WATER USE AND WATER USE EFFICIENCY OF FODDER CROPS UNDER IRRIGATION: PART 1 - ANNUAL SUBTROPICAL CROPS.

BY

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The members of the steering committee were:

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EXECUTIVE SUMMARY

Natural resources should be managed in a responsible way to ensure sustainable production of food, feed and other crops. In South Africa, before 1988, little was known on the water requirements of planted pastures. Applicable norms for irrigation scheduling were not in place and this resulted in ineffective use of irrigation water. To obtain a better idea of planted pasture water use, a project was started in 1988 with temperate fodder crops followed by tropical and subtropical fodder crops in 1993. This study was made possible with financial aid from the Water Research Commission.

The objectives of this project were to compare different pastures to determine if a single set of irrigation guidelines could be used for all pastures; to determine the water production functions as a tool to determine the economic optimum irrigation level for the different crops and to identify alternative crops, best suited for dryland and irrigation conditions.

The water use of five annual subtropical crops was determined in two consecutive seasons in a trial conducted under a rain-shelter on the Hatfield Experimental Farm of the University of Pretoria, Pretoria. The crops used were soybean, cowpeas, maize, fodder sorghum and pearl millet. Each crop was subjected to four irrigation levels, ranging from a stressed (W1) to a well watered control (W4).

Maize had the highest yield potential under control (W4) conditions to moderate

water stress (W2 and W3), but under severely stressed conditions (W1) fodder sorghum and pearl millet tended to have the highest yields. This might be ascribed to the better drought tolerance of the latter crops. Where water is not a limiting factor, the production of maize can be recommended, but where water is limiting, pearl millet or fodder sorghum might be a better choice.

The legumes gave the lowest yields for all four irrigation treatments in both seasons. Soybean had a higher yield than cowpeas at all four irrigation levels. These low production figures may, at first glance, make the viability of legume production questionable. It is, however, very important to evaluate crops in terms of both quantity and quality, before discarding one or more as inferior.

The crude protein content of legumes, especially cowpeas (18%), was relatively high in comparison with grasses (average of 8.4%). From the literature it has been concluded that the presence of plant protein in animal diets can result in a more efficient use of non-protein nitrogen sources (NPN), such as urea. There were, however, no advantages in using animal protein rather than plant protein. With the production of plant proteins, the farmer has the additional advantage of carbohydrates, which are not available in either NPN or animal protein. Where livestock farmers need a protein source for the optimal utilisation of a low quality forage, the planting of legumes can, therefore, be recommended, despite a relatively low yield potential.

There were no significant differences in digestibility between cowpeas, pearl millet, fodder sorghum and soybeans, although maize was the most digestible. The high digestibility of maize can be attributed to the large proportion of grain in the total yield.

Dry matter water use efficiency (WUE_{DM}) of maize was the highest for all the crops in both seasons, while that of cowpeas was the lowest. From the yield data it could not be ascertained whether pearl millet or fodder sorghum was the more drought tolerant. With the aid of WUE_{DM} data, however, this became more apparent. Pearl millet had a better WUE_{DM} at all irrigation levels. Under severe stress (W1) pearl millet had a markedly better WUE_{DM} than fodder sorghum. It may, therefore, be concluded that pearl millet would be a better choice under severe stress conditions than fodder sorghum, and definitely a better choice than maize. From a comparison between the WUE_{DM} of soybean and cowpeas, one might expect soybeans to do better than cowpeas in drought conditions.

Also of importance is the influence of irrigation level on the WUE_{DM} of the crops. Although there was only a significant interaction in the 1994/95 season, water was used more efficiently at the W1 and W2 irrigation levels than under well watered conditions.

Water use efficiency was also given in terms of digestible dry matter (WUE_{DDM}) and crude protein dry matter yield (WUE_{CP}). As could be expected, the WUE_{DDM} followed much the same trend as that of WUE_{DM}. In the case of WUE_{CP} , the legumes used water far more efficiently than in terms of dry matter or digestible dry matter than the grasses.

From the information gathered during this trial, it was evident that all five annuals have the potential to develop a deep root system (between 800 and 1 200 mm) when deficit irrigation treatments (W1, W2 and W3) are applied. Using deficit irrigation also resulted to higher water use efficiencies. Following the W1 irrigation level can not, however, be advised, due to the marked reduction of yield. Following a W2 and W3 irrigation regime could, however, save water without compromising yield too much . These irrigation regimes can, however, not be followed without knowing the soil water content. Usage of tensiometers, neutron probes and other instruments together with climatic data should, therefore, form the basis of decision making.

This study was conducted on a relatively small scale and did not include different cultivars, soil types, irrigation systems and climatic conditions. These variables influence evaporation, transpiration, drought tolerance and ultimately the quantity and quality of product produced. This emphasizes the importance of scheduling methods, including models, to take advantage of available water.

Maize should rather be planted under conditions where water is not limiting, while fodder sorghum and pearl millet are better choices where fodder is being produced in areas where limited water is available. Soybeans should rather be cultivated under the same conditions as maize, although they do not give the same yields. For a good quality feed, both highly digestible and protein rich fodder is needed.

Combining one of the grasses and soybean should thus give excellent results. Cowpeas, on the other hand, used the least water in both years, but also gave the lowest yields. The crude protein content of this crop, however, surpasses that of the other crops evaluated and should be kept in mind when protein need, rather than energy, is of major importance.

According to an economic analysis, done with the IrriCost and FARMS models by Prof Meiring and Mr Botha, it is more expensive, in terms of specified cost per ton dry matter as well as millimetre water, to produce any of the five crops under severe drought (W1) than control (W4) conditions. The assumption was, however, made that none of the treatments would receive any rain in an on-farm situation, but that all the water would be supplied through the irrigation system. This assumption was made to make extrapolation of this data possible.

The cash flow closing balance (R ha^{-1}) is negative for all the treatments due to a zero starting balance. Despite this, the cash flows for the severely water stressed treatments (W1) were better than that of the control (W4).

CHAPTER 1

INTRODUCTION AND LITERATURE STUDY

1.1 Introduction

South Africa is known as a dry country, where the potential evaporative losses are three to four times the annual precipitation. The generally low rainfall goes hand in hand with intense thunderstorms which result in excessive runoff, thereby decreasing the effectivity of rainfall.

On intensive livestock farms, subtropical pastures are being used extensively to fulfill the fodder needs of the animals (Heard, Tainton & Edwards, 1984a,b). A large percentage of these pastures are under irrigation, due to the high production potential of subtropical grasses. Subtropical grasses can, for example, produce two to three times as much dry matter as temperate grasses (Grunow & Rabie, 1985). An additional advantage of irrigating subtropical grasses is that peak production and a good quality fodder can be produced earlier in the season (Grunow & Rabie, 1985).

In South Africa close to 200 000 ha are planted to irrigated pastures (Steynberg, Nel & Rethman, 1993), with an annual potential use of 10^9 m^3 of irrigation water. With initiatives to remove pressure from veld and marginal maize fields, more and more irrigated planted pastures are being established, which increases the need for irrigation water. An increase in water use efficiency of only a few percentage points can make substantial volumes of water available for other uses. To increase water use efficiency the whole system needs to be taken in consideration. This includes the soil, climate and plant. Knowing the plant and its responses to a given water supply is a big step in using water more efficiently. This report will examine the five crops used in this trial, nl maize, fodder sorghum, pearl millet, cowpeas and soybean.

1.2. Literature study

This background information gives an overview of the status and use of the five crops as fodder in different parts of the world, as well as the variability of production due to different growing as well as water supply conditions.

1.2.1. Maize (*Zea mays* L.)

Maize originated from Mexico, and is an annual grass. Maize differs from other grasses in the sense that it is monoecious and has both female and male reproductive parts on the same plant, but not in the same flower as in the case of pearl millet and fodder sorghum. The result of pollination is a caryopsis (grain fruit) which is a staple food crop in Africa.

Although maize is known mainly as a food crop in Africa, it is also extensively used as animal feed. We should not, therefore, think only of the use of maize meal or grain, but of the whole plant. The plant material acts as a source of crude fibre, which can be given to animals as hay (with or without grain) or silage (whole plant). Although ensiling is more expensive than feeding the plants on the field, silage has the advantage that a high quality feed is available later in the season when the quality of the pasture or rangeland is declining (Van Pletzen & Oosthuizen, 1983).

The digestibility of maize can vary from 91.9 % for the grain (Esterhuyse, 1990) to as low as 41.3 % for the whole plant (Schoonraad, 1985) and 41.1 % for the stem (Esterhuyse, 1990). Crude protein contents of 11.9 % for the whole plant (Anonymous, 1994) to as low as 0.8 % for the cob (Esterhuyse, 1990) are given in the literature.

The differences in quality, given by different authors, may be due to different analytical methods, cultivars, soil fertility status, time of harvest, temperatures, etcetera. Despite these differences, general conclusions may be drawn. It appears that the grain is the most digestible component, followed by the leaves, stem and the cobs. The same may be noted for crude protein content. The grain contains the highest amount of protein and the cobs the lowest. When examining the digestibility of the whole plant, it is evident that the grain component plays an important role in determining the overall quality of the plant.

As with fodder quality, information on the variability in yield of maize, is to be found in the literature. In Table 1, some of these yields for maize fodder are summarised.

Table 1. Total above-ground dry matter yields of maize as reported in the literature.

Water use or Precipitation * (mm)	Plant density (1 000 plants ha^{-1})	Yield (t ha^{-1})	Locality	Reference
565 (Water use)	53	20.1	Manhattan & Tribune (Kansas)	Hattendorf, Redelfs, Amos, Stone & Gwin (1988)
558 (Precipitation)	35	7.5	Middelburg (MP) (RSA)	Van Pletzen, Meissner & Laas (1991)
526 (Precipitation)	50-80	15-17.5	Aurora (New York)	Graybill, Cox & Otis (1991)
390-535 (Water use)	22-32	6.3-12.6	Bushlands (Texas)	Eck & Winter (1992)
530 (Precipitation)	49-89	12.4-14.7	Ames (Iowa)	Russell, Irlbeck, Hallauer & Buxton (1992)
289-607 (Water use)	79	8.5-18	Salisbury (North Carolina)	Wagger & Cassel (1993)

* Water use = precipitation, irrigation and evaporative losses from soil were measured.
Precipitation = precipitaton and irrigation without measuring evaporative losses.

Transpiration and evaporation play a major role in water loss from the soil. Both processes are influenced by radiation, temperature, vapour pressure, wind and soil water content, and one must thus keep this in mind when interpreting the results presented in Table 1. Although the trial in Middelburg received more precipitation than the ones in Aurora and Ames, a part of that precipitation was in the form of hail and resulted in a reduction in yield. The distribution of precipitation is also critical and not only the total.

The variability in yields, despite similar water uses or precipitation, emphasizes the difficulty in extrapolating data to other areas. This emphasizes the need to develop models which incorporate this variability.

1.2.2. Fodder sorghum (*Sorghum x Sudangrass*)

According to Boonman (1993) the Sorghum genus originated from North East Africa, with special reference to Ethiopia. Unlike maize, fodder sorghum plants tend to be weak perennials.

Due to the genetic improvement of maize, sorghum has lost a lot of ground against maize as grain crop in Africa. Genetic improvement of maize has made it more resistant to certain diseases and insects and it also needs less care in storage than sorghum.

The National Research Council (1996) named sorghum as one of Africa's lost crops, due to the huge potential of sorghum that has been under-utilized. The ability of sorghum to survive severe droughts, makes this crop ideal for cultivation in drought prone areas around the world. Although sorghum is struggling to replace maize as a staple grain crop, it is being cultivated on an increasing scale as a fodder crop.

As forage, sorghum has one major limitation. This is the occurrence of prussic acid poisoning of livestock. The build-up of cyanide in the plants is, however, related to genotype, and cultivars have now been developed in which the risk for poisoning is reduced. Boonman (1993) stated that fodder sorghum silage posed less of a risk in this respect, than fresh matter or hay.

Due to a low grain:stem ratio, the quality of fodder sorghum silage is lower than that of maize. To improve the quality, a grain or energy source may be included together with the chopped fodder sorghum. In addition, the inclusion of protein, Ca, P and vitamin A are often also advised (Boonman, 1993).

The digestibility of fodder sorghum is a little lower than that of maize. The grain component can have a digestibility of up to 85.8% (Esterhuyse, 1990), while that of the stem can be as low as 38.8 % (Esterhuyse, 1990). The grain and leaf components of fresh fodder sorghum are easily digested, while the whole plant digestibility tends to be less than that of maize.

