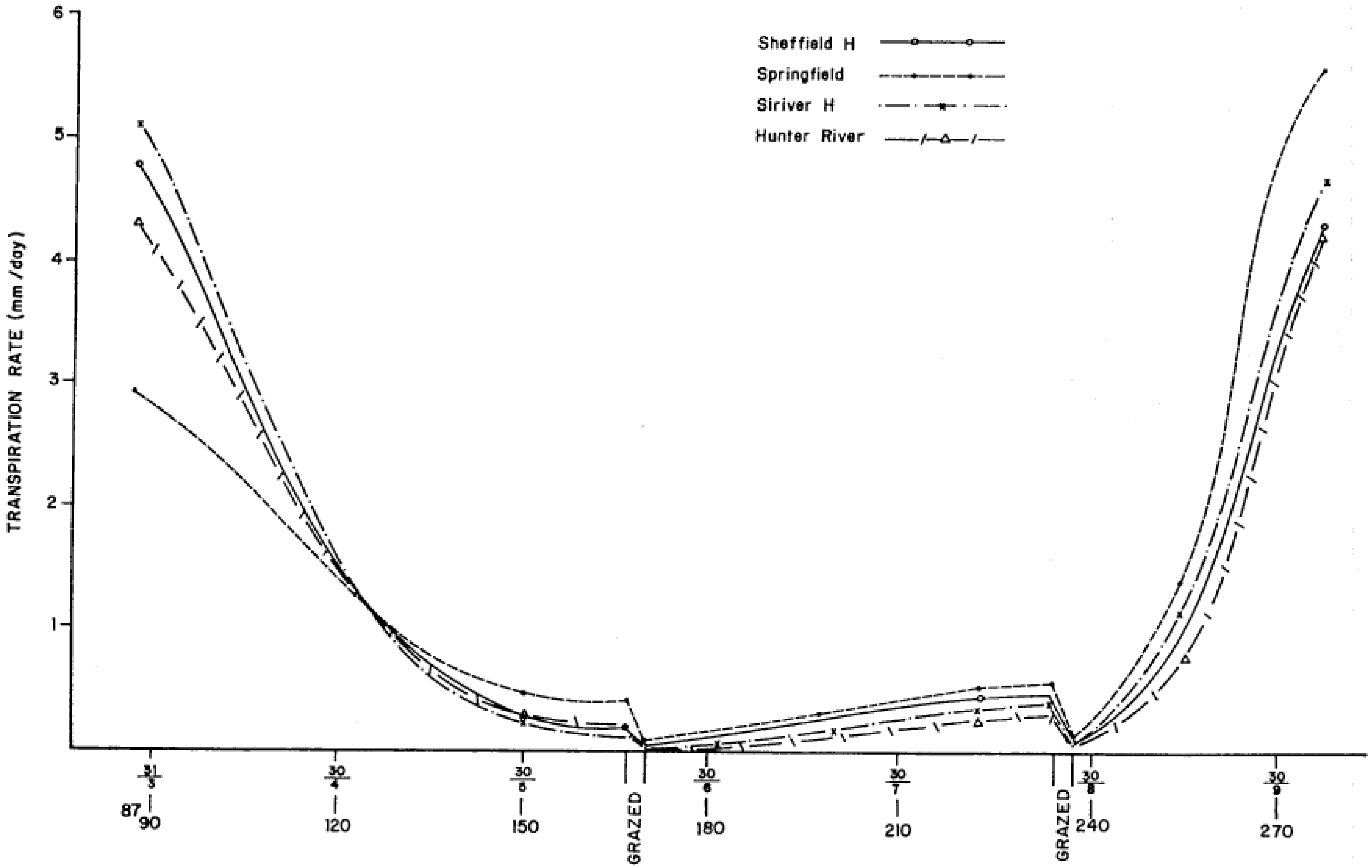

Figure 6 Seasonal transpiration rate of four lucerne cultivars at Gibson

