CHAPTER 5

WATER USE EFFICIENCY OF FIVE PERENNIAL SUB-TROPICAL GRASS SPECIES AT FOUR LEVELS OF WATER AVAILABILITY

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Abstract

The effect of four levels of water availability on the water use efficiency of five subtropical perennial grasses (*Cenchrus ciliaris,* a *Cynodon* hybrid*, Digitaria eriantha* subsp*. eriantha, Panicum maximum* and *Pennisetum clandestinum*) was evaluated in a small plot trial under a rain shelter at the University of Pretoria. The four treatments were: soil profile brought to 25 (W1), 50 (W2), 75 (W3) and 100% (W4 - the control) of field capacity on a weekly basis.

The grasses differed from each other in terms of water use efficiency, regardless of whether it was expressed as dry matter yield (WUE_{DM}), digestible dry matter yield (WUE_{DDM}) or crude protein yield (WUE_{CP}). As could be expected, WUE_{DM} (10.7 - 17.2 kg ha mm) was higher than that of WUE_{DDM} (5.9 - 9.9 kg ha mm) with WUE_{CP} (0.9 - 1.6 kg ha mm) the lowest for all the grass species.

In both seasons *C. ciliaris* was one of the more efficient water users. The relative

water use efficiency of the other grasses varied from season to season. Where WUE_{CP} is of particular importance (for example in dairy enterprizes), the *Cynodon* hybrid should be kept in mind, since it had the highest value over the two year period.

The WUE (WUE_{DM}, WUE_{DDM} and WUE_{CP}) of the grasses tended to be better under non-control conditions. Good management is, however, important under these conditions to ensure not only a high WUE, but also satisfactory yields.

Keywords

Cenchrus ciliaris, Cynodon hybrid*, Digitaria eriantha* subsp. *eriantha, Panicum maximum, Pennisetum* clandestinum, water use efficiency

5.1 Introduction

Water use efficiency (WUE) is a way to evaluate plant species in terms of their ability to produce with a certain amount of water available. There are many factors affecting WUE, including the type of plant/plant community, soil type, soil depth, climatic conditions, frequency and intensity of watering and utilization practices. To be able to evaluate a plant's WUE, as many of these factors as possible should be kept constant to ensure a fair comparison between the grass species. From there, plant species that are able to produce more with less water should be favoured in areas with limited water resources.

Water-use efficiency (WUE) can be expressed in a hydrological and physiological context. In a purely hydrological context, WUE has been defined as "the ratio of the

volume of water used productively, i.e., transpired and in some cases also evaporated, from the area under study, to the volume of water potentially available for that purpose, i.e., that reaching the crop growing region via rainfall and irrigation plus that available from the soil" (Stanhill, 1986).
Physiologically it can be defined as "the ratio of the weight of crop water loss to the atmosphere, to that of its yield or total dry matter production" (Stanhill, 1986). Most often the hydrological and physiological definitions are combined and WUE is expressed as the amount of dry material (kg) being produced per area (ha) per mm water. The latter can be defined as water transpired/evapotranspired/ irrigated etc. and should, therefore, be clearly defined.

In this report, WUE is given in terms of dry matter yield, digestible dry matter yield or crude protein dry matter yield (kg) per area (ha) per amount of water (mm) evapotranspired. The amount of water was calculated as the sum total of water applied throughout the trial period together with the water deficit at the end of the season (Marais *et al.*, unpublished (a)).

The hypotheses for this report are:

- that the grass species will differ in their ability to use water efficiently and
- that the grasses will use water more efficiently under water limiting than non-limiting conditions.

5.2 Materials and Methods

Five subtropical perennial grasses were established under an automatic rain shelter on the Hatfield Experimental Farm, of the University of Pretoria in Pretoria, (25˚45'S, 28˚16'E), South Africa, during December 1995. The trial ended in June 1998. The five grasses were *Cenchrus ciliaris* cv. Molopo (Blue buffel-grass), a *Cynodon* hybrid cv. Coastcross II (K11) (Coastcross bermudagrass), *Digitaria eriantha subsp. eriantha* cv. Irene (Smuts finger-grass), *Panicum maximum* cv. Gatton (Guinea grass) and *Pennisetum clandestinum* cv. Whittet (Kikuyu grass).