In Table 2 the potential above-ground dry matter yields of fodder sorghum are presented. In comparison to the rainfall / irrigation values of maize, fodder sorghum is more often cultivated under dryland conditions, or in more arid regions than maize. The growing conditions in Botswana were extremely harsh, but the plants could still produce a dry matter yield of 2.7 t ha^{-1}.

Table 2. Total above-ground dry matter yields of fodder sorghum as reported in the literature.

Water use or Precipitation * (mm)	Plant density	Yield (t ha^{-1})	Locality	Reference
401 (Water use)	185 000 plants ha^{-1}	8.6	Bushlands (Texas)	Unger (1988)
555 (Precipitation)	12-15 kg seed ha^{-1}	5.8	Potchefstroom (RSA)	Dannhauser, Drewes, van Zyl & van Rooyen (1990)
320 (Precipitation)	13 000 plants ha^{-1}	2.7	Goodhope (Botswana)	Youngquist, Carter & Clegg (1990)

* Water use = precipitation, irrigation and evaporative losses from soil were measured.
Precipitation = precipitaton and irrigation without measuring evaporative losses.

1.2.3. Pearl millet (*Pennisetum glaucum* (L.) R. Br.)

Pearl millet which originated from the western parts of Africa, possesses a potential which is often not realized (National Research Council, 1996).

Pearl millet is an annual grass (Dickinson, Hyam & Breytenbach, 1990; National Research Council, 1996). It has not, as yet, been much improved by breeding, with the result that maize is being cultivated in regions where pearl millet was previously found.

Pearl millet is also known as a drought tolerant crop, which can give stable yields under severe drought conditions, under which maize would register a complete crop failure. Due to a misconception that pearl millet grain is not palatable, it has, more often than not, been used as fodder.

The fodder qualities of pearl millet are as follows. The digestibility ranges from 67.2% for the whole plant (Dannhauser *et al.*, 1990) to 58% for the stem and leaves (Haasbroek, 1994). The crude protein content can range from as high as 19.2% for the whole plant (Dannhauser *et al.*, 1990), to as low as 8% for the stem (Haasbroek, 1994). In comparison with fodder sorghum, pearl millet tends to have a higher crude protein content.

Complete dry matter yield data for pearl millet is scarce. Only the data from trials conducted by Hattendorf *et al.* (1988) and Dannhauser *et al.* (1990) will thus be presented. At a planting rate of 8 kg seed ha^{-1} and a rainfall of 621 mm the yield was 3 t ha^{-1} (Dannhauser *et al.,* 1990) while with 489 mm and a planting density of 239 000 plants ha^{-1} the yield was 15 t ha^{-1} (Hattendorf *et al.,* 1988).

1.2.4. Soybean (*Glycine max* L. Merr.)

It is not certain where this subtropical legume originated, but it has been speculated that it originated in the eastern parts of Asia and China. In China soybeans were regarded as one of the five "holy" grain crops needed for the survival of the Chinese civilisation (Caldwell, 1973; Duke, 1981).

In China soybeans are used mainly as a food crop, while in America it has been used for many years as a fodder crop. It was only in approximately 1941 that the use of soybean as a food grain started to surpass its use as a fodder crop in America. As fodder, soybean is mainly used in the form of hay or silage. It is often planted together with maize in the field, or included in the silage mixture, to increase the crude protein content and thus the quality of the silage (Caldwell, 1973).

As a crude protein source, soybean can contain as much as 24.6 % crude protein in the pods (Hintz & Albrecht, 1994) and 18.8 % in the whole plant (Hintz, Albrecht & Oplinger, 1992). According to the Food and Agriculture Organization of the United Nations (FAO) (1959) the crude protein content of the grain can range from 18 - 40%.

In Table 3 the above-ground dry matter yields of soybean, at different planting densities and irrigation levels, are presented. From data compiled from 25 countries, where soybean is cultivated, the average dry matter yield is 5.8 t ha^{-1}, with a fresh mass of as high as 30 t ha^{-1} (FAO, 1959). Although very high plant populations are used in soybean fodder production, the resulting yields are relatively low in comparison to that of the grasses. One should, however, be aware that less energy is needed to produce a kilogram of carbohydrates than a kilogram of protein.

Table 3. Total above-ground dry matter yields of soybean as reported in the literature.

Water use or Precipitation * (mm)	Plant density (1 000 plants ha^{-1})	Yield (t ha^{-1})	Locality	Reference
382 497 (Water use)	- -	6.7 9.5	Stuttgart (Arkansas)	Scott, Ferguson & Wood (1987)
541 (Water use)	362	8	Manhattan & Tribune (Kansas)	Hattendorf *et al.* (1988)
437 (Precipitation)	740	7.4	Arlington (Wisconsin)	Hintz *et al.* (1992)

* Water use = precipitation, irrigation and evaporative losses from soil were measured.
Precipitation = precipitaton and irrigation without measuring evaporative losses.

1.2.5. Cowpeas (*Vigna unguiculata* L. Walp.)

Ethiopia is regarded as the region of origin for this legume (Duke, 1981). Cowpeas are today wide-spread in both subtropical and tropical regions of the world.

Not only can the pods be used as food, but the leaves (fresh and dry) and roots may also be used for this purpose. Cowpeas are also commonly used as a fodder crop which may be grazed, or used in hay or silage.

As with soybean silage, the inclusion with a grain crop in the ensiling process is often advised to ensure a high quality silage (Duke, 1981). Nell, Siebrits & Hayes (1992) analysed 150 cowpea samples for crude protein content. The results obtained ranged from 24.5 - 33.9%. The FAO (1959) has reported grain protein contents of ± 24%.

With a reported evapotranspiration of 225 mm, Shouse, Dasberg, Jury & Stolzy (1981) harvested above ground dry material of 5.4 t ha^{-1}, while Duke (1981) reported yields of 5 t dry matter ha^{-1}.

1.3. Motivation and Objectives

In 1988 a lack of information on the water requirements of planted pastures was identified. If norms for irrigation scheduling are not in place this can result in ineffective use of water. To obtain more detailed information on the water use of planted pastures, a long term project was initiated with temperate fodder crops in 1988 (Steynberg *et al.* 1993) followed by tropical and subtropical crops in 1993.

The crops, discussed in the foregoing pages were used in a small plot irrigation trial from 1993 to 1995. The annual crops (Part 1) were followed by perennial fodder crops (Part 2) in 1995. These latter crops will be discussed in Part Two of this Report. The objectives for both annual and perennial subtropical fodder crops were to:

- develop irrigation norms;
- develop water production functions as a tool in the planning of economic optimum irrigation levels;
- identify alternative crops with high water use efficiencies for use under both dryland and irrigated conditions.

CHAPTER 2

GENERAL PROCEDURE

2.1. Trial area, material and design

A randomized block design trial with five species, four levels of irrigation and three replications was established under an automatic rain-shelter. This area was divided into 60 plots, each 2 m x 2.5 m. The roots in each plot were separated from the adjacent plots using asbestos sheets to a depth of 1.2 m. Each plot had a neutron probe access tube to a depth of 1.8 m. These access tubes were situated in approximately the centre of each plot. The soil is a Hutton form, Shorrock series with about 30% clay in the top soil (MacVicar *et al.*, 1991). The soil is uniform for the first 1.2 m, at which depth a characteristic gravel layer is evident.

Five annual subtropical fodder crops were used as trial material. The planting densities of the crops are presented in Table 4.

Cultivars for the different crops (Table 4) were not only chosen on grounds of previous experience. In the case of cowpeas and pearl millet, there was not a large variety to choose from and seed that was available had to be used. According to the Sensako and Pannar cultivar booklets, the three grass cultivars have a wide adaptation range, do well under irrigation and can produce a good quality silage. A limited number of plots were, however, available and more than one cultivar per species could not, therefore, be accommodated. New cultivars might have better characteristics than the ones used in this trial and one should keep this in mind when comparing performance.

Table 4. Planting details of the different subtropical crops under an automatic rain-shelter.

Crop	Cultivar	Plant density/ seeding rate	Row spacing (m)
Maize	SNK 2340	60 000 plants ha^{-1}	0.5
Soybean	Ibis	300 000 plants ha^{-1}	0.5
Cowpeas	Dr. Saunders	40 000 plants ha^{-1}	0.5
Pearl millet	SA Standard	10 kg ha^{-1}	0.5
Fodder sorghum	PAN 888	20 kg ha^{-1}	0.5

All five crops were planted on 16 November 1993. The maize was re-established on 30 November, due to a poor stand. In 1994 the crops were planted on the 1st and 2nd of December.

2.2. Fertiliser application

In both seasons, legume crops were not inoculated with nitrogen fixing bacteria. This was done to prevent possible nitrogen deficiencies which might occur due to poor nitrogen fixation under inflicted drought conditions. The fertilisers used were limestone ammonium nitrate (LAN) (28% N); superphosphate (8.3% P) and potassium chloride (KCl) (50% K).

1993/94 Season

Each plot was fertilised with phosphorus and potassium, according to a soil analysis, conducted prior to spring planting. The aim was to build up a phosphorus status of 40 mg P kg^{-1} and a potassium status of 100 mg K kg^{-1}. In the previous seasons, perennial temperate crops, which included lucerne (*Medicago sativa*) and white clover (*Trifolium repens*), were grown on some of the plots. To minimize a possible carry over from the previous season, wheat was grown during the winter of 1993, without any nitrogen, to try and use up any residual nitrogen in the soil.

At planting in November, the plots received only nitrogen, at a rate of 50 kg N ha^{-1} with no phosphorus nor potassium. Nitrogen was also applied to all plots as a top dressing, on three occasions during the summer growing season at a rate of 56 kg N ha^{-1}.

1994/95 Season

Each plot received the following amounts of fertiliser at planting: 40 kg N ha^{-1}, 40 kg P ha^{-1} and 40 kg K ha^{-1}. After planting, nitrogen was applied at six week intervals as a topdressing at a rate of 40 kg N $ha^{-1,}$ in the form of LAN, to all plots. The total amount of nitrogen applied was as follows: 80 kg N ha^{-1} for cowpeas and 120 kg N ha^{-1} for soybean, maize, pearl millet and fodder sorghum, the difference being due to differences in the growing season of the crops.

2.3. Soil water monitoring and irrigation treatments

1993/94 Season

The soil profile was brought to field capacity, to a depth of 1.8 m, at planting. The soil water content of this profile was determined on a weekly basis using a Campbell Pacific Nuclear neutron probe (503 DR). The field capacity readings for nine 0.2 m depth increments were determined beforehand. The difference between field capacity and the weekly readings then represented the soil water deficit for that layer. The soil water deficit for the top metre of the soil profile was then determined and the water applied. Only the deficit in the top metre was used to prevent drainage.

Water was applied from November (1993) to the end of January (1994) using a micro-jet irrigation system. In February (1994) this system was replaced by a drip irrigation system (Figure 1) to prevent losses due to strong winds and also to prevent spray drift to adjacent plots.

The irrigation treatments (henceforth referred to as irrigation levels) were applied on a weekly basis as follows:

W1 -apply 25% of the amount applied to W4

W2 - apply 50% of the amount applied to W4

W3 -apply 75% of the amount applied to W4

W4 - control, irrigated weekly to restore field capacity to a depth of one metre

Due to the lack of any visual water stress and the possibility that deep drainage was occurring, the irrigation treatments were adjusted in January 1994:

W1 -apply 25% of the amount applied to W4

W2 - apply 50% of the amount applied to W4

W3 -apply 75% of the amount applied to W4

W4 - control, only 90% of the amount needed to bring the top one metre to field capacity was applied each week.

1994/95 Season

The soil profiles of each plot were brought to field capacity at planting. Thereafter the soil water content of the whole 1.8 metre profile was determined on a weekly basis with a neutron probe. Unlike the previous season, the amount of irrigation was calculated for the whole 1.8 metres and not only for the top metre, to encourage root growth. The irrigation treatments used were:

W1 - after bringing the soil profiles to field capacity, these plots received no irrigation, except to dissolve and incorporate the nitrogen top dressings. On each such occasion 20 mm of water was applied and the replication of this depended on the length of the growing season of the crop.