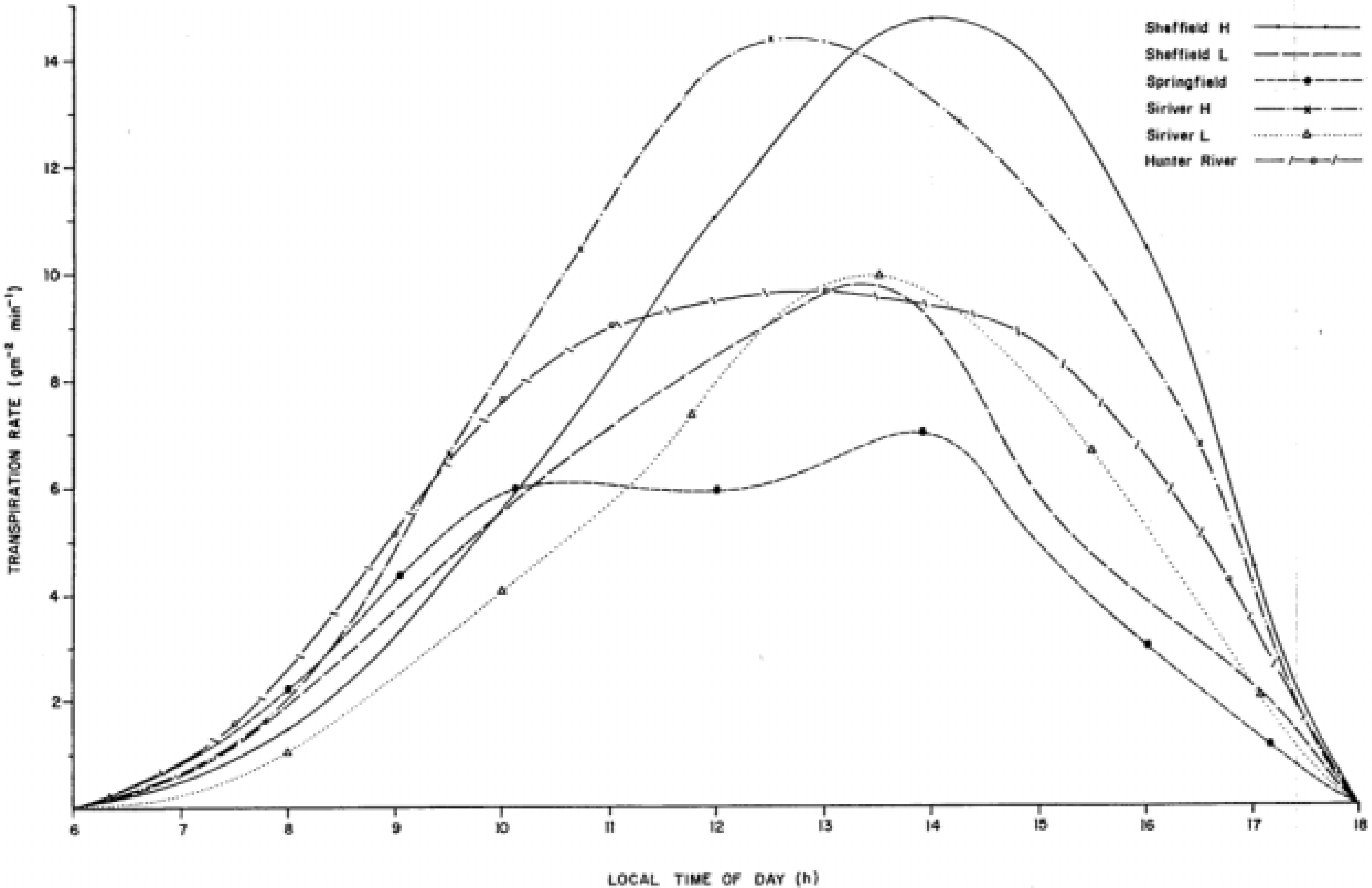

Figure 7 Daily transpiration rate of six lucerne cultivar at Gibson on March 28, 1985.

