CHAPTER 8

THE EFFECT OF WATER AND NITROGEN AVAILABILITY ON THE YIELD AND WATER USE EFFICIENCY OF THREE SUB-TROPICAL PERENNIAL GRASS SPECIES

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Abstract

The effect of three levels of water availability and four levels of nitrogen on the yield and water use efficiency of three subtropical perennial grasses (*Cenchrus ciliaris, a Cynodon* hybrid and *Pennisetum clandestinum*) was evaluated in a pot trial in a greenhouse at the University of Pretoria. The three levels of water availability were: soil profile brought to 33 (W1), 66 (W2) and 100% (W3) of field capacity twice per week. The grasses also received four levels of nitrogen namely: N0 = 10 kg N ha^{-1}, N1 = 80 kg N ha^{-1}, N2 = 160 kg N ha^{-1} and N3 = 280 kg N ha^{-1}.

The *Cynodon* hybrid used significantly ($P \leq 0.05$) less water than *C. ciliaris*, but was able to produce significantly ($P \leq 0.05$) the highest yields in this trial . As was expected, the grasses tended to use more water and produce higher yields as the level of nitrogen was increased. All three grasses tended to produce higher yields at

the N3 level than at the N0 level, despite restricted water supply. Where water availability is thus restricted, nitrogen should still be applied. The amount of nitrogen will, however, be determined by the economic return. The economics are emphasized when comparing the yields at W2 and W3, regardless of the amount of nitrogen applied. The yields at these two levels of water availability were similar and diminishing increases in yield may lead to a drop in profit.

Water use efficiency was improved with increased amounts of nitrogen, but was not significantly ($P \leq 0.05$) different at the N2 and N3 levels of nitrogen. This demonstrates that even a little nitrogen can increase the WUE, while WUE may not be negatively affected if a high level of nitrogen availability is not maintained.

The root systems of all three grass species tended to be weaker under W1 than W2 and W3 conditions, with that of the *Cynodon* hybrid being the poorest. The root systems also tended to be stronger with N2 and N3 than with N0 and N1 levels of nitrogen, regardless of the amount of water applied.

Keywords

Cenchrus ciliaris, Cynodon hybrid*, Pennisetum clandestinum*, nitrogen, water, water use efficiency

8.1. Introduction

In a field trial with small plots under a rainshelter (Marais *et al.*, unpublished (b)), it was found that grasses receiving adequate amounts of water (100% of field capacity) (W4) on a weekly basis often produced less dry matter than the grasses receiving 25% less water (75% of field capacity) (W3). It was speculated that the grasses with adequate amounts of water, were not receiving enough nitrogen to satisfy the N demand under these ideal growing conditions. To verify this, a pot trial was conducted where combinations of water availability and nitrogen supply were applied to three of the grass species.

The hypotheses for this investigation were that:

- the grasses would produce the highest yields at the highest level of water and nitrogen availability;
- the grasses would have better water use efficiencies under water limiting than non-limiting conditions and
- the grasses would have better water use efficiencies under non nitrogen limiting than nitrogen limiting conditions.

8.2. Materials and Methods

Three subtropical perennial grasses were established in 5ℓ pots filled with soil from the experimental farm (Red Hutton) (MacVicar *et al.*, 1991) and placed in a glasshouse situated on the Hatfield Experimental Farm, Pretoria, (25˚45'S, 28˚16'E), South Africa, during the 2002/2003 growing season. The trial ended in June 2003. The grass species used in this trial were *Cenchrus ciliaris* (Blue buffel-grass, cv. Molopo), a *Cynodon* hybrid cv. Coastcross II (K11) (Coastcross bermudagrass), and *Pennisetum clandestinum* (Kikuyu, cv. Whittet).

Before the start of the trial, the water holding capacity of the soil was determined after the plastic pots were filled with 5kg of air dry soil. Small pieces of shade cloth were placed over the holes in the pots to prevent the soil from spilling, but did allow for drainage. After weighing, the pots were watered with enough water to saturate the soil, before covering it with plastic bags to prevent evaporation. The pots were then left for two days, weighed again, left for another 12 hours and weighed again to ensure that field capacity had been reached. The difference in weight then represented the amount of water that would be needed to bring the soil to field capacity.

During June 2002, seeds of *C. ciliaris* and *P. clandestinum* were sown in seedling trays and kept in the glasshouse till October 2002. The *Cynodon* hybrid was established from vegetative material collected on the experimental farm.

During October 2002 the seedlings were transplanted (1 plant per pot) to 5ℓ pots with the soil brought to field capacity. For the first month the plants were irrigated on a regular basis to ensure good establishment. From November 2002, the pots were differentially watered, twice a week, as follows:

- W1 - received 33% of the amount needed to restore field capacity
- W2 - received 66% of the amount needed to restore field capacity
- W3 - was brought back to field capacity

The plants were cut back to a height of 10 cm for C. ciliaris and 5 cm for the *Cynodon* hybrid and *P. clandestinum*, as soon as they started to flower (*C. ciliaris* and the *Cynodon* hybrid) or when they reached a height of 25 cm (*P. clandestinum*). This resulted in harvests every four to five weeks. The harvested material was dried to a constant mass for 48 hours at 65˚C.