W2 - apply 33% of the amount given to W4

W3 - apply 66% of the amount given to W4

W4 - control, the whole 1.8 m soil profiles were brought to field capacity on a weekly basis

For the latter part of the 1993/94 season, dripper lines were used to apply water (Figure 1). There were five lines for each plot, one of which ended with a single dripper in a plastic can. The can was necessary to monitor the amount given to the specific plot. The cans were calibrated beforehand and were marked in 10 mm increments. During irrigation, two or more taps per water point were opened. If the pressure was not high enough, it could have caused the dripper, dripping in the can, to drip less than the ones lying flat on the soil surface. This irrigation system is illustrated in Figure 2. The hypothesis was that yields would decline with less water being applied, but in some cases the opposite was recorded. It is thus suspected that plots which should have received less water than the control, often received the same or more than the control plots or that n were leached from the control plots.

To try and ensure more accurate water monitoring in the 1994/95 season, there was a switch to a flood irrigation system. Each plot had its own tap, and by opening only one tap for a given water point, one could accurately determine the amount of water applied by reading off the amount on the Kent water meters. The Kent water meters were checked at the end of the 1994/95 season to determine their accuracy. Errors varied from zero to five percent at the most.

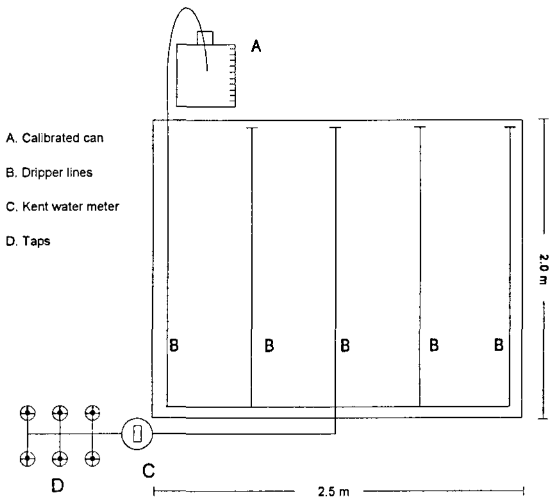


Figure 1. Dripper lines used in the 1993/94 season

Figure 2. Sketch of the can - dripper line system used to apply and control irrigation in the 1993/94 season.

2.4. Harvest and further analysis of the dry matter produced

The crops were established with the aim of producing silage. The maize, soybeans and cowpeas were harvested as soon as the seed reached the hard dough stage, while pearl millet and fodder sorghum were harvested for the first time just after flowering had commenced. In subsequent harvests the plants were harvested as soon as they reached a height of 1.5 m. The fodder sorghum and pearl millet were cut to a height of 0.2 m at each harvest. This harvest routine was repeated in the following season, with the exception of the first harvest for fodder sorghum and pearl millet. In the 1994/95 season these two species were harvested for the first time when they reached a height of 1.5 m, and thus before flowering commenced. The harvest dates for the two seasons are presented in Figure 3.

The W1-irrigation levels of cowpeas, maize and soybean were harvested a little earlier to prevent leaf losses. The plants showed signs of severe drought stress and had relatively small leaves in comparison to those of the control. The leaves also exhibited yellow colouring and were brittle (Figure 4).

From each 5 m^2 plot, 1 m^2 was harvested to determine the dry matter yield. After the samples had been taken, the rest of the plot was also cut to a height of 0.2 m. Four plants per plot for soybean, cowpeas and maize and four 0.25 x 0.25 m samples for fodder sorghum and pearl millet were taken and divided into leaf, stem and reproductive components to determine the dry matter contribution of each to the above-ground plant dry mass. The soybean and cowpea stems were taken as the main and side stems, while the stems of maize, fodder sorghum and pearl millet included both the stem and leaf sheath material. The leaves were taken as the leaf blades for the grass crops and included the petiole and pinna for the legumes. Reproductive components were taken as the intact ear (cob, kernels and cob leaves) of maize, the panicle for fodder sorghum, the ear of pearl millet and the flowers and pods for soybeans and cowpeas.

Intact plants as well as the different yield components, for each crop, 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 as well as the crude protein content of the crops.

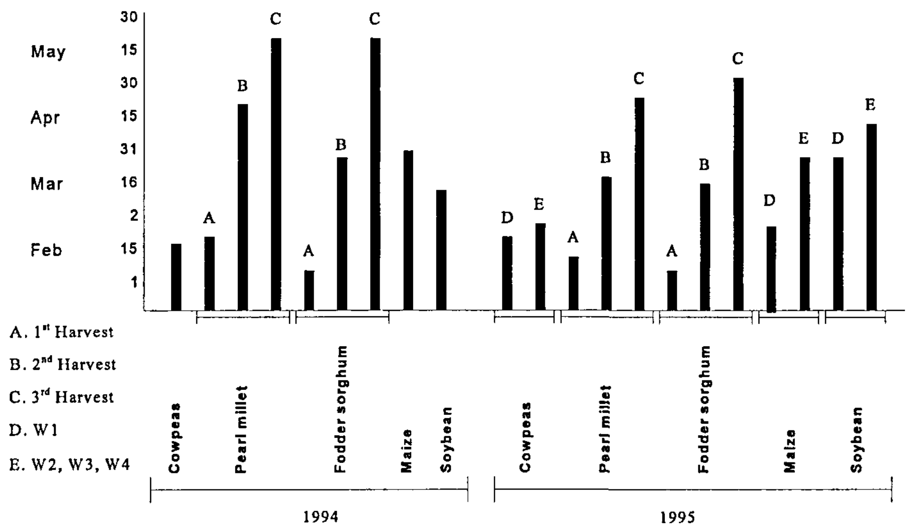


Figure 3. Harvest dates of five subtropical fodder crops in 1993/94 and 1994/95 seasons.

W1

W2

Figure 4(a). Appearance of maize plants just before harvest in the 1994/95 season.

W1 - irrigation level experiencing severe drought.

W2 - irrigation level receiving 33% of the amount of water given to W4.

W3

W4

Figure 4(b). Appearance of maize plants just before harvest in the 1994/95 season.

W3 - irrigation level receiving 66% of the amount of water given to W4.

W4 - irrigation level where the soil profile were brought to field capacity - control.

2.5. Fodder quality

2.5.1. *In vitro* digestibility

The dry matter, organic matter and ash content of the samples were determined by drying 2 g of each 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 & Terry (1963).

2.5.2. Crude protein content

The milled plant samples were analysed for nitrogen content using the Kjeldahl technique (Association of Official Analytical Chemists, 1984). These values were multiplied by 6.25 (Van der Merwe & Smith, 1991) to determine the crude protein content of the samples.

2.6. Statistical analysis

The material of each plot was kept apart to facilitate statistical analysis. With the aid of Statomet, a division of the Department of Statistics of the University of Pretoria, the data were analysed with the statistical software programme, SAS (Statistical Analysis System).

The least significant difference of Tukey (LSD_T), at the 95% probability level was used to determine significant differences between means.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. Dry matter yield

The dry matter yields presented in Figures 5 and 6, represent the total above-ground yield for the whole season. Cowpeas, maize and soybean were harvested only once during a season while fodder sorghum and pearl millet were harvested three times (Figure 3).

Although there is some uncertainty about the water use of the crops in the 1993/94 season, general conclusions on the average yield, over the four irrigation levels of each of those crops, can be made (Figure 5). The average dry matter yields of the legumes were lower than those of the grasses (Figures 5 and 6). A comparison based solely on dry matter yield, without taking into account the quality of the product being produced (carbohydrates vs protein), may wrongfully exclude the legumes when considering the best crop for a specific situation. The yields of cowpeas were rather low, but not unusually so, in comparison to the 5.4 t ha^{-1} and 5 t ha^{-1} of Shouse *et al.* (1981) and Duke (1981) respectively. The yields of soybean also compared well with the yield data in Table 3.

There was a significant crop (C) x irrigation level (I) interaction in the 1994/95 season, as indicated in Figure 6. For cowpeas, fodder sorghum and maize the yields under the W2, W3 and W4 irrigation levels were within a close range, with a

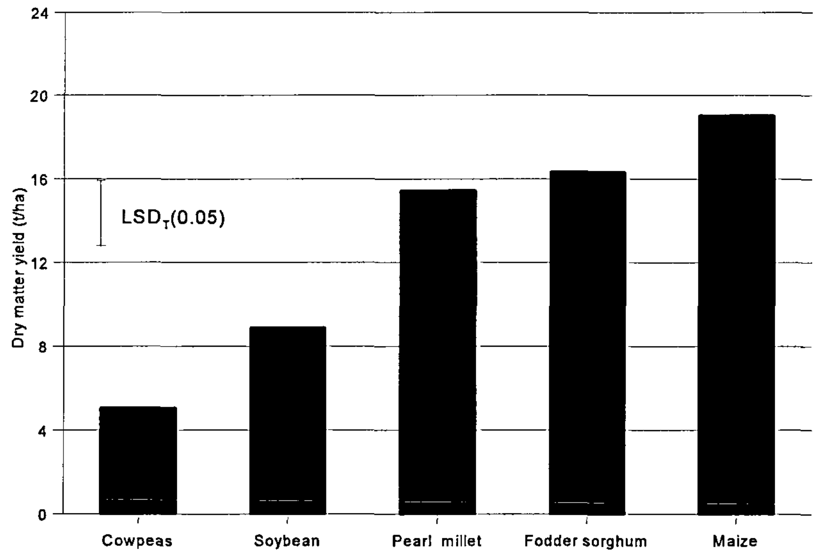
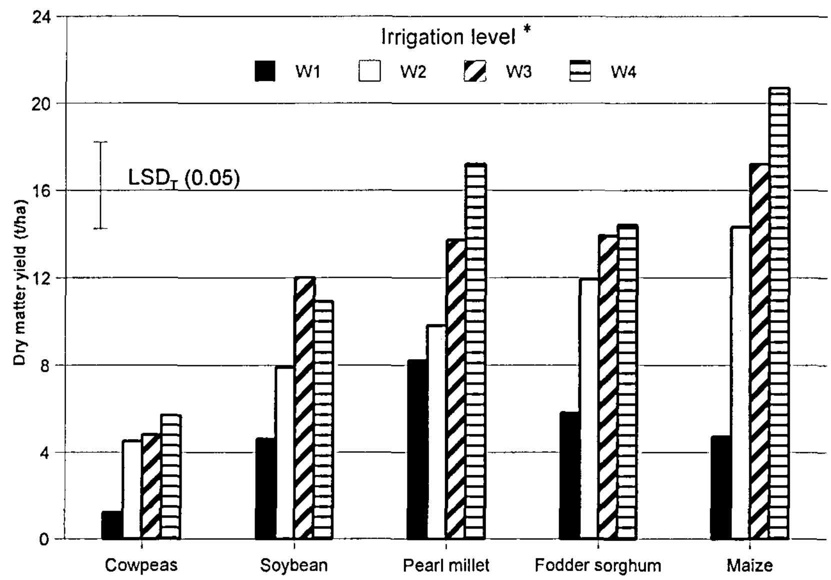


Figure 5. Total above-ground dry matter yield of five annual fodder crops in the 1993/94 season.



* W1 -severely water stressed level, W4 - control

Figure 6. Total above-ground dry matter yield of five annual fodder crops as influenced by four irrigation levels in the 1994/95 season.

large drop in yield from the W2 to W1 irrigation levels. The same was, however, not true for pearl millet and soybean, where the reduction in yield was not as marked.

Pearl millet clearly demonstrates an ability to produce under extreme water limiting conditions (W1), while both pearl millet and fodder sorghum out-produced maize under these conditions (Figure 6). When comparing cowpeas and soybean, it can be concluded that soybean may be a better choice under any water availability level, and especially under extreme water limiting conditions (W1).

3.2. Dry matter contribution of the yield components to the above-ground plant dry matter yield

A comparison was made between the contribution of yield components (Figures 7 and 8) for the well watered plots (W4) in both seasons. From these data it is evident that different harvesting criteria for fodder sorghum and pearl millet influenced the contribution of yield components, but the general trend for all the crops remained the same.