The soil at the site is a Shorrock series of the Hutton form (MacVicar *et al.*, 1991) with 30% clay in the top soil. The A-horizon of the soil is uniform to a depth of 1.2 m, before reaching the B-horizon, which contains coarse gravel. The experimental plots were 2.5 x 2.0 m in size and separated by asbestos plates to a depth of 1.2 m.

During June 1995, seeds of *C. ciliaris*, *P. maximum*, *D. eriantha* and *P. clandestinum* were sown in seedling trays and kept in a greenhouse until December 1995. *C. ciliaris, P. maximum* and *D. eriantha* which are tufted or bunch grasses, were established at a rate of 300 000 plants ha^{-1}, while the creeping grasses (the *Cynodon* hybrid & *P. clandestinum*) were established at 160 000 plants ha^{-1}. The *Cynodon* hybrid was established using vegetative material collected on the experimental farm. The initial germination rate of *D. eriantha* was less than adequate and additional seedlings had to be propagated. This delayed transplanting of this species from trays to the field site by ten weeks compared to the other species.

A neutron probe access tube was located in the centre of each plot. Neutron probe counts, using a Campbell neutron probe (503 DR), were taken at nine depth increments, each of 200 mm, on a weekly basis for all plots. These counts, which are related to the volumetric water content, were then incorporated into a calibration equation to determine the water deficit for each layer. Just before the onset of each growing season, the soil profiles of all the plots were brought to field capacity. Only then were the plants subjected to four levels of water availability.

The water availability levels used were:

W1 - apply 25% of the amount given to W4.

W2 - apply 50% of the amount given to W4

W3 - apply 75% of the amount given to W4

W4 - control, the soil profiles were brought to field capacity on a weekly basis

Water was applied by means of flood irrigation and the amounts of water applied were monitored using water flow meters.

During the establishment season (1995/96), the grasses were not subjected to differential irrigation treatments to ensure a good establishment as it has been found that some of these grasses only start to produce optimally during the second or third year . To ensure a fair comparison of the species, treatments were thus only imposed in the second (1996/97) and third seasons (1997/98).

According to soil analyses, the pH(H_2O) of the experimental soil was neutral. The phosphorus (Bray II) and potassium (Ammonium acetate extractable cations) status in the top soil (30 mg kg^{-1} P; 108 mg kg^{-1} K) was much higher than that of the subsoil (8 mg kg^{-1} P; 67 mg kg^{-1} K). To achieve a non-limiting soil phosphorus and potassium status of 40 mg kg^{-1} P and 150 mg kg^{-1} K, which would ensure that these nutrients were not limiting, annual applications of these nutrients were necessary. As the plots were not grazed, but removed as hay, N, P and K were lost from the soil and the fertilizer regime was designed to replace these losses. At planting (1995/96 season), the plots received 75 kg N ha^{-1}, 40 kg P ha^{-1} and 200 kg K ha^{-1}. Nitrogen and potassium were also applied to all plots as top dressings during the summer growing season, resulting in a total of 450 kg N ha^{-1} a^{-1}, 40 kg P ha^{-1} a^{-1} and 400 kg K ha^{-1} a^{-1}. In the subsequent seasons (1996/97 and 1997/98), nitrogen and potassium were applied to all plots as top dressings at rates of 225, 338, 394 and 450 kg N ha^{-1} a^{-1} and 200, 300, 350 and 400 kg K ha^{-1} a^{-1} for the W1, W2, W3 and W4 water availability levels respectively. The fertilizers used were limestone ammonium nitrate (LAN) (28.0% N), superphosphate (8.3% P) and potassium chloride (KCl) (50.0% K).

The grasses were harvested at the 10% flowering stage, except for *P. clandestinum*, which was not allowed to grow taller than 40 cm. This resulted in an average of three to four cuts during each season. *C. ciliaris, D. eriantha* and *P. maximum* (tufted grasses) were cut to a height of 10 cm while the *Cynodon* hybrid and *P. clandestinum* (creeping grasses) were cut to 5 cm. A sample plot of one square metre, in the middle of each plot, was harvested, after which the rest of the plot was also cut to the same height. The sample plots were permanently marked to ensure that the samples were taken from the same area at each harvest. The material was dried to constant mass for 48 hours at 65˚C.

Intact plants, as well as the different yield components, were milled after drying. A Wiley no. 3 mill, with a 1 mm sieve was used. The milled product was then used to determine the *in vitro* dry matter digestibility and crude protein content of the crops.