At planting, during October 2002, each pot received N , P (75mg P per pot) and K (250mg K per pot). The amount of P and K were based on advice from a [1]Plant Nutritionist. The amounts of N applied were 10 kg N ha^{-1} for N0 and N1 treatments, 20 kg N ha^{-1} for the N2 and 40 kg N ha^{-1} for the N3 treatments respectively. After each cut, nitrogen was applied at the following rates:

- N0 - control - received no nitrogen, apart from the initial application of 10 kg N ha^{-1} at planting
- N1 - received 10 kg N ha^{-1} at planting and after each cut
- N2 - received 20 kg N ha^{-1} at planting and after each cut
- N3 - received 40 kg N ha^{-1} at planting and after each cut

The grasses were cut seven times during the trial period resulting in total applications of 10 kg N ha^{-1}, 80 kg N ha^{-1}, 160 kg N ha^{-1} and 280 kg N ha^{-1} respectively for the N0, N1, N2 and N3 treatments over the growing season. The fertilizers used were limestone ammonium nitrate (LAN) (28.0% N), superphosphate (8.3% P) and potassium chloride (KCl) (50.0% K).

A fully randomized block design with 10 replications was used. The statistical analysis was done with 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

[1] Personal communication: Prof AS Claassens, Department of Plant Production and Soil Science, University of Pretoria, Pretoria, South Africa.

presented in the Appendix (Tables A8.1 - A8.6).

8.3. Results

8.3.1. Water use

The water use for this trial represented the total amount of water evapotranspired over the experimental period expressed as ℓ per pot (Figures 8.1 - 8.3).

The treatments received and used significantly ($P \leq 0.05$) different amounts of water, with treatment W1 using the least and W3 using the most water (Figure 1). As with the earlier rainshelter trial (Marais *et al.*, unpublished (b)), the W1 and W2 treatments lost respectively more than the 33 and 66% water allocated to them, by tapping into water reserve created at the beginning of the trial when the soil in all pots was brought to field capacity. This higher water loss may be attributed to higher evaporation losses due to smaller plants in these two treatments.

More water was used with higher rates of nitrogen fertilization (Figure 8.2), with N0 and N1 using the least and N3 the most water. The water use of N0 plants did not differ significantly ($P \geq 0.05$) from that of N2 plants. This may again be attributed to higher water loss through evaporation due to smaller plants.

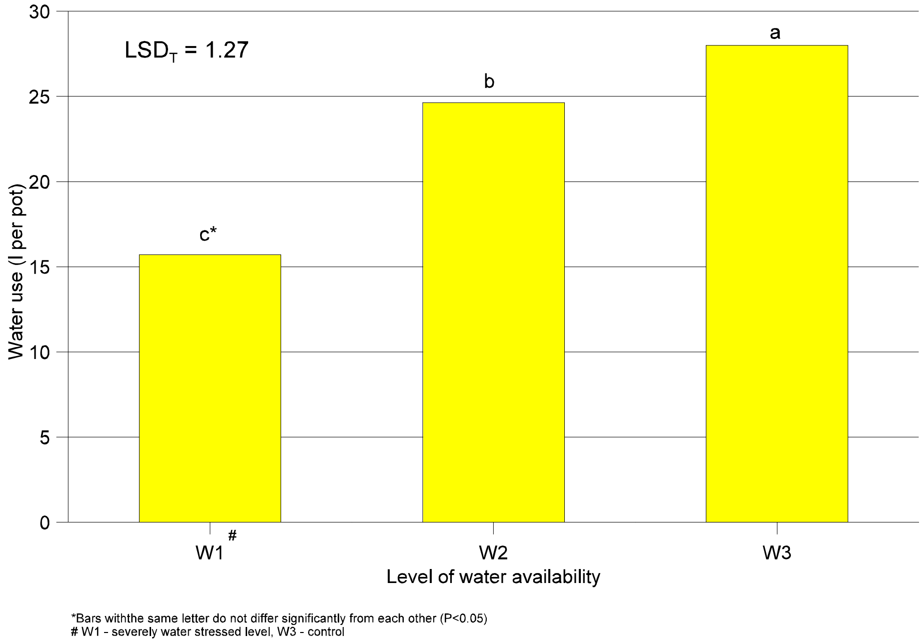


Figure 8.1 Average water used at three levels of water availability.