The stem yields of pearl millet, but more so for fodder sorghum, were higher in the 1993/94 than 1994/95 season, due to a younger harvesting date in the latter season. The stem yields of cowpeas, soybean, pearl millet and fodder sorghum (1993/94 season) tend to be higher than the other yield components, while that of maize tended to be much less than the reproductive component yield. The leaf contribution to the whole plant yield remained approximately the same for cowpea, soybean and

maize in both seasons, while with pearl millet and fodder sorghum the leaf contribution increased due to harvesting younger plants in 1994/95. There was only a small difference in the contribution of the reproductive component to the whole plant for cowpeas, despite a shorter growing season in 1994/95. There was a general observation that cowpeas kept on producing new stems and leaves and not flowers, under well watered conditions.
Maize was planted on the 30th of November in 1993 and on the 1st and 2nd of December in 1994 and harvested with a day difference in the two seasons, thus resulting in equally long growing seasons, but with a small difference in reproductive component contribution. Comparing planting and harvesting dates for soybean, also resulted in an equally long growing season, but there was an increase of about 15% in the contribution of the reproductive component in the 1994/95 season. A growth analysis of soybean (Hintz & Albrecht, 1994) indicated that the dry matter contribution of leaves was the highest until the plants became reproductive. Thereafter the contribution of the pod fraction increased rapidly, while that of the leaves decreased. At harvest the pods contributed the largest proportion to the whole plant dry matter yield, while the leaves contributed the least. Schoonraad, Schoeman, Laas & Beukes (1987) reported similar results for maize.

As mentioned previously, the pearl millet and fodder sorghum plants were harvested at a younger stage in the 1994/95 season, resulting in a lower contribution of the reproductive component. In a cultivar trial with pearl millet and fodder sorghum Haasbroek (1994) found that the stem component was the largest while the contribution of leaves was between 12 - 25%. In this trial the plants were left to produce seed and the contribution of the grain to the whole plant was a little higher than that of the leaves.

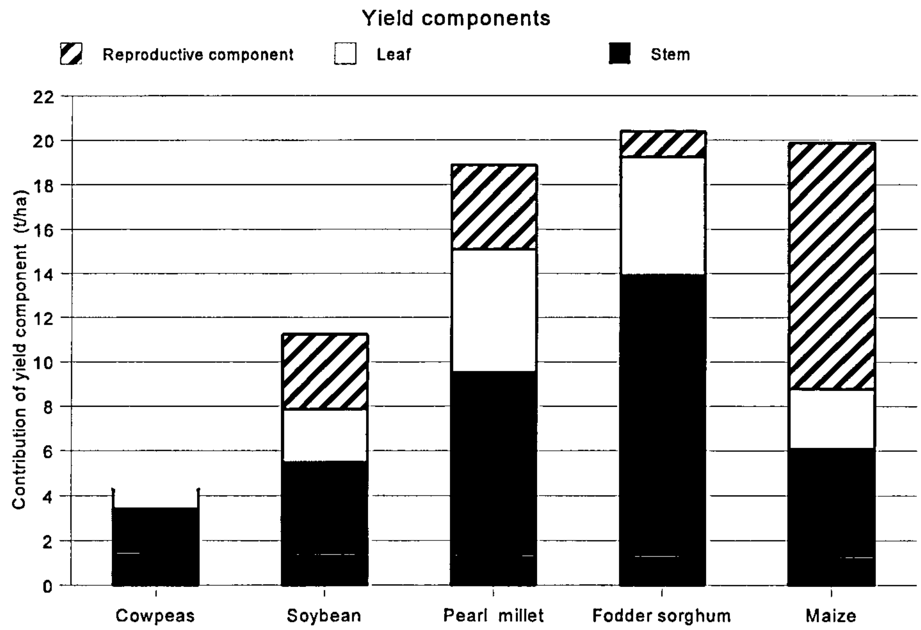


Figure 7. Dry matter contribution of the yield components of five annual fodder crops at the well watered level (W4) in 1993/94.

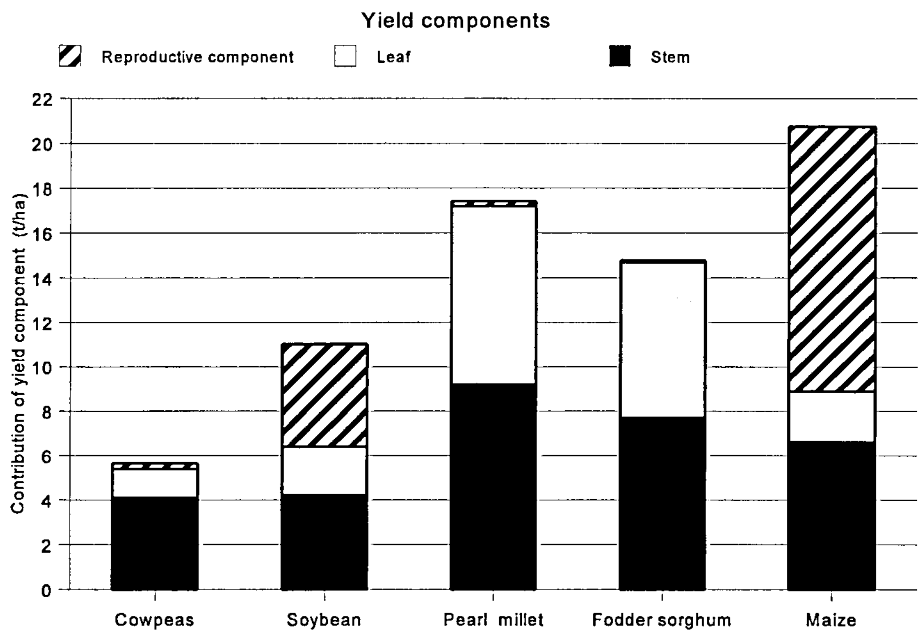
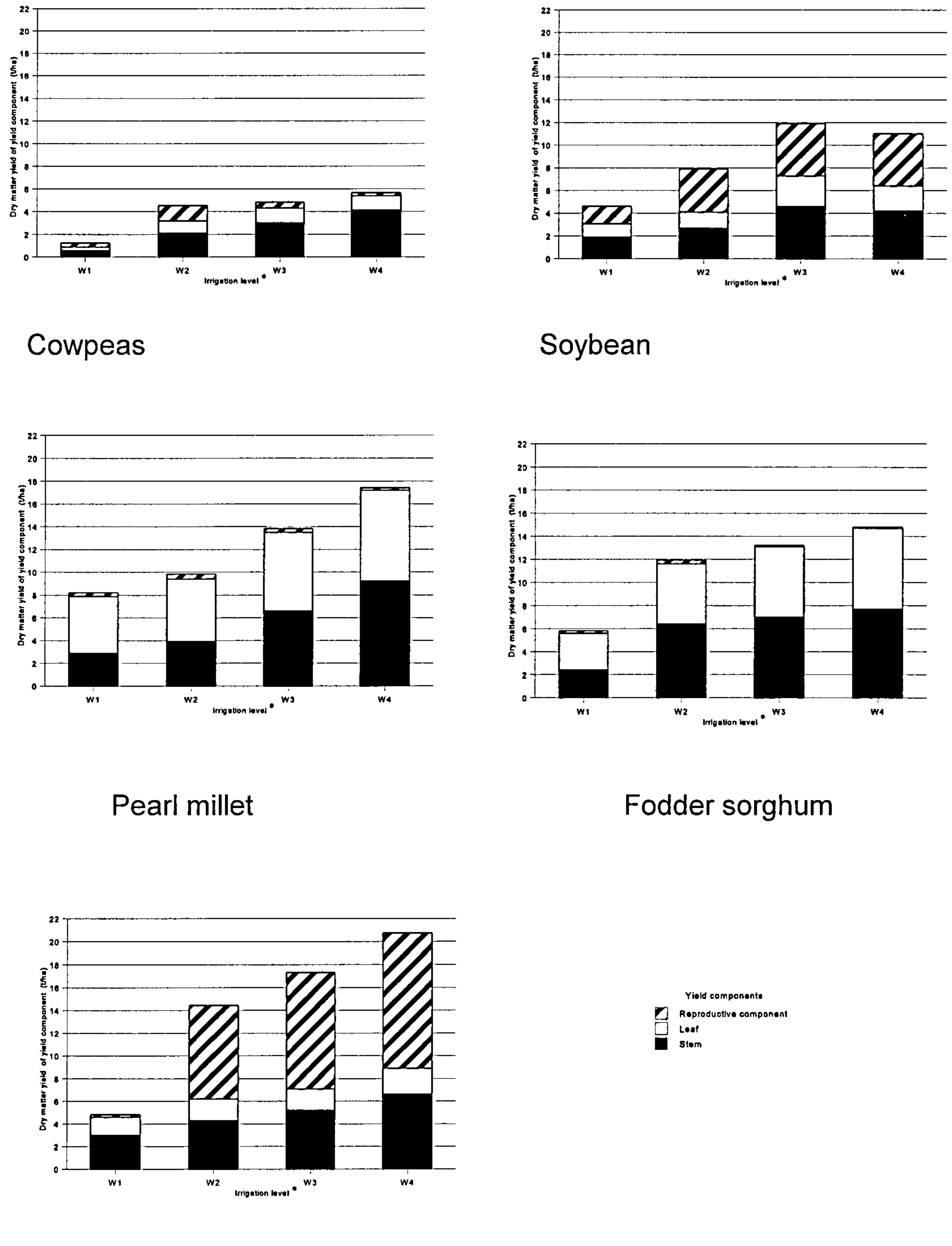


Figure 8. Dry matter contribution of the yield components of five annual fodder crops at the well watered level (W4) in 1994/95.

3.2.1. Influence of irrigation levels on dry matter contribution of the yield components in the 1994/95 season

By increasing the amount of water applied (W2, W3 and W4) the dry matter yield of the cowpea and maize leaves were not markedly influenced (Figure 9). There were, however, slight increases in the stem and leaf yields of soybean, pearl millet and fodder sorghum and the reproductive component of soybean and maize, while the reproductive component yield of cowpeas, pearl millet and fodder sorghum decreased with more water being applied.

The decrease in dry matter yield from the control (W4) to the severely water limited treatment (W1) for the grain crops (cowpeas, maize and soybean) was far more than the decrease in yield for pearl millet and fodder sorghum over the same range. The grain component of the latter two crops was relatively small in comparison to that of the traditional grain crops, except for cowpeas (Figure 9). This illustrates the importance of water availability during the reproductive phase. According to Schussler & Westgate (1991) the developing maize kernels are supplied with a small amount of carbohydrates from the stem and leaf reserves, but the main source of carbohydrates is from photosynthesis taking place at that stage. The result of poor water availability is that, although kernels may develop, a carbohydrate deficiency results in poor grain fill.



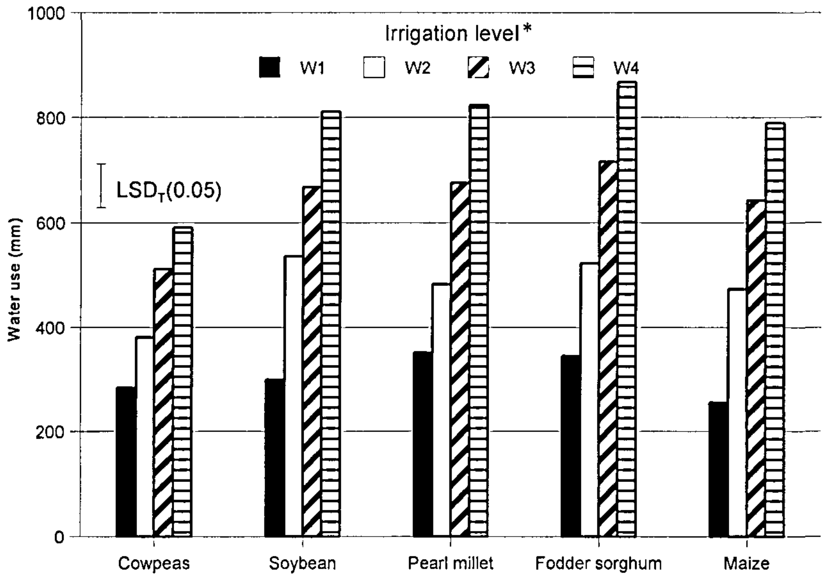
* W1 -severely water stressed level, W4 - control

Figure 9. Dry matter yield of the yield components of five annual fodder crops at four irrigation levels in the 1994/95 season

3.3. Water use

The water use values for the 1994/95 season (Figure 10) represent the sum of the weekly irrigation amounts as well as the difference in water deficit in the soil profile between the beginning and the end of the season. For the control treatments (W4) cowpeas used the least water while fodder sorghum used the most.