In vitro dry matter digestibility

The dry matter, organic matter and ash content of the samples were determined by drying 2 g or each milled sample for 24 hours at 60˚C (dry matter content), before incinerating at 600˚C for 4 hours (ash content). The organic matter content was calculated as the difference between the dry matter and ash contents. For the *in vitro* digestibility of the crops, 0.2 g plant material was used for the analysis using the method proposed by Tilley and Terry (1963).

Crude protein content

The milled plant samples were analysed for nitrogen content using the Kjeldahl technique (Association of Official Analytical Chemists, 1984). The analysis were done by the Soil Science Laboratory of the Department of Plant Production and Soil Science. The values were multiplied by 6.25 (Van der Merwe and Smith, 1991) to express the results in terms of crude protein content.

A fully randomized block design with three replications was used. The statistical analysis was done using the Statistical Analysis System (SAS, 1996). Tukey's least significant difference at the 5% level of probability was used to determine significant differences between treatment means. Relevant statistical analysis data is presented in the Appendix (Tables A5.1 - A5.10).

5.3 Results

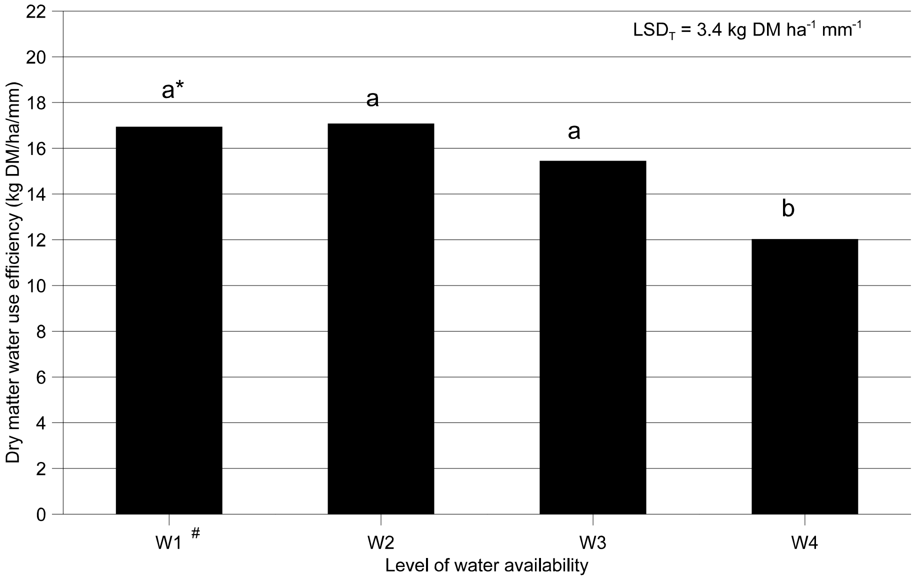
5.3.1 Water use efficiency in terms of dry matter yield (WUE_{DM})

In both seasons there were significant ($P \leq 0.05$) differences in the WUE_{DM} of the different irrigation levels. Water was used more efficiently under "non-control" conditions (Figures 5.1 and 5.2). In the 1996/97 season (Figure 5.1) it was only the control (W4) treatment that used water less efficiently than the other three treatments (W1, W2 & W3), while in the following season (Figure 5.2) both the well watered treatments (W3 and W4) used water less efficiently than under severe water limiting conditions (W1). Bielorai (1982) and Aggarwal and Sinha (1983) also observed better WUE under water stress than under non-limiting conditions. There was, however, a poor correlation between water use and WUE due to many factors contributing to water losses that do not necessarily contribute to yield.

The grasses tended to differ from each other in terms of water use efficiency. In both seasons *C. ciliaris* was one of the more efficient water users. The relative water use efficiency of the other grasses varied from season to season.