Table 9. Transpiration for period 27/3 - 7/10/85 of four lucerne cultivars grown on deep sand at Gibson

Cultivar	**Rainfall (mm)**	**Transpiration (mm)**	**(R-T)(min)**
Springfield	303	248	55
Siriver	303	286	17
Sheffield	303	277	26
Hunter River	303	230	73

Table 10. Leaf area index (LAI) (m^2/m^2) and above ground dry matter (DM) (t/ha) for four lucerne cultivars grown at Gibson

Cultivar	Springfield		Siriver		Sheffield		Hunter River	
Sample Date	LAI	DM	LAI	DM	LAI	DM	LAI	DM
28.03.85	0.7	0.76	2.0	2.09	1.8	1.68	1.1	1.04
30.05.85	0.7	1.49	0.4	0.75	0.5	0.80	0.5	0.98
17.07.85	0.7	0.53	0.3	0.26	N.A	N.A	N.A	N.A
14.08.85	1.9	1.42	1.2	0.93	1.4	0.92	1.0	0.57
19.09.85	0.8	0.50	0.7	0.73	0.7	0.50	0.4	0.30
7.10.85	1.5	1.05	1.1	0.94	0.9	0.60	1.0	0.74
Tonne days		192		234		196		150

6. Discussion

The most notable result from this work was the transpiration of lucerne relative to wheat at Gairdner River (Table 6). To use 433 mm of water during the 12 month period the lucerne had to reduce the soil moisture storage by almost 50 mm. Under these conditions it is unlikely that any recharge to the groundwater system would have occurred.

During the wheat growing season the lucerne used 86 mm less water than fell as rain. Since there was no observed runoff from the area this excess must have been catered for by satisfying a soil moisture deficit created by the lucerne during the preceding summer. This contrasts with the wheat, which although it used all but 10 mm of the rain which fell during its growing season, was simply not there to use the 143 mm of rain that fell over the summer period. Thus, for the year the soil under the wheat received an additional 153 mm of water. This water would either be added to soil moisture storage or drain beyond the root zone and contribute to the groundwater system. Obviously additions to soil moisture storage can only continue until the storage is satisfied. Given that this land has been developed for some 20 years there is probably, on average, no change in soil moisture storage at the beginning of each wheat growing season. Thus, the water not used by the crop contributes to groundwater recharge.

Although the above assumes a one dimensional hydrologic system, and in that respect is oversimplified, it does illustrate the importance of growing plants which will minimize the recharge to groundwater. The only estimate of net recharge to groundwater in the south coastal region of Western Australia is that of George (1978). He estimated that under native vegetation recharge was I.6% of rainfall while under traditional agricu1ture-~-subterraneanr clover-cereal rotation) it was 7% of rainfall. Assuming that these figures apply at Gairdner River, the recharge under native vegetation and traditional agriculture would be 6 and 27 mm respectively. It is the difference of only about 20 mm annually that causes the salinity problem. Lucerne grown on recharge areas appears to have the potential to negate this recharge and at least prevent further salt encroachment.

Selection of appropriate plant species for soils with different hydraulic characteristics is essential for recharge reduction. The data from Cuballing (Table 1) and Bedford Harbour show that crops growing on soils with low water holding capacity and relatively high hydraulic conductivities cannot use the water before it drains beyond the root zone.

To minimise recharge it is essential to maximise plant water use. This can only be achieved by growing crops appropriate to the prevailing climatic and edaphic conditions. While minimizing recharge is an admirable land conservation strategy there needs to be some economic incentive to encourage adoption of the practice. There is a relationship between crop or pasture yield and water used, usually expressed as a water use efficiency in kg/ha/mm. However, there is difficulty in determining what the extra yield will be if an extra mm of water is used. Tennant (1981) suggests that in the wheatbelt of Western Australia the water use efficiency of wheat is 10 kg/ha/mm after 110 mm of rainfall is discounted for soil evaporation and interception losses. French and Shultz (1984) showed that in South Australia wheat yield did not exceed 20 kg/ha/mm (again discounted for 110 mm soil evaporation and interception losses). The mm of Tennant and French and Schultz refer to changes in soil water content plus rainfall and thus include both the drainage and runoff components of the water use term which may result in an underestimation of actual water use efficiency.

Where other factors do not limit growth there is evidence of a linear relationship between transpiration and yield (de Wit, 1958; Hanks et al. 1969; Tanner and Sinclair, 1983). The analysis of Tanner and Sinclair indicates that the upper limit of water use efficiency is genetically and environmentally determined with the environmental limit being a function of the integrated vapour pressure deficits over the growing season.