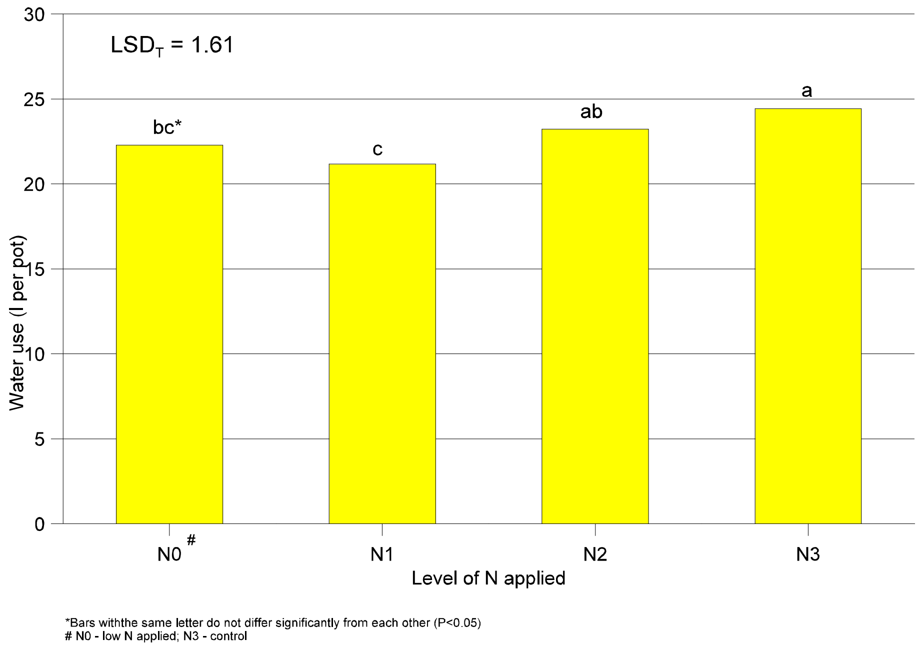
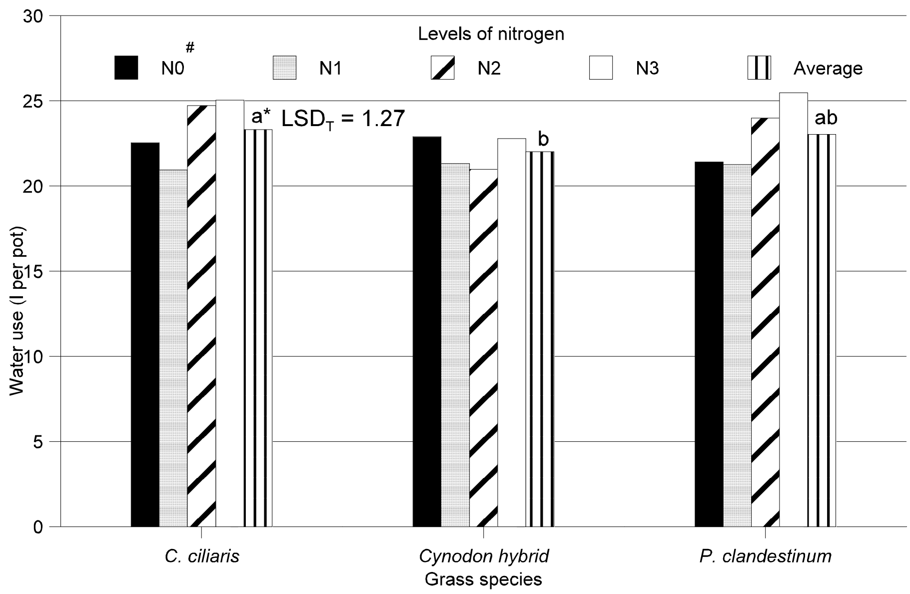


Figure 8.2 Average water use at four levels of nitrogen fertilization.

Only the average water use of *C. ciliaris* and the *Cynodon* hybrid differed significantly (P≤0.05) from each other with the *Cynodon* hybrid using the least and *C. ciliaris* the most water (Figure 8.3). These results are similar to the results reported in an unpublished article by Marais *et al.,* (a) in a rainshelter trial. There was a significant (P≤0.05)species x nitrogen interaction with *C. ciliaris* and *P. clandestinum* tending to use more water at higher applications of nitrogen (Figure 8.3). For the *Cynodon* hybrid there was, however, no clear tendency.



*Bars, representing the average water use, with the same letter do not differ significantly from each other (P<0.05)
N0 - low N applied; N3 - control

Figure 8.3 The average water use of three grass species over all levels of water and nitrogen, as well as the water use of three grass species at four levels of nitrogen.

8.3.2. Dry matter yield

The dry matter yield is the cumulative yield of seven cuttings taken over the 2002/2003 growing season and is presented as dry matter yield per plant in Figures

8.4 - 8.7.

As also reported by Marais *et al.*, (unpublished (a)) the two treatments receiving the most water (W2 and W3), produced yields which were not significantly ($P \geq 0.05$) different from each other (Figure 8.4), but which were significantly ($P \leq 0.05$) higher than the treatment receiving the least water (W1).

When the dry matter yields are presented as averages of the different levels of nitrogen applied (Figure 8.5), the grasses receiving the most nitrogen (N3) produced significantly ($P \leq 0.05$) more dry material than the other three nitrogen treatments. Treatment N0, receiving the least amount of nitrogen, produced significantly ($P \leq 0.05$) the least dry matter with no significant ($P \geq 0.05$) difference in the dry matter yields produced at the N1 and N2 levels.