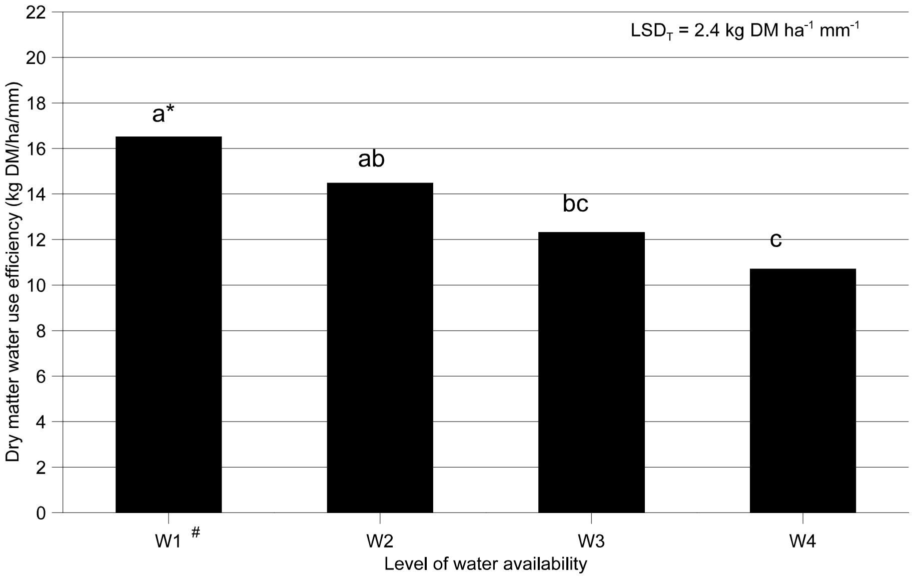
In both seasons *C. ciliaris*, *P. maximum* and *P. clandestinum* used water most efficiently under W1 conditions, while the *Cynodon* hybrid and *D. eriantha* used water most efficiently under W1, W2 and W3 conditions (Table 5.1). All five grasses, however, used water the least efficiently when water was not limiting (W4). This is contrary to the findings of Dobrenz *et al*. (1969) who reported a decrease in WUE for *P. maximum antidotale* when soil moisture stress increased.

In this trial *C. ciliaris* and the *Cynodon* hybrid were the most efficient water users. The use of these grasses under a wide range of moisture conditions can, therefore, be recommended. The same can not, however, be said for *P. maximum* and *P. clandestinum* which were the least efficient water users in this trial. From this trial, no definite conclusions can be drawn about *D. eriantha*, except that water was more efficiently used under water limiting (W1) than control conditions (W4).



* Treatments with the same letter do not differ significantly from each other ($P<0.05$)
\# W1 - severely water stressed level, W4 - control

Figure 5.1 The average dry matter water use efficiency of five grass species for four levels of water availability in the 1996/97 season.



* Treatments with the same letter do not differ significantly from each other ($P<0.05$)
\# W1 - severely water stressed level, W4 - control

Figure 5.2 The average dry matter water use efficiency of five grass species for four levels of water availability in the 1997/98 season.

Table 5.1 Influence of level of water availability on the WUE_{DM} (kg DM ha^{-1} mm^{-1}) of five perennial grasses.

Grass	Level of water availability (I)*				Mean
	W1	W2	W3	W4	
			1996/97 season		
C. ciliaris	24.9	24.7	22.8	17.6	22.5
Cynodon hybrid	17.4	14.3	16.2	12.4	15.1
D. eriantha	19.4	24.9	19.0	14.3	19.4
P. maximum	14.9	14.6	12.7	11.4	13.4
P. clandestinum	8.6	7.5	7.3	5.2	7.2
Mean	17.0	17.2	15.6	12.1	
$LSD_T(G)$ = 4.0					
$LSD_T(I)$ = 3.4					
			1997/98 season		
C. ciliaris	23.9	19.3	16.3	12.7	18.0
Cynodon hybrid	19.9	20.0	18.8	16.3	18.7
D. eriantha	13.0	11.3	9.5	7.9	10.4
P. maximum	11.6	8.5	6.7	6.4	8.3
P. clandestinum	14.2	13.4	10.4	10.4	12.1
Mean	16.5	14.5	12.3	10.7	
$LSD_T(G)$ = 2.9					
$LSD_T(I)$ = 2.4					

* W1 -severely water stressed level, W4 - control

5.3.2 Water use efficiency in terms of digestible dry matter yield (WUE_{DDM})

The digestible dry matter yields of *C. ciliaris*, *P. maximum* and *D. eriantha*, were higher in the 1996/97 than the 1997/98 season (Table 5.2). This is in accordance with the dry matter yields (Marais *et al.,* unpublished (b)), where the *Cynodon* hybrid and *P. clandestinum* were the only grasses which produced higher yields in the 1997/98 than the 1996/97 season. In the 1996/97 season only *C. ciliaris* produced significantly ($P \leq 0.05$) higher digestible dry matter yields than the other grasses

(Table 5.2). In the following season (1997/98 season), the *Cynodon* hybrid also (in addition to *C. ciliaris*) produced significantly ($P \leq 0.05$) higher digestible dry matter yields than *D. eriantha*, *P. maximum* and *P. clandestinum*. In terms of the level of water availability (Table 5.2), the digestible dry matter yields were significantly ($P \leq 0.05$) higher under W3 and W4 than under W1 conditions, in both seasons. This was also true for the dry matter yields reported by Marais *et al.* (unpublished (b)).