Despite significant differences in water use (Figure 10), significant differences in yield were limited to the W1 and W4 irrigation levels of cowpeas, pearl millet, fodder sorghum and maize (Figure 6). The dry matter yields at the W3 and W4 irrigation levels of soybean did, however, differ from those at the W1 and W2 irrigation levels (Figure 6).

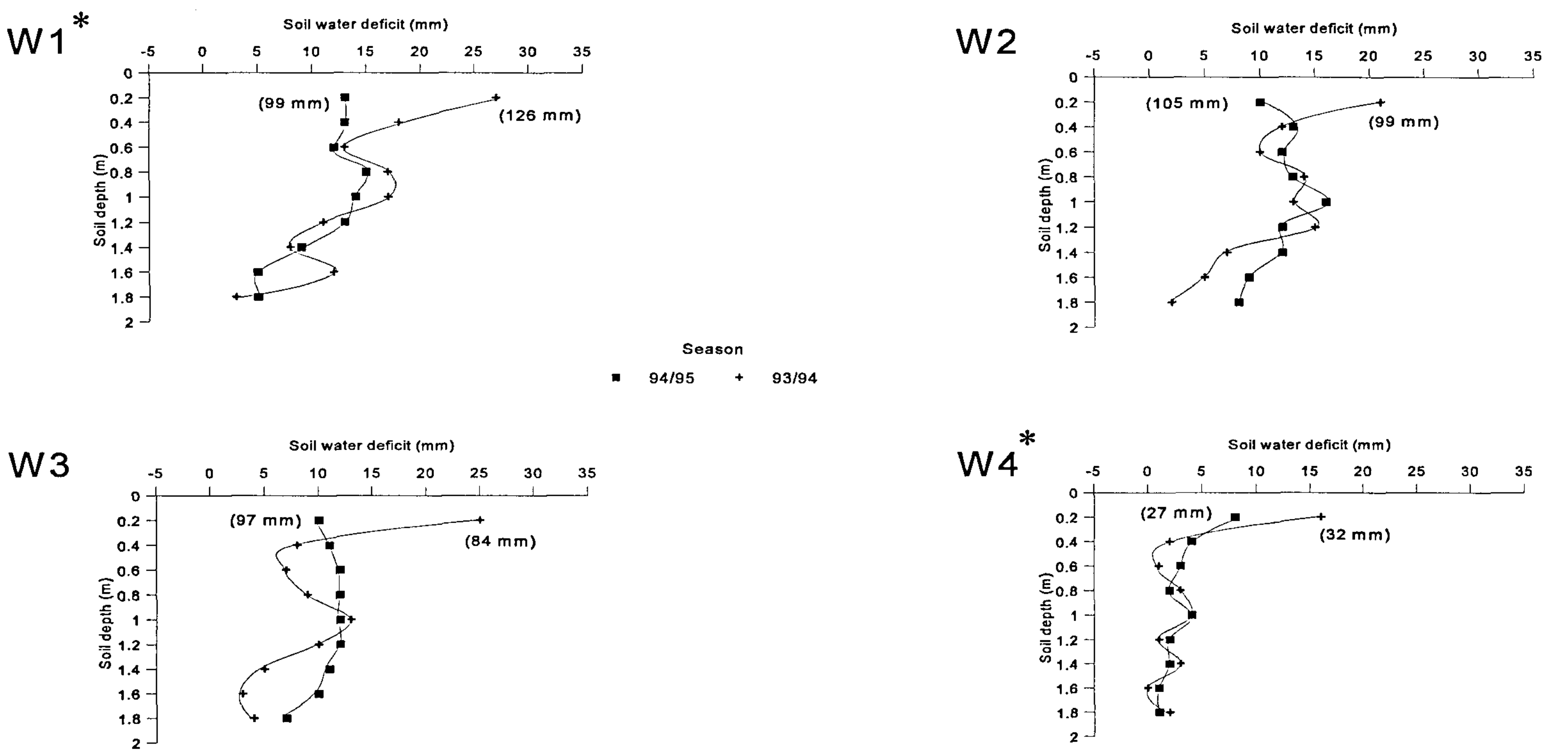


* W1 -severely water stressed level, W4 - control

Figure 10. Water use of five annual fodder crops as influenced by four irrigation levels.

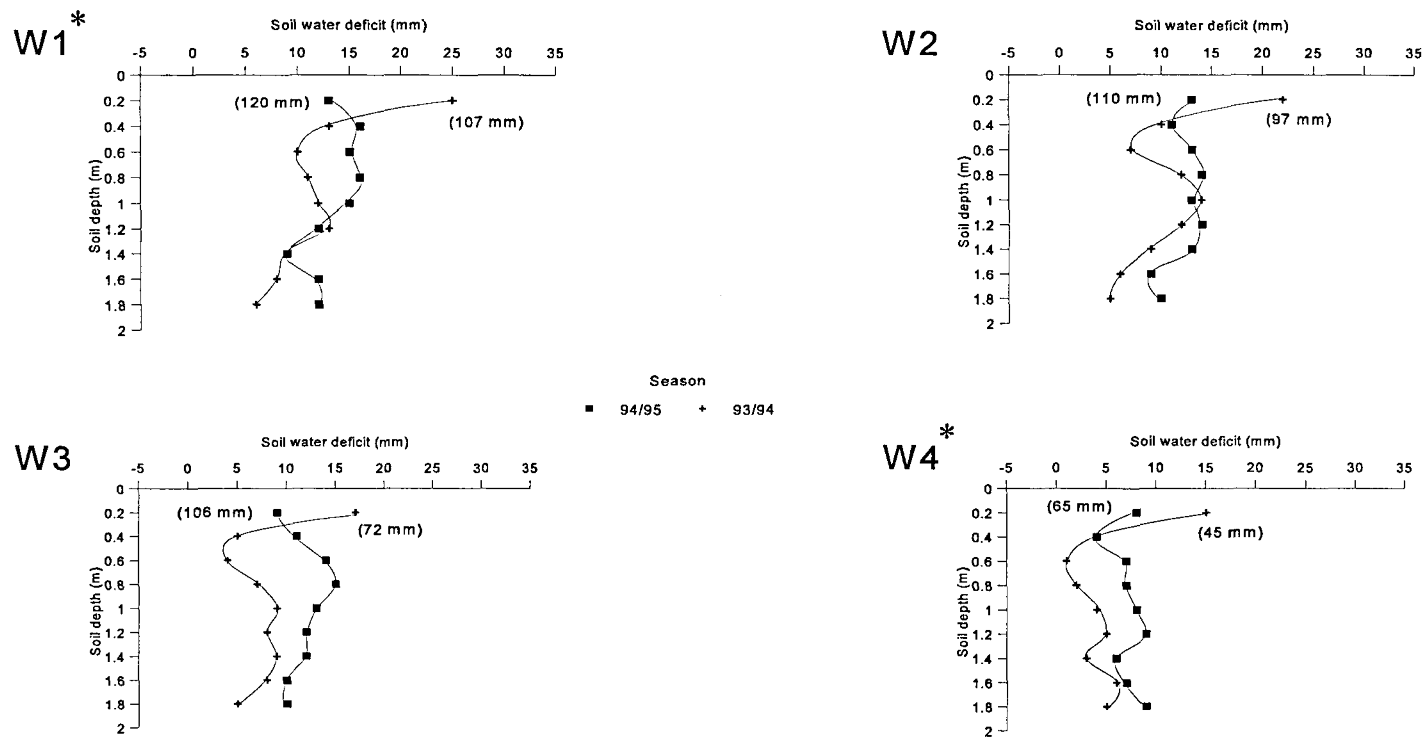
Although the W1 plots received 75%, W2 plots 50% and W3 plots 25% less water over the 1993/94 season than the W4 plots, it is not reflected in the water use of these respective treatments. The same is true for the 1994/95 season where the W1 plots received less than 75%, W2 plots 66% and W3 plots 33 % less water than the W4 plots. A comparison of the soil water deficits for the different irrigation levels at the end of the season (Figures 11 - 15), provides the reason for this finding. While the soil water deficit of the W4 plots was approximately 5 mm per soil layer, that of the W1 plots was approximately 15 mm per soil layer at the end of the growing season. Thus more of the stored soil water was used under W1 than under W4 irrigation conditions. The implication of this for water management in the following season becomes clear. Growing a crop on the W1 plots without supplying additional water can cause serious plant losses early in the season while a crop on the W4 plots, also without additional water, might still be able to produce some yield. It is clear from this that monitoring soil water content is no longer a luxury, but a necessity. The more frequently soil water monitoring can be done during the growing season the better, but sampling at the beginning of the season should be a prerequisite.

From Figures 11 - 15 it can be concluded that all five crops used the whole profile to extract water under W1, W2 and W3 irrigation level conditions. It is also important to note the extraction pattern of the crops in the top 0.8 to 1.2 m and the implications of this on managing the water availability in that part of the soil.



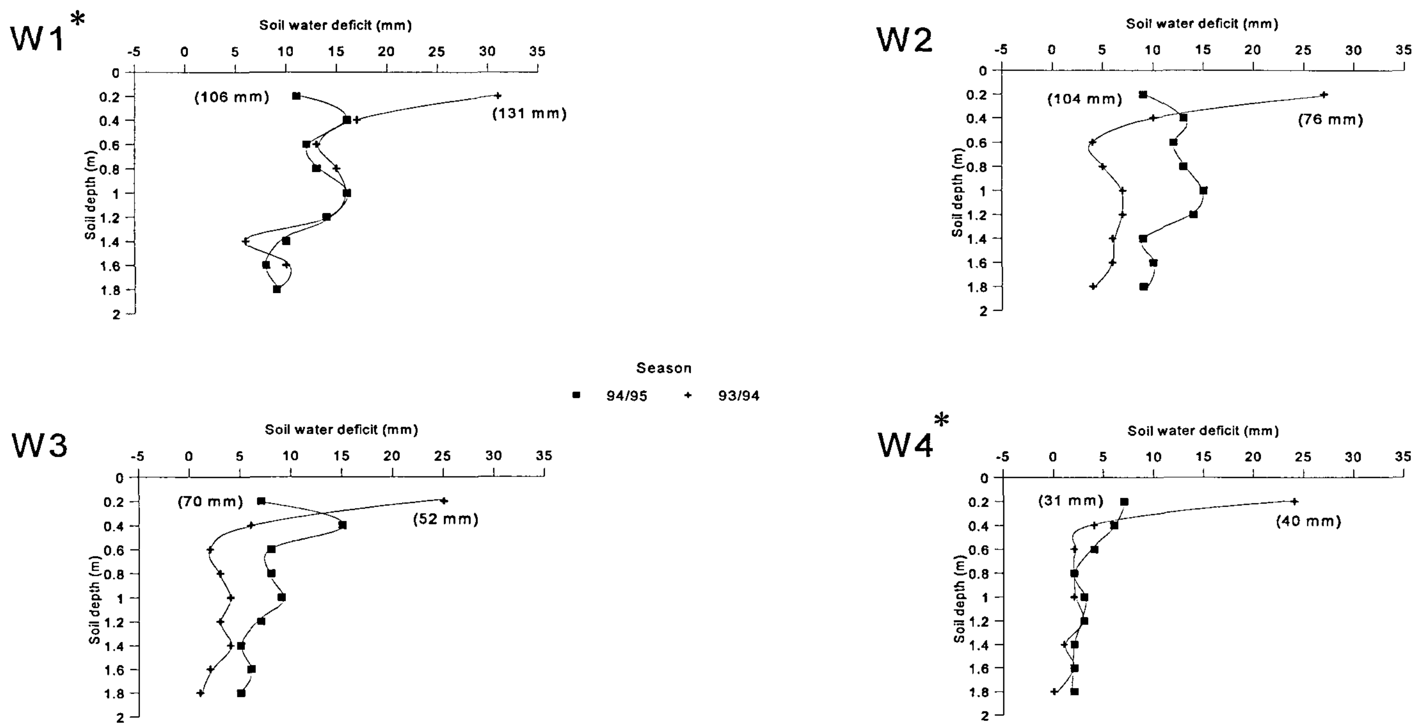
* W1 - severely water stressed treatment, W4 - control treatment

Figure 11. Water deficit at the end of the growing season for cowpeas at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