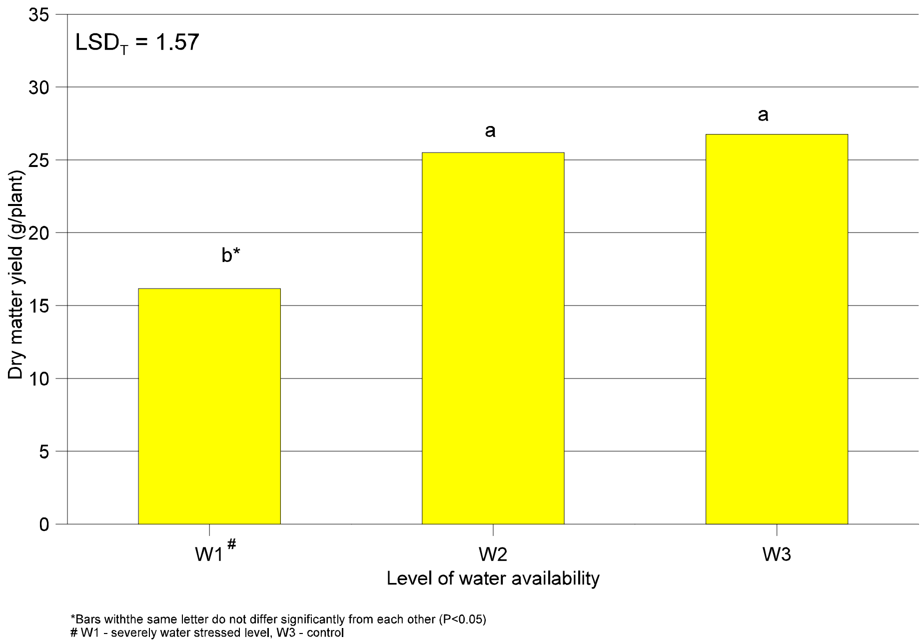


Figure 8.4 Average dry matter yield per plant as affected by three levels of water availability.

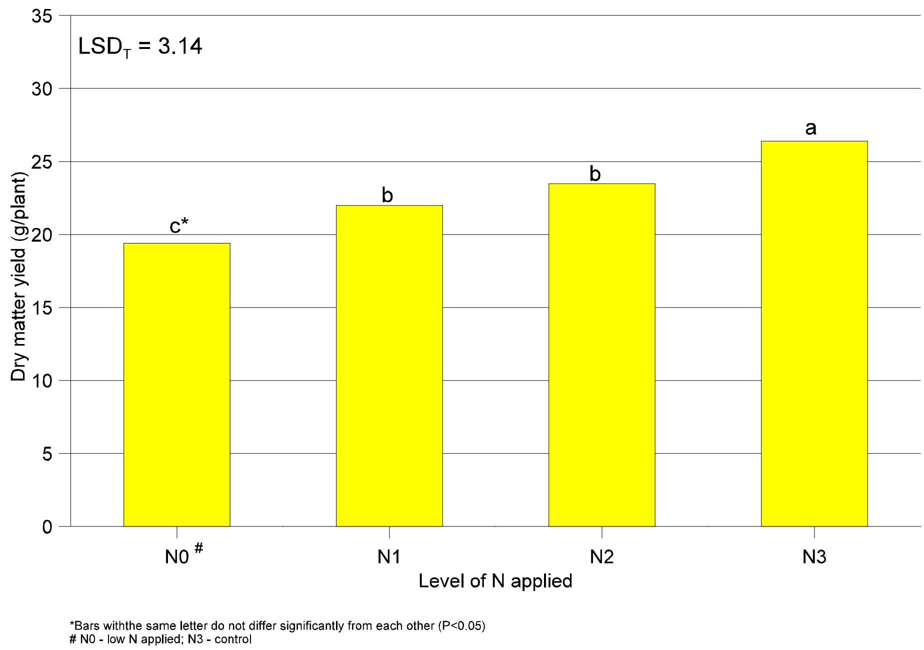


Figure 8.5 Average dry matter yield per plant as affected by four levels of nitrogen.

The average dry matter yield of the three grass species over three levels of water availability and four levels of nitrogen, differed significantly ($P \leq 0.05$) from each other (Figure 8.6). The *Cynodon* hybrid produced significantly ($P \leq 0.05$) the highest and *P. clandestinum* significantly ($P \leq 0.05$) the lowest yields in this trial. In the rainshelter trial, reported by Marais et al. (unpublished (a)) *P. clandestinum* also produced significantly ($P \leq 0.05$) the lowest yields in both seasons, but the ranking order of the *Cynodon* hybrid and *C. ciliaris* differed in the two experimental seasons.

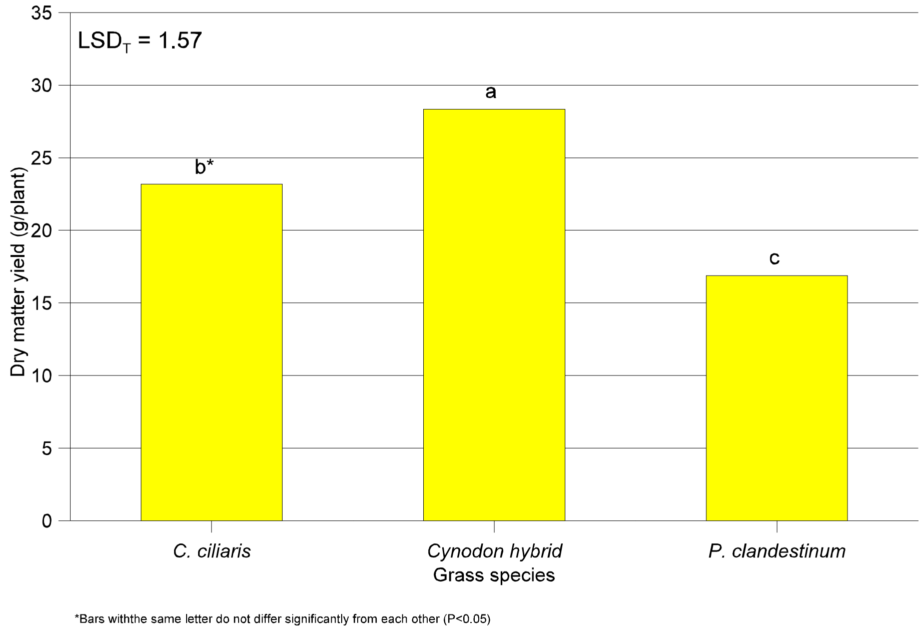


Figure 8.6 Average dry matter yield of three grass species over all levels of water availability and nitrogen.