There was a significant ($P \leq 0.05$) interaction between water availability and grass species in the 1997/98 season (Table 5.3) for WUE_{DDM}. During that season, *C. ciliaris* and *D. eriantha* used water most efficiently with an increase in water deficit. For *P. maximum*, the *Cynodon* hybrid and *P. clandestinum* water was used more efficiently under W1, and sometimes W3 conditions, than under control conditions (W4). The differences in WUE_{DDM} between W2, W3 and W4 were not, however, always significant ($P \leq 0.05$) for the latter three grasses. As with WUE_{DM}, WUE_{DDM} was again better under water stressed than under control conditions (Table 5.3). In both seasons, *P. maximum* and *P. clandestinum* used water the least efficiently.

Table 5.2 Influence of level of water availability on the digestible dry matter yield (t DDM ha^{-1}) of five perennial grasses.

Grass	Level of water availability (I)*				Mean
	W1	W2	W3	W4	
		1996/97 season			
C. ciliaris	5.9	8.5	10.8	10.6	9.0
Cynodon hybrid	4.3	4.8	6.6	6.5	5.6
D. eriantha	3.1	5.6	5.5	7.9	5.6
P. maximum	4.3	5.7	5.8	5.1	5.2
P. clandestinum	2.5	3.3	4.0	3.7	3.4
Mean	4.0	5.6	6.5	6.8	
$LSD_T(G)$ = 2.4					
$LSD_T(I)$ = 2.0					
		1997/98 season			
C. ciliaris	7.5	8.1	8.4	7.6	7.9
Cynodon hybrid	5.3	6.7	8.6	9.4	7.5
D. eriantha	4.0	4.6	5.2	5.8	4.9
P. maximum	3.6	3.5	4.2	5.1	4.1
P. clandestinum	3.3	2.8	3.8	5.7	3.9
Mean	4.7	5.2	6.0	6.7	
$LSD_T(G)$ = 1.2					
$LSD_T(I)$ = 1.0					

* W1 -severely water stressed level, W4 - control

Table 5.3 Influence of level of water availability on the WUE_{DDM} (kg DDM ha^{-1} mm^{-1}) of five perennial grasses.

Grass	Level of water availability (I)*				Mean
	W1	W2	W3	W4	
		1996/97 season			
C. ciliaris	12.6	12.4	12.3	9.7	11.8
Cynodon hybrid	10.2	7.8	8.8	6.7	8.4
D. eriantha	12.1	14.5	11.1	8.5	11.6
P. maximum	9.1	9.3	7.9	7.4	8.4
P. clandestinum	5.3	4.8	4.7	3.4	4.5
Mean	9.9	9.8	9.0	7.1	
$LSD_T(G) = 2.2$					
$LSD_T(I) = 1.9$					
		1997/98 season			
C. ciliaris	14.4	11.3	9.8	6.9	10.6
Cynodon hybrid	11.0	10.1	11.3	9.7	10.5
D. eriantha	7.8	6.3	5.4	4.6	6.0
P. maximum	5.9	3.9	3.6	3.5	4.2
P. clandestinum	6.0	4.5	4.2	5.0	4.9
Mean	9.0	7.2	6.9	5.9	
$LSD_T(G) = 1.7$					
$LSD_T(I) = 1.4$					
$LSD_T(GxI) = 0.7$					

* W1 -severely water stressed level, W4 - control

5.3.3 Water use efficiency in terms of crude protein yield (WUE_{CP})

The crude protein yield of all the grasses, except that of *D. eriantha*, tended to be higher in the 1997/98 than 1996/97 season (Table 5.4). In both seasons, *C. ciliaris* and the *Cynodon* hybrid produced higher crude protein yields than the other grasses. The crude protein yields tended to be higher under control (W4) than severely water stressed (W1) conditions in both seasons.