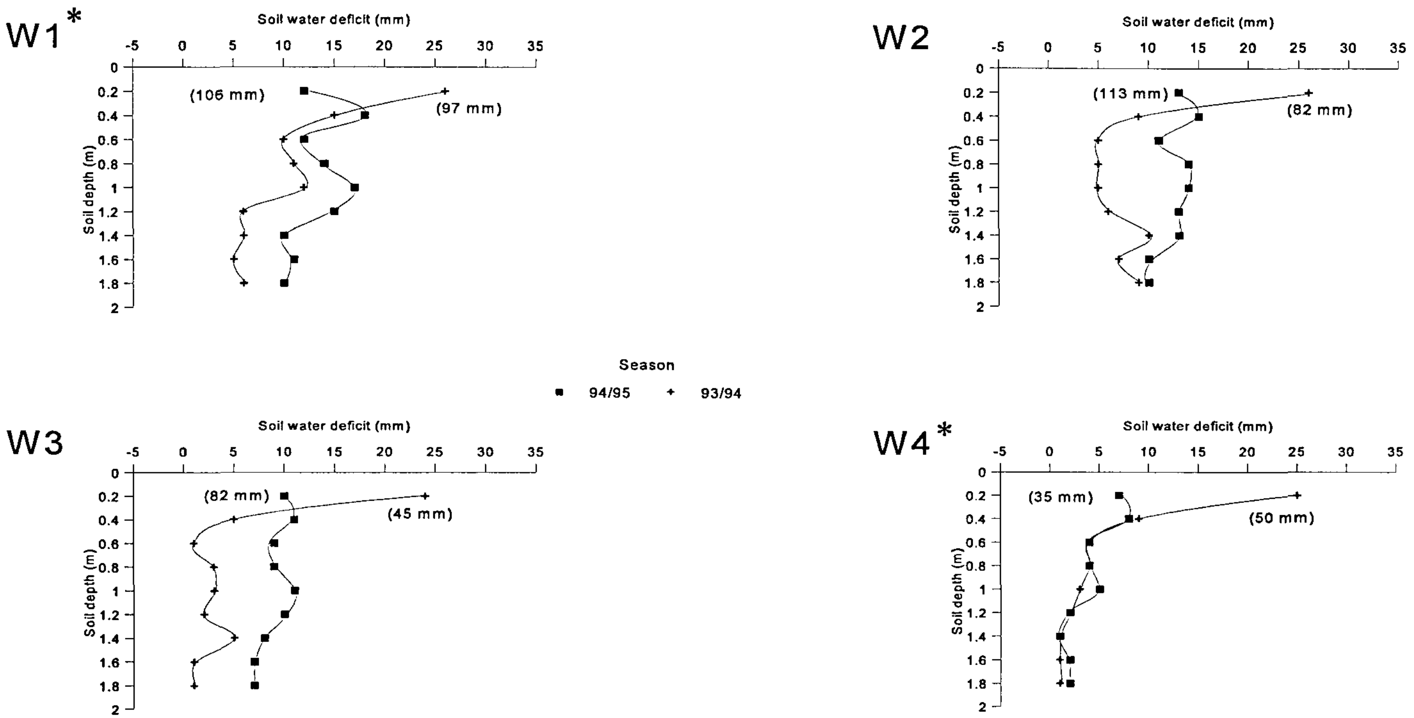
* W1 - severely water stressed treatment, W4 - control treatment

Figure 12. Water deficit at the end of the growing season for soybean at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



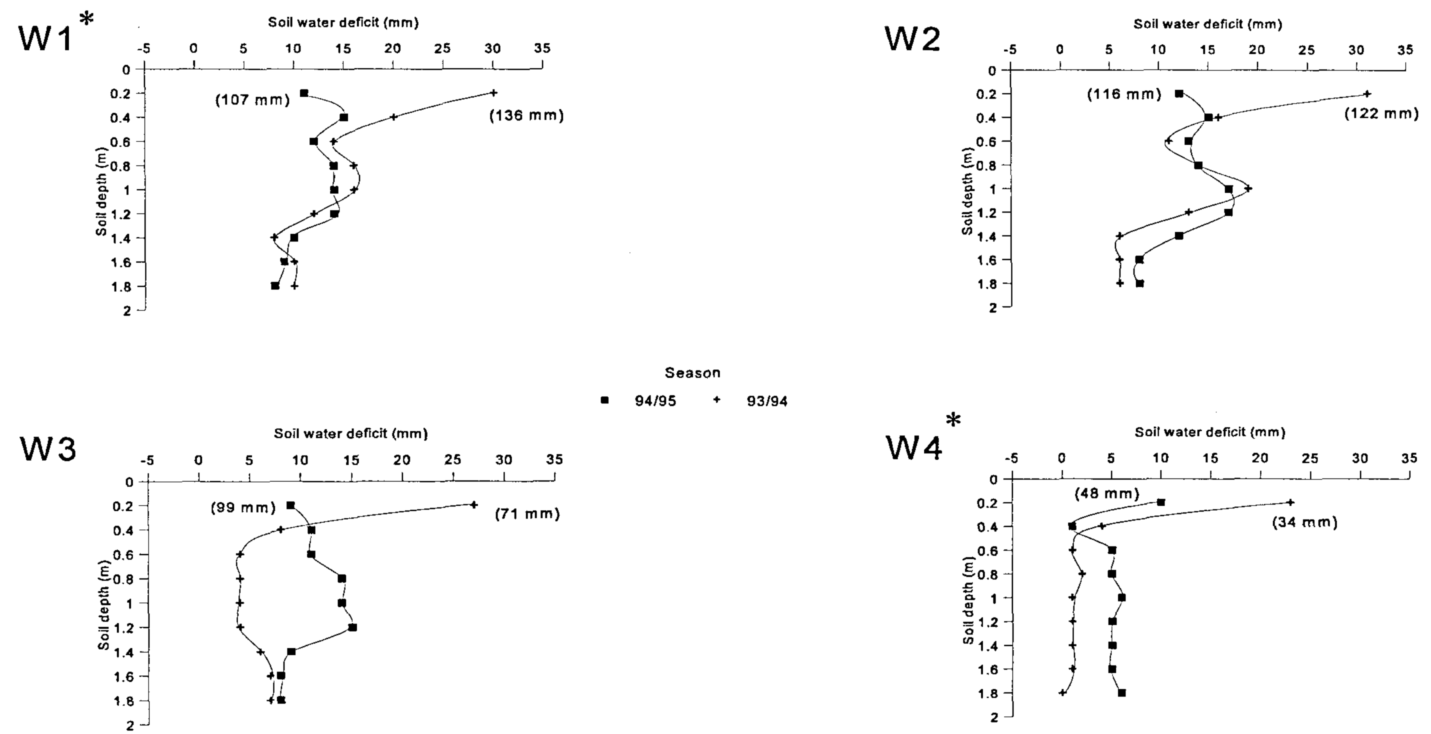
* W1 - severely water stressed treatment, W4 - control treatment

Figure 13. Water deficit at the end of the growing season for pearl millet at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



* W1 - severely water stressed treatment, W4 - control treatment

Figure 14. Water deficit at the end of the growing season for fodder sorghum at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



* W1 - severely water stressed treatment, W4 - control treatment

Figure 15. Water deficit at the end of the growing season for maize at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)

The main differences between the profile graphs of the two seasons were, however, to be found in the 0 - 20 cm and 20 - 40 cm layers. These differences may be due to a compaction layer, identified in a penetrometer study. The data from this study is summarized in Table 5.

Table 5. Summary of the mean penetration readings for three depth increments under the rain-shelter in 1994/95 Season.

Increment (mm)	Penetration reading (kg cm^{-2})	Penetration depth (cm)	Observation
0 - 150	59	10	Soil was loose and gave almost no resistance to penetration.
150 - 300	87	1 - 2	Soil was very hard and the penetrometer could not penetrate more than 20 mm.
300 - 400	66	10	Not as loose as on the surface, but much easier to penetrate than the layer above.

Through years of wheel and foot traffic, the soil could have been compacted at a depth of between 150 - 300 mm (Table 5). The reason why the W4 plots, especially, show the compaction layer may be due to the relatively wet subsoil of those plots in comparison to that of the W1, W2 and W3 plots.

3.4. Fodder quality

3.4.1. Dry matter digestibility

The *in vitro* digestibility of whole plants for the 1993/94 season is only given for the well watered irrigation level (Figure 16), while the effects of all the irrigation levels are presented for the 1994/95 season (Figure 17).

In the 1994/95 season (Figure 8) the proportion of stem in both soybean and cowpeas was lower, while the proportion of reproductive material was higher, than in the previous season (Figure 9). This lower proportion of stem may explain why the two legumes had a better digestibility in the 1994/95 season (Figure 17). For cowpeas there was a negative correlation (Table A16 in Appendix) between digestibility and stem dry matter yield (r^2 = - 0.9), while no correlation was evident for soybean (r^2 = 0.5).

There were no clear tendencies in the 1993/94 season, but in the 1994/95 season it appears that an increase in water deficit improved the digestibility of cowpeas, pearl millet and fodder sorghum plants (Figure 17). This increase in digestibility was, however, only significant for cowpeas.

Maize and soybean plants at the W1 irrigation level had the lowest digestibility (Figure 17). If the contribution of the yield components to the whole plant dry mass is examined, it appears as if the stem and reproductive components play an important role in digestibility, although it could not be confirmed with a correlation analysis (Table A16 in Appendix). At the W4 irrigation level the reproductive component of these crops was lower, while the stem component was higher than at the other irrigation levels (Figure 9).

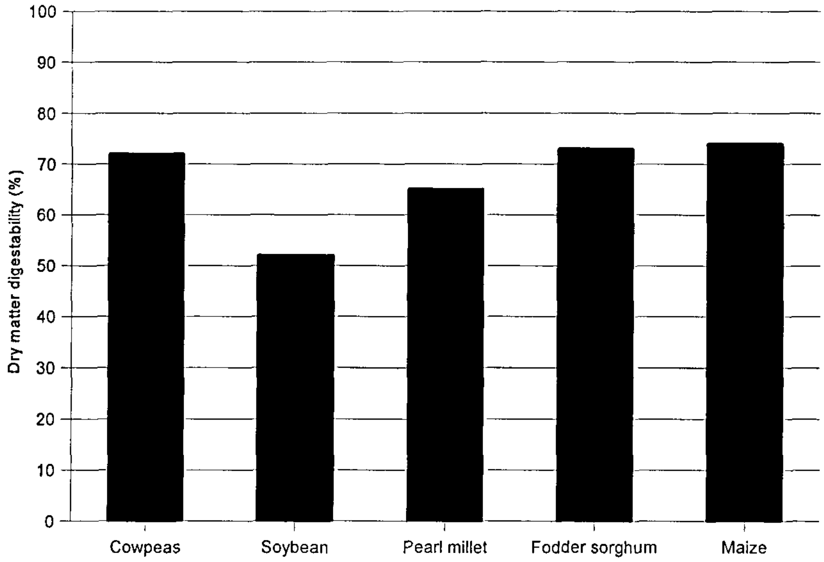
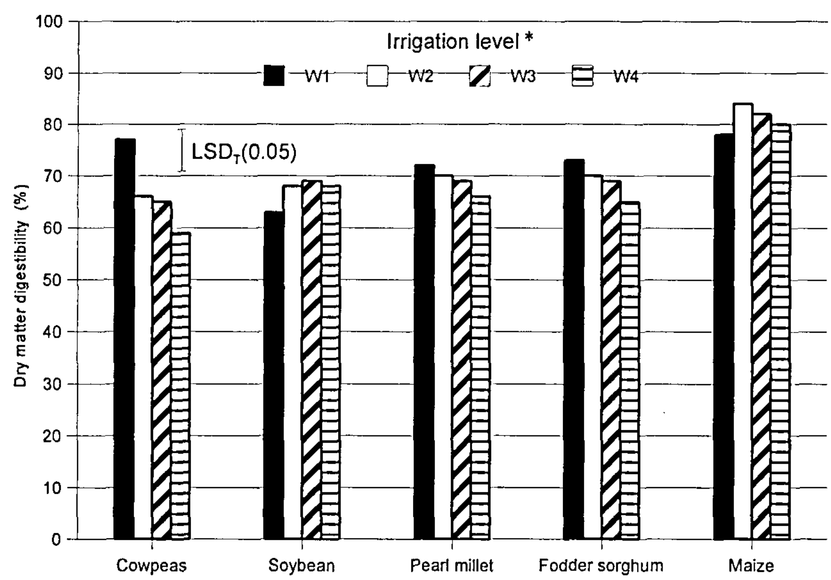


Figure 16. Dry matter digestibility of five annual crops under well watered conditions in the 1993/94 season.