The influence of other factors on water use efficiency is illustrated by the wheat yields at Mallee Road (Table 4) and Gairdner River (Table 8) where the growing season rainfalls were identical (241 mm). The crop at Mallee Road yielded 2.16 t/ha with transpiration efficiency of 18.0 kg/ha/mm. At Gairdner River the yield was 2.4 t/ha and the transpiration efficiency 10.4 kg/ha/mm. The crop at Gairdner River failed to develop its potential yield, as indicated by the above ground biomass, due to disease late in the season. However, the crop at Gairdner River transpired some 100 mm more water than that at Mallee Road. Thus grain yield cannot be used to determine plant water use. Above ground biomass may be a better indicator, since total above ground dry matter at harvest at Mallee Road and Gairdner River was 2.16 and 8.8 t/ha respectively. Tanner and Sinclair (1983) suggest that transpiration is a function of total biomass (roots plus shoots) and integrated vapour pressure deficit.

Although there is dispute about the absolute values of water use efficiency there is no doubt that there is a relationship between yield and water use.

In an environment where water often limits yield it is provident to use the water available. While it is not practicable to change the relationship between water lost by soil evaporation and transpiration it is possible to select crops appropriate to-the soil type to reduce- water-draining-beyond the root zone. For each mm of water lost to recharge potential crop yield decreases by 10 to 20 kg/ha. This is the profit incentive for reducing recharge.

7. Acknowledgements

We sincerely thank the Wheat Industry Research Council of Western Australia for their financial support of this project.

Thanks to Mr N. Witham for his able technical assistance in taking measurements and processing and collating data.

Without the support of the landholders this project would not have been possible. We thank Mr R. Falls owner of Falls' Farm Catchment at Cuballing, Mr R. Hurst of Gairdner River, Mr M. Slade of Fitzgerald (Mallee Road Sump), Mr M. Quinlivan of the Esperance Land Development Company for access to Bedford Harbour Station and Mr D. Johnston of Ireland Farms, Gibson.

8. Literature Cited

Baxter, I.N. and Nulsen, R.A. 1986. Comparative crop transpiration calculated from infra-red temperature and leaf diffusive resistance. Agric. Water Managmt (submitted).

French, R.J. and Schultz, J.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I The relation between yield, water use and climate. Aust. J. Agric. Res. 35: 743-764.

George, P.R. 1978. The hydrogeology of a dryland salt seepage area in south-western Australia. Proc. Subcomm. Salt Affected Soils. 11th mt. Soil Sci. Congr. Edmonton. 3.1 .3.13.

Hanks, R.J., Gardner, H.R. and Florian, R.L. 1969. Plant growth .evapotranspiration relations for several crops in the Central Great Plains. Agron. J. 61: 30-34.

Miller, M.R., Brown, P.L., Donovan, J.J., Bergatino, R.N., Sonderegger, J.L. and Schmidt, F.A. 1981. Saline seep development and control in the North American Great Plains .hydrological aspects. Agric. Water Managmt. 4: 115-141.

Nulsen, R.A. and Baxter, I.N. 1982. The potential of agronomic manipulation for controlling salinity in Western Australia. J. Aust. Inst. Agric. Sci. 48: 222-226.

Peck, A.J. and Hurle, D.H. 1973. Chloride balance of some farmed and forested catchments in south-western Australia. Water Resour. Res. 9:648-657.

Riou, C.R. 1984. Simplified calculation of the zero-plane displacement from wind-speed profiles. J. Hydrol. 69: 351-357.

Tanner, C.B. and Sinclair, T.R. 1983. Efficient water use in crop production; research or re-search. In 'Limitations to Efficient Water Use in Crop Production' H.M. Taylor and W.R. Jordan eds. Am. Soc. Agron. Monograph pp -1-27.

Tennant, D. 1981. Effect of fallowing on cereal yield. J. Agric. West. Aust. 22: 38-41.

Thom, A.S. and Oliver, H.R. 1977. On Penman's equation for estimating regional evaporation. Quart. J. Roy. Meteorol. Soc. 103: 345-357.

de Wit, C.T. 1958. Transpiration and crop yields. Versl. Landbouwk. Onderz 64: 1-88.