As with WUE_{DM} and WUE_{DDM}, water use efficiency in terms of crude protein yield was considerably better under severe water limiting (W1) than under control conditions (W4) (Table 5.5).The *Cynodon* hybrid*, C. ciliaris* and *D. eriantha* used water the most efficiently in the 1996/97 season while the WUE_{CP} of the *Cynodon* hybrid and *C. ciliaris* were the best in the following season. *P. maximum* and *P. clandestinum* were highly variable in this respect.

Table 5.4 Influence of level of water availability on the crude protein yield (t CP ha^{-1}) of five perennial grasses.

Grass	Level of water availability (I)*				Mean
	W1	W2	W3	W4	
			1996/97 season		
C. ciliaris	0.5	0.7	1.0	0.9	0.8
Cynodon hybrid	0.8	0.8	1.3	1.3	1.0
D. eriantha	0.3	0.4	0.5	0.8	0.5
P. maximum	0.4	0.5	0.4	0.5	0.4
P. clandestinum	0.4	0.5	0.6	0.5	0.5
Mean	0.5	0.6	0.7	0.8	
$LSD_T(G) = 0.3$					
$LSD_T(I) = 0.2$					
			1997/98 season		
C. ciliaris	1.1	1.6	0.9	1.0	1.1
Cynodon hybrid	1.3	1.4	1.4	2.2	1.6
D. eriantha	0.4	0.4	0.5	0.5	0.5
P. maximum	0.5	0.5	0.4	0.6	0.5
P. clandestinum	0.8	0.7	0.7	1.0	0.8
Mean	0.8	0.9	0.8	1.1	
$LSD_T(G) = 0.3$					
$LSD_T(I) = 0.2$					
$LSD_T(GxI) = 0.1$					

* W1 -severely water stressed level, W4 - control

Table 5.5 Influence of level of water availability on the WUE_{CP} (kg CP ha^{-1} mm^{-1}) of five perennial grasses.

Grass	Level of water availability (I)*				Mean
	W1	W2	W3	W4	
		1996/97 season			
C. ciliaris	1.1	1.0	1.1	0.9	1.0
Cynodon hybrid	1.8	1.3	1.7	1.3	1.5
D. eriantha	1.1	1.0	1.0	0.9	1.0
P. maximum	1.4	1.3	1.2	1.0	1.2
P. clandestinum	0.8	0.7	0.7	0.5	0.7
Mean	1.2	1.1	1.1	0.9	
$LSD_T(G)$ = 0.3					
$LSD_T(I)$ = 0.3					
		1997/98 season			
C. ciliaris	2.2	2.2	1.0	1.0	1.6
Cynodon hybrid	2.7	2.1	1.8	2.3	2.2
D. eriantha	0.7	0.5	0.6	0.4	0.6
P. maximum	0.9	0.5	0.3	0.4	0.5
P. clandestinum	1.4	1.1	0.7	0.9	1.0
Mean	1.6	1.3	0.9	1.0	
$LSD_T(G)$ = 0.3					
$LSD_T(GxI)$ = 0.3					
$LSD_T(GxI)$ = 0.1					

* W1 -severely water stressed level, W4 - control

5.4 Discussion and Conclusions

The grasses did differ from each other in terms of water use efficiency, regardless of whether this was expressed as dry matter yield (WUE_{DM}), digestible dry matter yield (WUE_{DDM}) or crude protein yield (WUE_{CP}). As could be expected, WUE_{DM} (10.7 - 17.2 kg ha^{-1} mm^{-1}) was higher than that of WUE_{DDM} (5.9 - 9.9 kg ha^{-1} mm^{-1}) with WUE_{CP} (0.9 - 1.6 kg ha^{-1} mm^{-1}) the lowest for all the grass species.

In both seasons *C. ciliaris* was one of the more efficient water users. The relative water use efficiency of the other grasses varied from season to season. Where WUE_{CP} is of particular importance (for example in dairy enterprizes), the *Cynodon* hybrid should be kept in mind, since it had the highest value over the two year period.