* W1 -severely water stressed level, W4 - control

Figure 17. Dry matter digestibility of five annual crops as influenced by four irrigation levels in the 1994/95 season.

3.4.2. Crude protein content

In both the 1993/94 and 1994/95 seasons the percentage crude protein content of cowpeas was the highest while that of maize was the lowest (Figures 18 and 19).

In the 1994/95 season (Figure 19) the crude protein content of pearl millet, maize and soybean was the lowest under the most severe water deficit, while that of cowpeas was the highest under such treatments. It appears that the relative contribution of the yield components played an important role in determining crude protein content. Again this could not be confirmed by correlation analysis (Table A16 in Appendix).

Plants are not the only source of protein for livestock, but from the literature it can be concluded that plant protein in feed rations should not be entirely substituted by animal protein and/or non-protein nitrogen. There is, however, no advantage in terms of meat or wool production, when plant proteins are substituted with other non-plant protein sources (Hussein & Jordan, 1990; Sindt, Stock, Klopfenstein & Shain, 1992; Broderick, Craig & Ricker, 1993; Sahlu, Fernandez, Jia, Akinsoyinu, Hart & The, 1993; Cozzi, Andrighetto, Berzaghi & Andreoli, 1995). Ultimately the availability and transport costs, as well as the cost of the source itself, will play a decisive role in the choice of protein source.

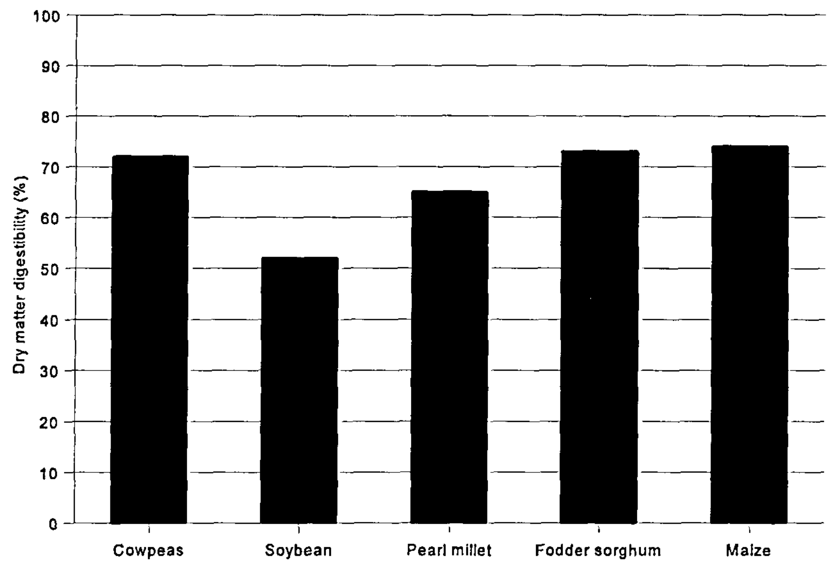


Figure 18. Average crude protein content of five annual fodder crops in the 1993/94 season.

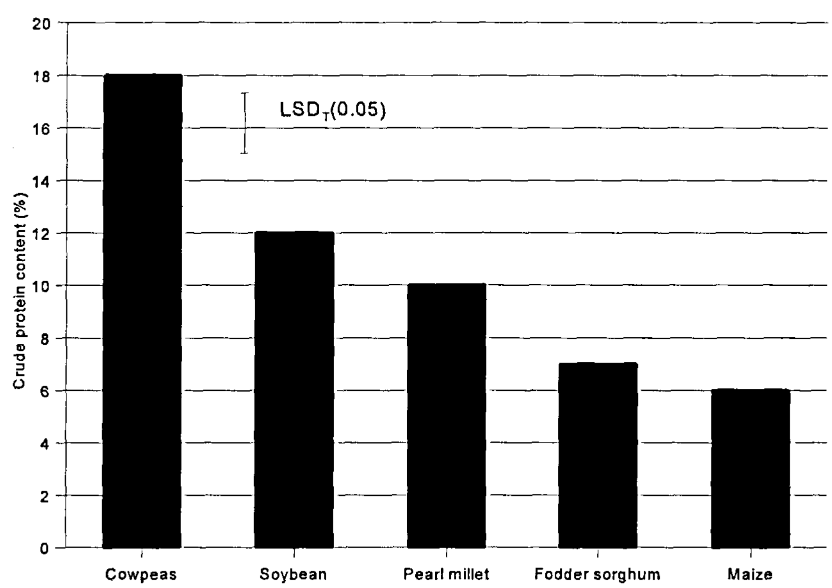


Figure 19. Average crude protein content of five annual fodder crops in the 1994/95 season.

3.5. Water use efficiency (WUE)

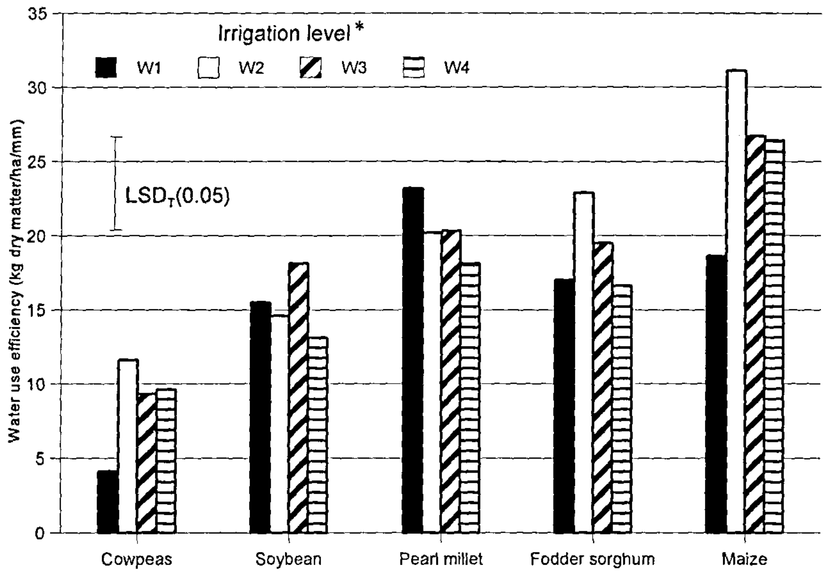
Water use efficiency is usually expressed as a mass per area per depth of water used by the crop. In this case the unit water being used is the total amount of water used during a specific season, while the mass can be one of three variables. It was noted early in the study that there is a difference in the product being produced by grass and leguminous crops. This difference in product may be quantified by expressing the WUE in terms of dry matter yield, digestible dry matter yield or crude protein dry matter yield.

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

In the 1994/95 season, there was a significant crop x irrigation level interaction (Figure 20). The WUE_{DM} of pearl millet was better under severe water stress conditions (W1) than at the W2, W3 and W4 irrigation levels, while water was used more efficiently under the W2 irrigation level than under control conditions in the case of fodder sorghum, maize and cowpeas. Soybeans used water more efficiently under W3 conditions than at any of the other irrigation levels. Despite this, only the fodder sorghum difference was significant.

Turner & Passioura (1986) and Steynberg *et al.* (1993) also reported better water use efficiency under stressed than under control conditions.

WUE_{DM} is not only influenced by transpiration, but also by evaporation. To see these results in perspective one should keep in mind that the irrigation frequency as well as the irrigation system may have a large influence on the evaporation component, as will the density of the crop canopy.



* W1 -severely water stressed level, W4 - control

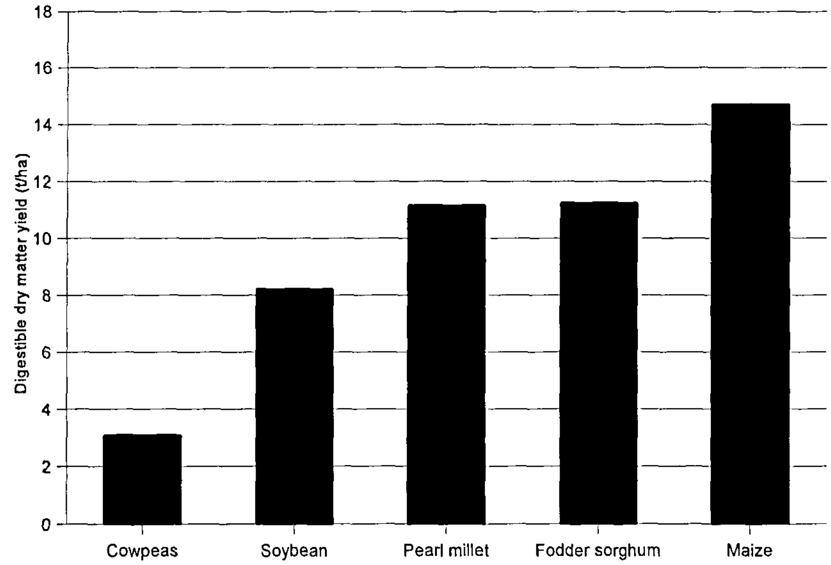
Figure 20. Dry matter water use efficiency of five annual crops influenced by four irrigation levels in the 1994/95 season.

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

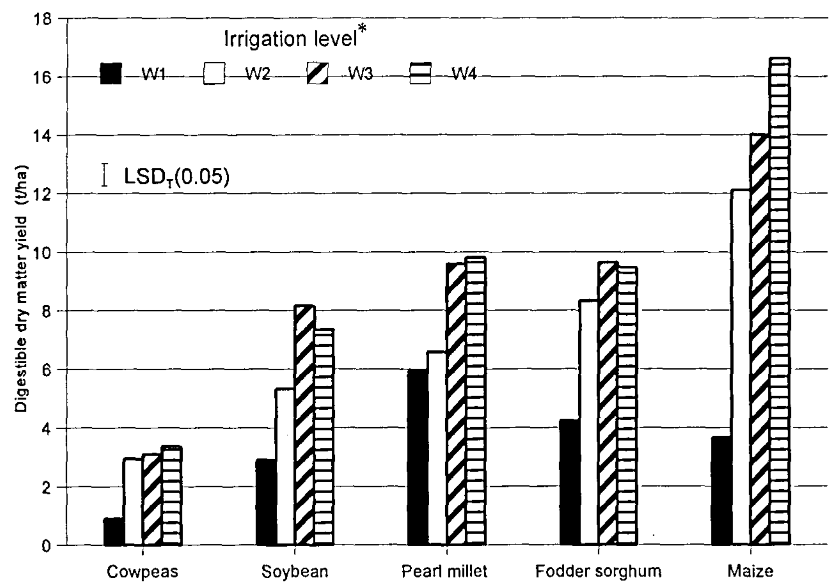
As expected the mean digestible dry matter yield (Figure 21 (a)) of the five crops followed the same pattern as the dry matter yield (Figure 5) for the 1993/94 season. The same was true for cowpeas, soybean, pearl millet and maize at four irrigation levels in the 1994/95 season (Figures 6 and 21 (b)). For fodder sorghum the digestible dry matter yield (Figure 21 (b)) was more at the W3 than the W4 irrigation levels, which is not reflected in the dry matter yield graph (Figure 6).

The WUE $_{DDM}$ (Figure 22) is similar to the situation for WUE_{DM} (Figure 20). Maize is still the most efficient user of water of the five crops, regardless of irrigation level.