There was a significant ($P \leq 0.05$) water x nitrogen x species interaction (Figure 8.7), which can be summarised as follows:

- For *C. ciliaris* there was a tendency for higher yields with increased amounts of nitrogen where the grasses received the lowest amount of water (W1) during the season. There was, however, no such tendency for the *Cynodon* hybrid and *P. clandestinum*, although these grasses did produce higher yields at the highest levels of applied nitrogen (N3), as compared with plants receiving the least (N0) nitrogen, when subjected to low levels of water (W1).
- The dry matter yields of the *Cynodon* hybrid at the W2 and W3 treatments, regardless of amount of nitrogen applied, were quite similar. This was also true for

C. ciliaris and *P. clandestinum*, with the exception of *C. ciliaris* N2 and *P. clandestinum* N0 and N1.

- *P. clandestinum* tended to produce the lowest, while the *Cynodon* hybrid tended to produce the highest yields, regardless of the amount of water or nitrogen applied.

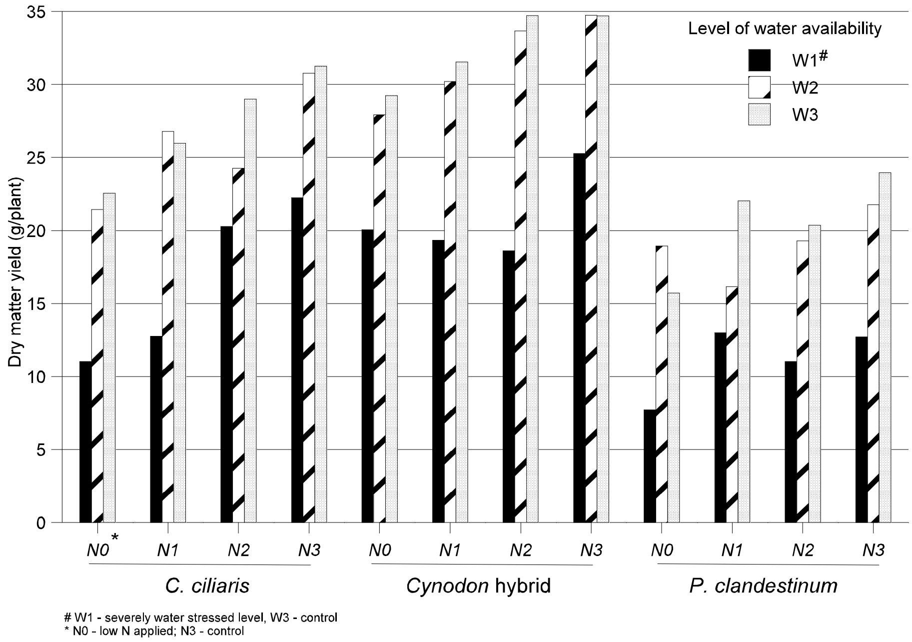
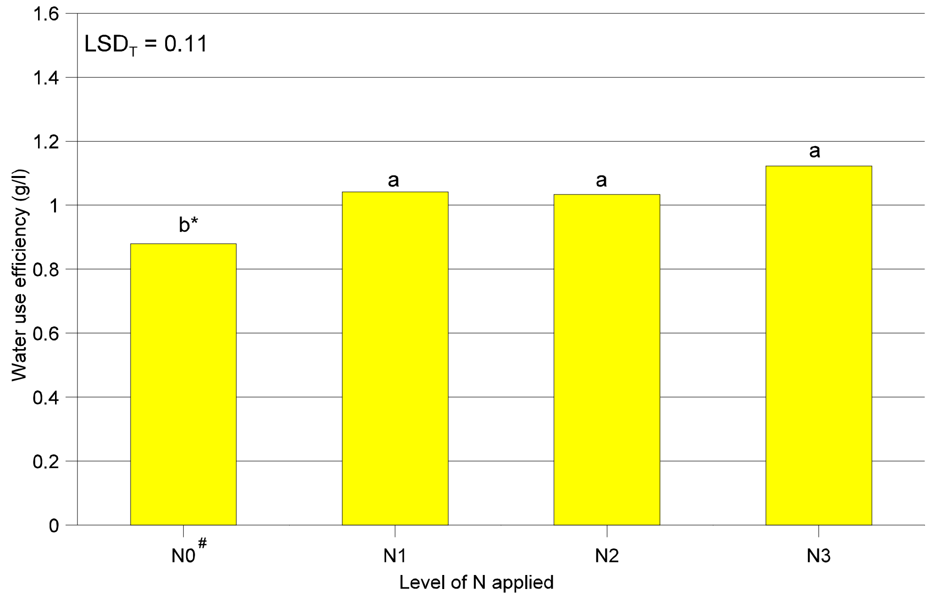


Figure 8.7 Dry matter yield of three grass species as affected by three levels of water availability and four levels of nitrogen.