In the literature a few WUE_{DM} values have been reported, but these are far lower (3 - 9 kg DM ha^{-1} mm^{-1} for *D. eriantha*; 2 - 6 kg DM ha^{-1} mm^{-1} for *P. maximum* and 2.5 - 7 kg DM ha^{-1} mm^{-1} for *C. ciliaris* (Snyman *et al.*, 1987; Snyman, 1989;1994) than the values reported for this trial (7.9 - 24.9 kg ha^{-1} mm^{-1} for *D. eriantha*; 6.4 - 14.9 kg ha^{-1} mm^{-1} for *P. maximum*; 5.2 - 24.9 kg ha^{-1} mm^{-1} and 12.7 - 24.9 kg ha^{-1} mm^{-1} for *Cenchrus*). The reasons being that:

- some of the grasses reported on were rangeland species (Snyman *et al.*, 1987; Snyman, 1989; 1994) where the growing conditions were not ideal (seed quality, fertilizer, crop protection etc.)
- evaporation and transpiration are influenced by the vapour pressure deficit, which differs from area to area (for example low at the coastal areas and higher in the dry Karoo) and season to season. For correct comparisons, the WUE should first of all be corrected for the vapour deficit in that area for the specific time the trial was conducted
- the type of plant/plant community, soil type, soil depth, climatic conditions, frequency and intensity of watering and utilization practices may differ for each situation and thus have an affect on the results (Opperman *et al.*, 1977; Snyman *et al.*, 1980 and 1987; Stanhill, 1986; Stout, 1992; Saeed and El-Nadi, 1997).

It was only Stout (1992) who reported comparable WUE values (of 4.4 - 25.0 kg DM ha^{-1} mm^{-1}) for *Dactylis glomerata* and *Panicum virgatum*.

The WUE (WUE_{DM}, WUE_{DDM} and WUE_{CP}) of the grasses tended to be better under non-control conditions. Beukes and Barnard (1985); Devitt *et al*., (1992); Moolman (1993)and Garrot and Mancino (1994) also reported better WUE under conditions where the soil profiles were not brought back to field capacity with each watering. There is, however, a threshold of tolerance and when water deficits become too severe it can lead to not only poor WUE but also to poor dry matter production. This implies a higher management input to ensure optimum production and WUE.

Although no C_3 grass species were used in this particular trial, it is of value to mention that C_4 grass species were found to be far more WUE than C_3 grass species (Ng *et al*., 1975; Forde *et al*., 1976; Christie, 1978; Brown and Simmons, 1979; Frean *et al*., 1980; Kramer, 1983; Feldhake and Boyer, 1995). Due to a better WUE of C_4 than C_3 grass species, the introduction of C_4 grass species into a new system should not have a negative effect on the ecosystem (Feldhake and Boyer, 1995) and under South African conditions where drought often occurs, the use of C_4 grasses could mean more fodder with less water.

5.5 References

AGGARWAL, P.K. AND SINHA, S.K., 1983. Water stress and water-use efficiency in field grown wheat: A comparison of its efficiency with that of C_4 plants. *Agricultural Meteorology*, 29, 159-167.

BEUKES, D.J. AND BARNARD, S.A., 1985. Effects of level and timing of irrigation on growth and water use of lucerne. *South African Journal of Plant and Soil*, 8, 197-202.

BIELORAI, H., 1982. The effect of partial wetting of the root zone on yield and water use efficiency in a drip and sprinkler irrigated mature grapefruit grove. *Irrigation Science*, 1982, 3, 89-100.

BROWN, R.H. AND SIMMONS, R.E., 1979. Photosynthesis of grass species differing in CO_2 fixation pathways. I. Water-use efficiency. *Crop Science,* 19, 375-379.

CHRISTIE, E.K., 1978. Ecosystem processes in semi-arid grasslands. I. Primary production and water use of two communities possessing different photo synthetic pathways. *Australian Journal of Agricultural Research*, 29, 773-787.

DEVITT, D.A., MORRIS, R.L. AND BOWMAN, D.C., 1992. Evapotranspiration, crop coefficients, and leaching fractions of irrigated desert turfgrass systems. *Agronomy Journal*, 84, 717-723.

DOBRENZ, A.K., NEAL WRIGHT, L., MASSENGALE, M.A. AND KNEEBONE, W.R., 1969. Water-use efficiency and its association with several characteristics of Blue Panicgrass (*Panicum antidotale* Retz.) clones. *Crop Science,* 9, 213-216.

FELDHAKE, C.M. AND BOYER, D.G., 1995. Soil water depletion by C_3 and C_4 pasture grasses in central Appalachia. *Journal of Soil and Water Conservation*, 50, 106-109.