8.3.3. Water use efficiency (WUE)

The water use efficiencies (WUE) of the grasses are presented as the amount of dry matter produced per litre of water used (Figures 8.8 - 8.10).

The average WUE, as effected by nitrogen level (Figure 8.8), tended to increase with the more nitrogen applied. Despite this, the WUE of the grasses at the N1, N2 and N3 levels did not differ significantly (P$\geq$0.05) from each other, although they differed significantly (P$\leq$0.05) from the N0 treatment.



*Bars withthe same letter do not differ significantly from each other (P<0.05)
N0 - low N applied; N3 - control

Figure 8.8 Average water use efficiency as affected by four levels of nitrogen.

The *Cynodon* hybrid used water significantly (P$\leq$0.05) more efficiently than the other grasses, followed by *C. ciliaris* and *P. clandestinum* (Figure 8.9). The WUE of *P. clandestinum* was particularly low in comparison to that of the *Cynodon* hybrid, which was also true for the rainshelter trial (Marais *et al.*, unpublished (c)).

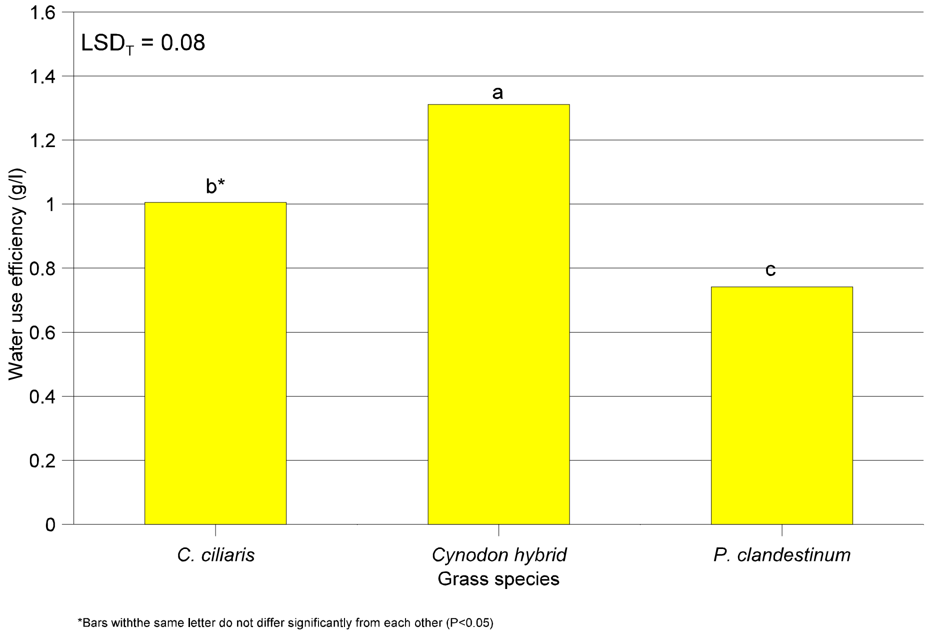


Figure 8.9 Average water use efficiency of three grass species as affectec by water availability and nitrogen.

The grasses (especially the *Cynodon* hybrid) tended to use water more efficiently at lower levels of water availability (W1 and W2) regardless of the amount of nitrogen applied (Figure 8.10). The exception to this trend being the *P. clandestinum* N1 treatment.

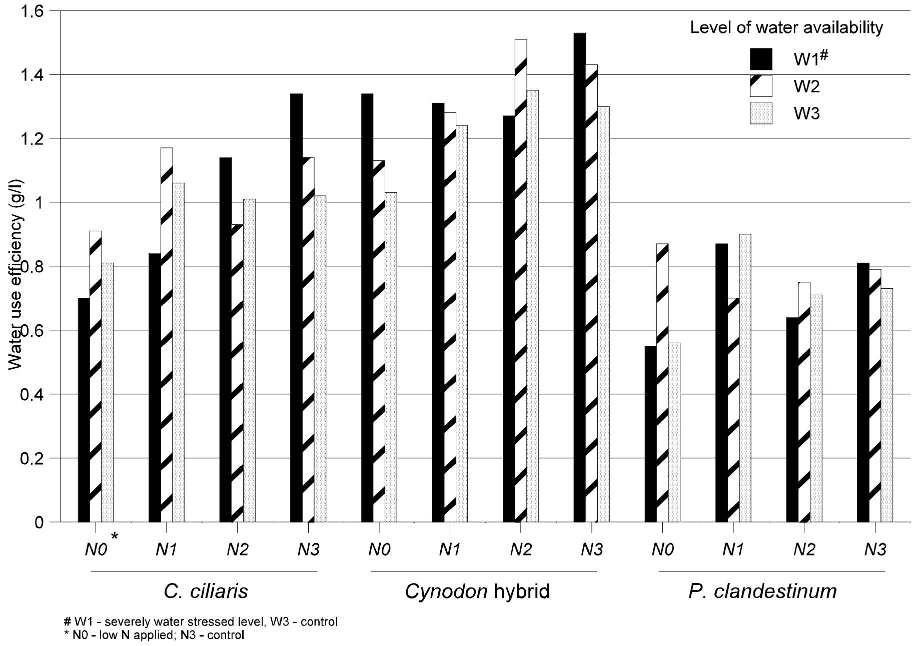


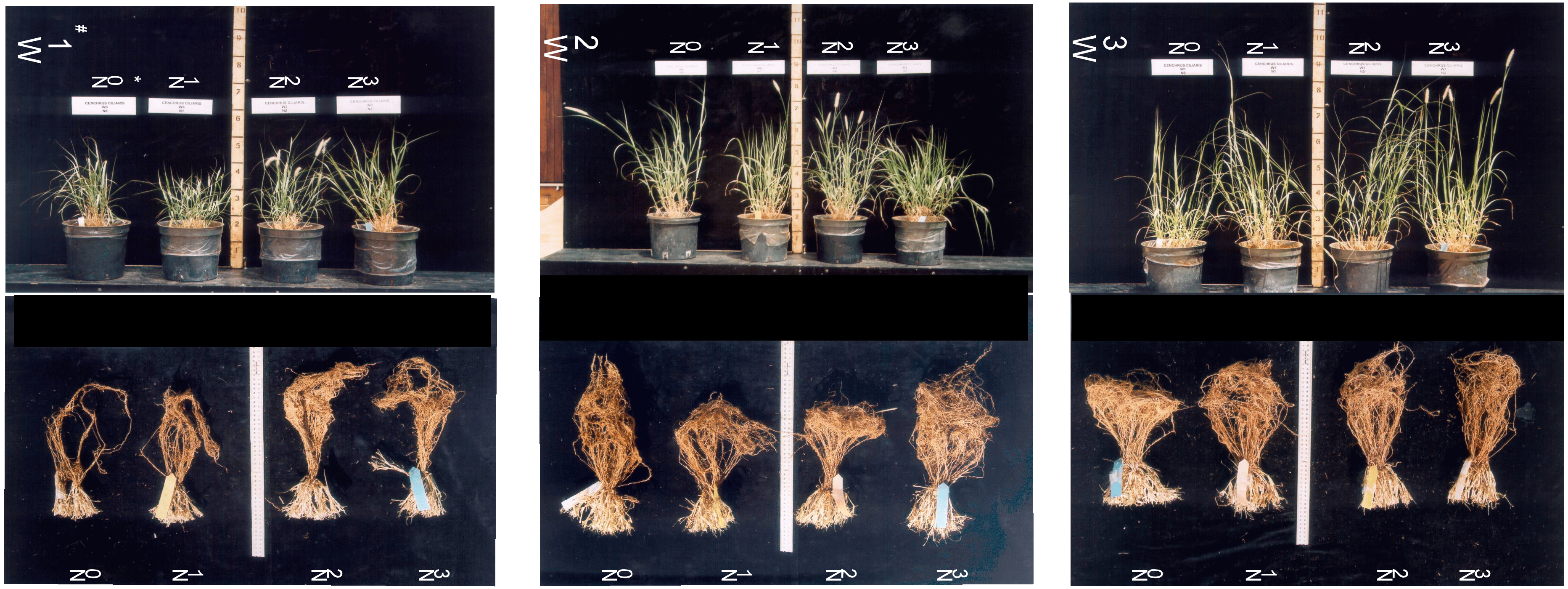
Figure 8.10 Water use efficiency of three grass species as affected by three levels of water availability and four levels of nitrogen.

8.3.4. Above and below ground production

Visually there was little difference between the W2 and W3 plants of all three grass species (Figures 8.11 - 8.13), with W2 plant often looking better than the W3 plants. The W1 plants, however, were notably smaller.

The same trend was evident in the root systems (Figures 8.11 - 8.13). W2 and W3 root systems did not differ much, with W2 root systems often appearing better than those of W3 plants. The W1 root systems was notably poorer than those of the other two levels of water availability. The root system of the *Cynodon* hybrid at W1 was the poorest of the three grass species.

With respect to the above ground components it was not always clear what the effect of the nitrogen was, but for the root systems it was clearer. The roots tended to become much more branched with N2 and N3 than with N0 and N1 levels of nitrogen. This was, furthermore, more pronounced at the W1 and W3 than the W2 treatments.



#W1, severe water stress; W3, control
*N0, no N applied; N3, control

Figure 8.11 A difference of three levels of water availability and four levels of nitrogen on the above and below ground growth of *C. ciliaris*.