FORDE, B.J., SLACK, C.R., ROUGHAN, R.G. AND WHITEHEAD, H.C.M., 1976. Growth of tropical and temperate grasses at Palmerston North. I. Warm season yields with and without irrigation. *New Zealand Journal of Agricultural Research*, 19, 135-142.

FREAN, M., BARRETT, D. AND CRESSWELL, C.F., 1980. Variability in leaf surface features and water efficiency utilisation in C_3 and C_4 forms of *Alloteropsis semialata* (R.Br.) HITCHC. *Proceedings of the Grassland Society of Southern Africa,* 13, 99-103.

GARROT, D.J. AND MANCINO, C.F., 1994. Consumptive water use of three intensively managed bermudagrasses growing under arid conditions. *Crop Science*, 34, 215-221.

KRAMER, P.J., 1983. Drought tolerance and water use efficiency in *Water relations of plants,* 391 - 415.

MACVICAR, C.N., BENNIE, A.T.P., DE VILLIERS, J.M., ELLIS, F., FEY, M.V., HARMSE, VON M.H.J., HENSLEY, M., LAMBRECHTS, J.F., BRUCE, R.W., DOHSE, T.E., ELOFF, J.F., GREY, D.C., HARTMAN, M.O., IDEMA, S.W.J., LAKER, M.C., MERRYWEATHER, F.R., MICHAEL, D., SCHLOMS, B.H.A., SCHÖNAU, A.P.G., SNYMAN, K., VAN NIEKERK, B.J., VERSTER, E., LOXTON, R.F., MEYER, J.H., PATERSON, D.G., SCHOEMAN, J.L., SCOTNEY, D.M., TURNER, D.P., VAN ROOYEN, T.H. AND YAGER, T.U., 1991. Soil classification: A taxonomic system for South Africa. Department of Agricultural Development, Pretoria.

MARAIS, D., RETHMAN, N.F.G. AND ANNANDALE, J.G., Unpublished (a). Water use of five perennial subtropical grasses at four levels of water availability.

MARAIS, D., RETHMAN, N.F.G. AND ANNANDALE, J.G., Unpublished (b). Dry matter yields of five grass species at four levels of water availability.

MOOLMAN, C.P., 1993. The influence of water stress on two *Cenchrus ciliaris* cultivars. MSc(Agric) Dissertation. University of the Orange Free State.

NG, T.T., WILSON, J.R. AND LUDLOW, M.M., 1975. Influence of water stress on water relations and growth of a tropical (C_4) grass, *Panicum maximum* var *trichoglume*. *Australian Journal of Plant Physiology*, 2, 581-595.

OPPERMAN, D.P.J., HUMAN, J.J. AND VILJOEN, M.F., 1977. Evapotranspiration studies on *Themeda triandra* FORSK. under field conditions. *Proceedings of the Grassland Society of Southern Africa*, 12, 71-76.

SAEED, I.A.M. AND EL-NADI, A.H., 1997. Irrigation effects on the growth, yield, and water use efficiency of alfalfa. *Irrigation Science*, 17, 63-68.

SAS INSTITUTE INC., 1996. The SAS system for Windows. SAS Institute Inc. SAS Campus drive, Cary, North Carolina, USA.

SNYMAN, H.A., 1989. Evapotranspiration and water-use efficiency of different grass species in the central Orange Free State. *Journal of the Grassland Society of Southern Africa*, 6, 146-151.

SNYMAN, H.A., 1994. Evapotranspiration, water use efficiency and quality of six dryland planted pasture species and natural vegetation, in a semi-arid rangeland. *African Journal of Range and Forage Science,* 11, 82-88.

SNYMAN, H.A., OPPERMAN, D.P.J. AND VAN DEN BERG, J.A., 1980. Hydrological cycle and water use efficiency of veld in different successional stages. *Proceedings of the Grassland Society of Southern Africa*, 15, 69-72.

SNYMAN, H.A., VENTER, W.D., VAN RENSBURG, W.L.J. AND OPPERMAN, D.P.J., 1987. Ranking of grass species according to visible wilting order and rate of recovery in the central Orange Free State. *Journal of the Grassland Society of Southern Africa*, 4, 78-81.

STANHILL, G., 1986. Water use efficiency. *Advances in Agronomy,* 39, 53-85.

STOUT, W.L., 1992. Water-use efficiency of grasses as affected by soil, nitrogen and temperature. *Soil Science Society of America Journal*, 56, 897-902.