W1 #
N0 *
N1
N2
N3
W2
N0
N1
N2
N3
W3
N0
N1
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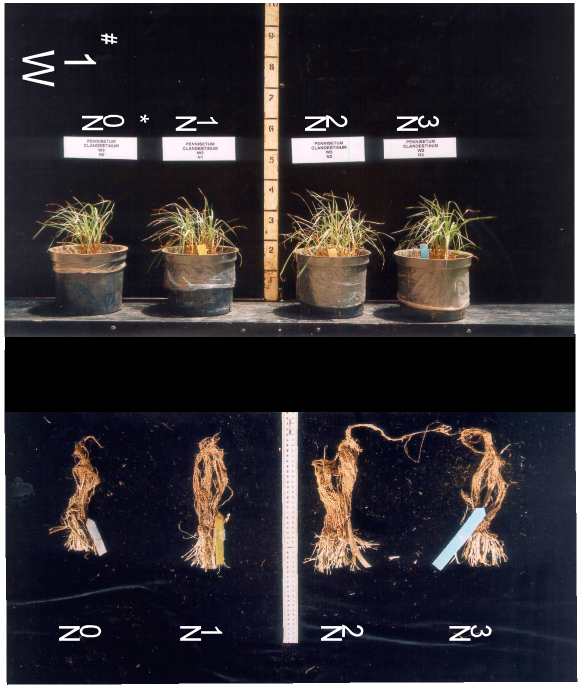

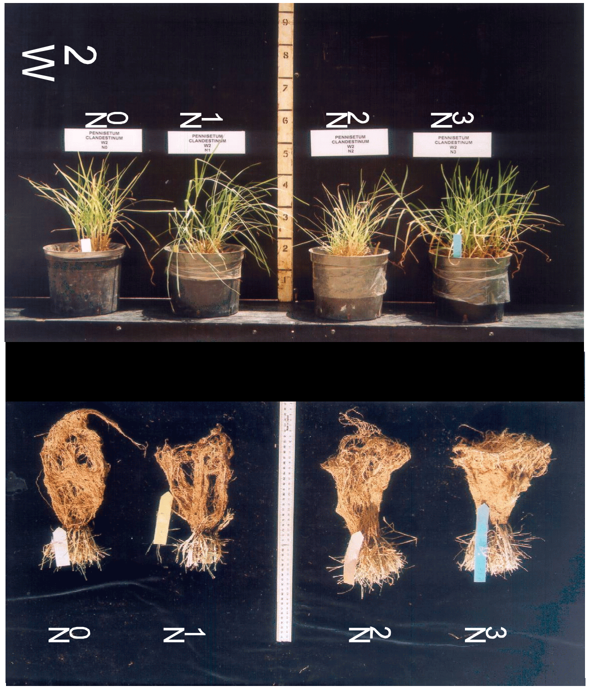

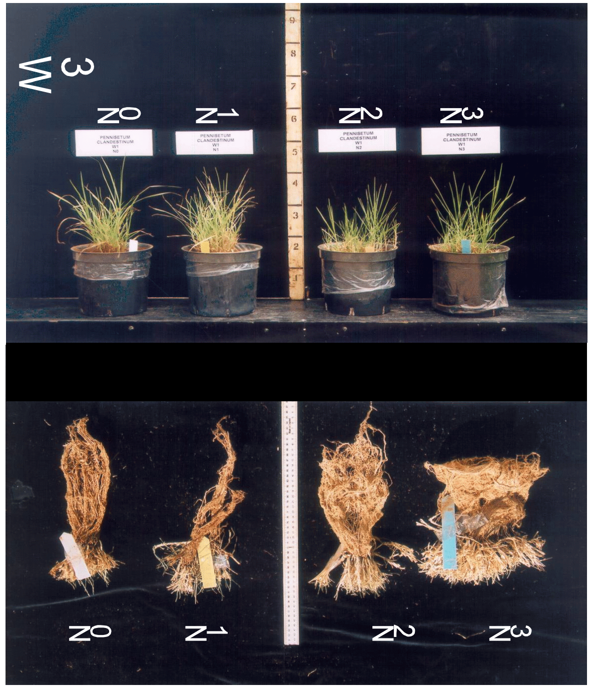

#W1, severely water stressed level, W3, control
*N0, no N applied, N3, control

Figure 8.13 Affect of three levels of water availability and four levels of nitrogen on the above and below ground growth of *P. clandestinum*.

8.4. Discussion and Conclusions

The beneficial effect of nitrogen on dry matter production is well documented (Olsen, 1972; 1974; Mathias *et al.*, 1973; Whitney, 1974(a); 1974(b); Kathju *et al.*, 1979; Monson & Burton, 1982; Cook & Mulder, 1984; Miles, 1991; 1997; Pieterse *et al.*, 1997; Pieterse & Rethman, 1999). In this trial the highest yields were most often recorded with the highest amounts of water and nitrogen applied, but did not differ significantly ($P \geq 0.05$) from plants receiving a little less water and nitrogen. This has significant applications when determining the economic feasibility of production systems.

These results also shed some light on the yields obtained in the rainshelter trial (Marais *et al.*, unpublished(a)). The yields under the rainshelter tended to be higher under slight water limitations than under non-water limiting conditions. It was speculated that a nitrogen deficiency could have been the cause for this lower than expected yields. In the pot trial, the same trend was followed, non-significant ($P \geq 0.05$) differences between the yields at slight and non-water limiting conditions, receiving the highest amount of nitrogen. This might imply that under these conditions the grasses have reached their optimum production potential where not even the addition of more water and or nitrogen could increase it. Another explanation might be the lack of other limiting growth factors which are not as obvious to detect.

Water use efficiency is usually improved by adding nitrogen to the system (Mathias *et al.*, 1973; Pieterse *et al.*, 1997). Seven out of the twelve treatment combinations showed better WUE under water limiting than with adequate amounts of water available. In this trial the addition of nitrogen, thus had a positive effect on the WUE, but above a certain level, the increase became insignificant.

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