(a)



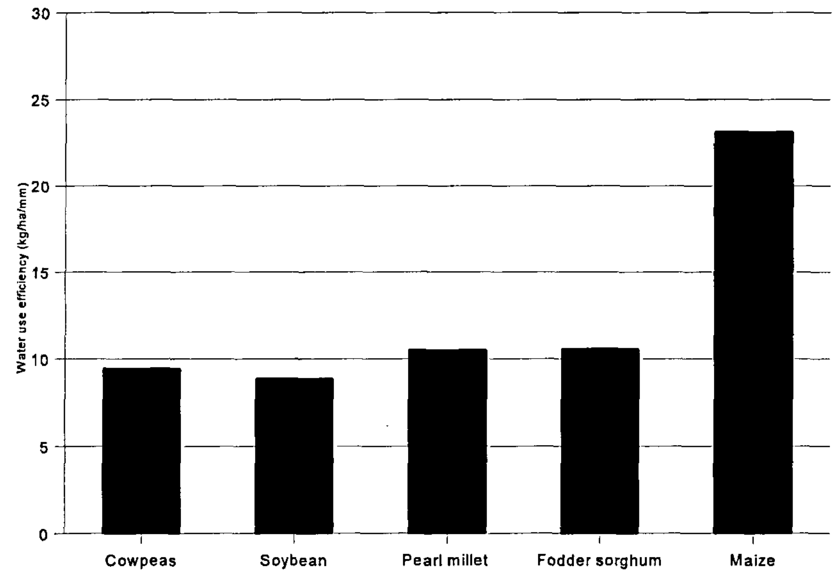
(b)



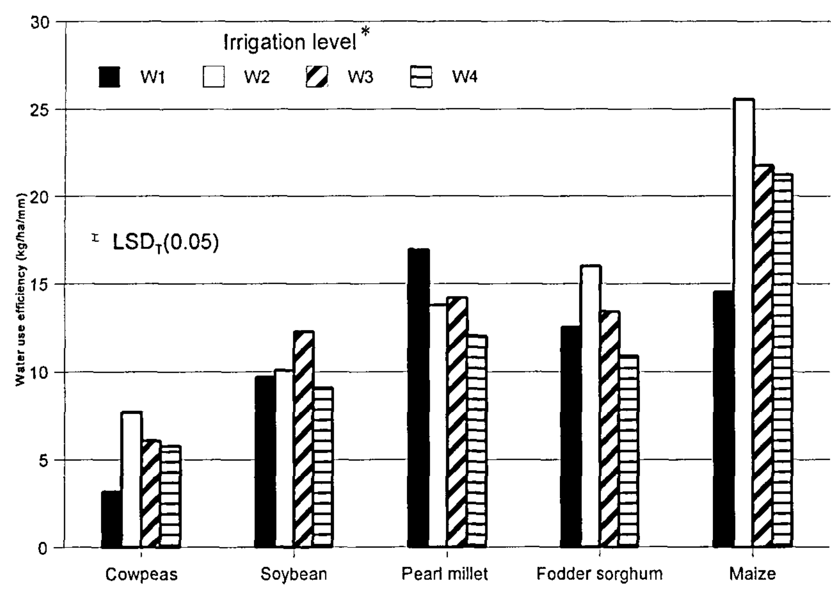
* W1 -severely water stressed level, W4 - control

Figure 21. Digestible dry matter yield of five annual crops (a) 1993/94 season, (b) 1994/95 season as influenced by irrigation level.

(a)



(b)



* W1 -severely water stressed level, W4 - control

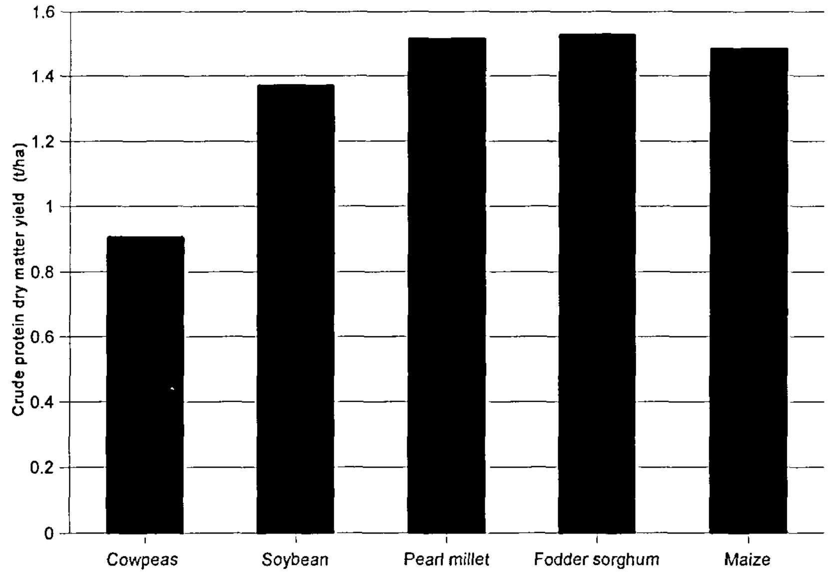
Figure 22. Water use efficiency in terms of digestible dry matter yield of five annual crops (a) 1993/94 season, (b) 1994/95 season as influenced by irrigation level.

3.5.3. Water use efficiency in terms of crude protein dry matter yield (WUE_{CP})

When comparing the average crude protein dry matter yields of the five crops, maize no longer produced the highest yield (Figure 23). Pearl millet (1993/94 and 1994/95 seasons) and soybean (1994/95 season) are the higher crude protein dry mass producers. Despite this observation, there is not as big a difference in crude protein dry matter yield between the crops, compared with either the dry matter (Figures 5 and 6) or digestible dry matter yields (Figure 21).

Due to a high crude protein content, cowpeas and soybean used water far more efficiently in terms of crude protein (Figure 24) than in terms of digestible dry matter yield (Figure 22). In both seasons there was little differences in the WUE_{CP} of cowpeas and maize, while that of fodder sorghum was the lowest (Figure 24).

(a)



(b)

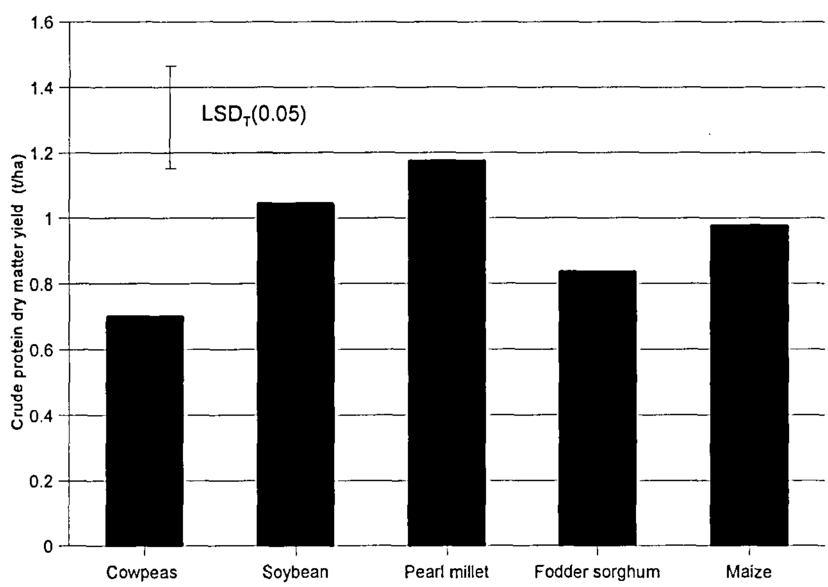
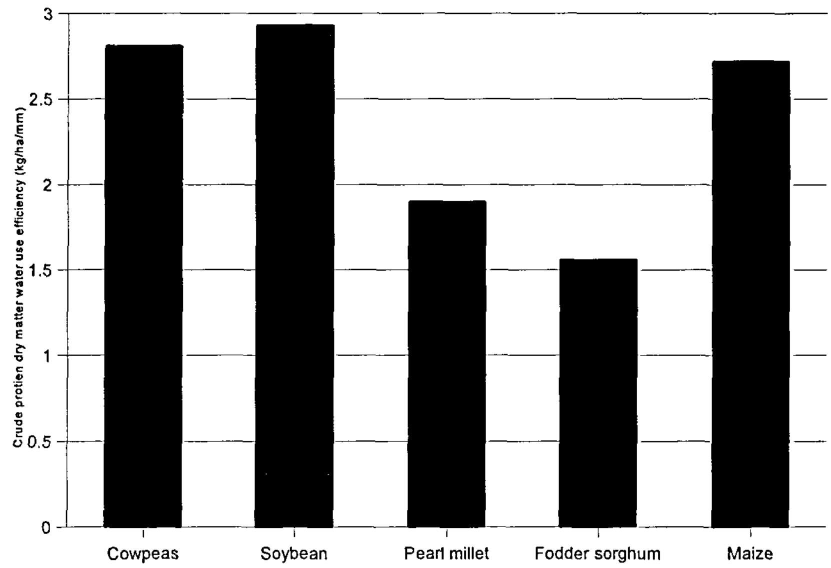


Figure 23. Mean crude protein dry matter yield of five annual crops. (a) 1993/94 season, (b) 1994/95 season.

(a)



(b)

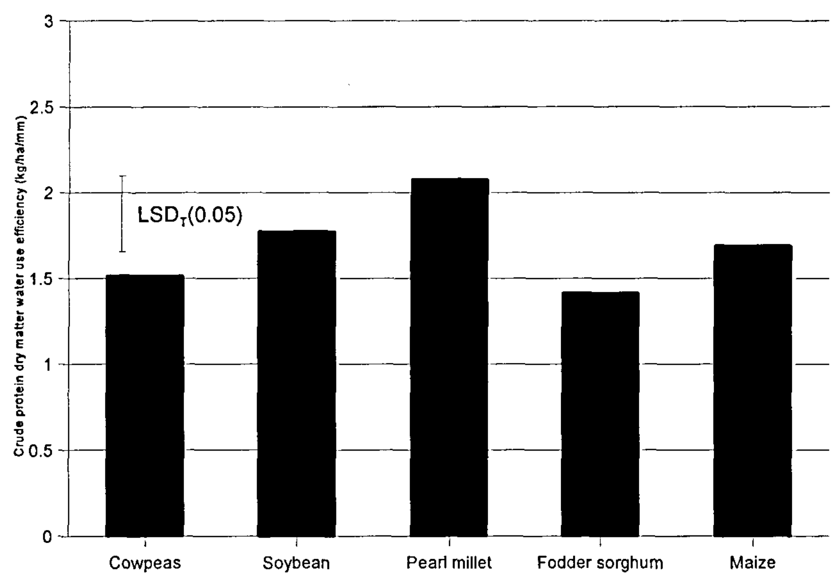


Figure 24. Mean water use efficiency in terms of crude protein dry matter yield (WUE_{CP}) of five annual crops. (a) 1993/94 season, (b) 1994/95 season.

CHAPTER 4

ECONOMIC ANALYSIS

4.1 Methodology

A hypothetical centre pivot irrigation system was used for the economic analyses because systems employed in the trial are not used for fodder crops under commercial conditions. The centre pivot was 30.58 hectare in size. It was assumed that the site fell within the Roodeplaat Dam Government Water Scheme. The annual quota for this scheme is 6 500 m^3 per hectare and the tariff R 670.10 per hectare. An extra 4 000 m^3 per hectare can be purchased under surplus conditions at the same rate per m^3 as the initial 6 500 m^3. The centre pivot was provided with a 50 kVA electricity supply (Landrate 2 tariff). Depreciation of the irrigation system and the opportunity cost of capital used to purchase the system (interest) were not taken into account.

The trial was carried out under an automatic rain shelter preventing the crops from receiving any rain. To make the analyses applicable to all areas the water application levels of the trial were used to estimate irrigation costs.

Weed control was done by hand in the trial, whereas herbicides had to be added to the crop enterprise budgets for commercial conditions. Land preparation actions were not recorded during the trial but were done by hand as well. Therefore, assumptions had to be made regarding cultivation actions. The most cost effective mechanisation system was compiled for each crop. As in the case of the irrigation system, depreciation and interest on the mechanisation system were not taken into account. One permanent labourer was assumed employed at R 750 per month.

The utilisation of the crops by a livestock enterprise was not considered because too little information regarding the nutritional value of these crops was available. Irrigation costs were calculated with the aid of the IrriCost programme (Irrigation Cost programme) whereas the FARMS programme (Firm level Agricultural Management Simulator programme) was employed to generate enterprise budgets and cash flow statements. Both programmes form a part of the FARMS system (Firm level Agricultural Risk Management Simulator system).

4.2 Results

The specified costs per ton dry matter as well as per millimetre water, cash flow closing balance and crude protein content of the annual fodder crops at the four irrigation levels are presented in Table 6. Specified costs consist of operating and allocated ownership costs. The irrigation of fodder sorghum W4 exceeded the extra water purchases. Costs for the planned quantity irrigated were included although further purchases were not feasible. Maize W2 realises the lowest specified costs per ton dry matter, namely R 228. The costs of soybean W4 are R 344 and that of pearl millet W4 R 233. These specified costs per ton dry matter are the lowest for the different crops. However, turning points were not reached. Cowpeas W2 had costs of R 601 and fodder sorghum W4 costs of R 236. These are the lowest specified costs per ton dry matter for the different crops. However, both reveal multiple turning points because the dry matter yield for W3 was lower than for W2 and W4.

The specified costs per millimetre water of W4 were the lowest for all the crops. Only variable irrigation costs differ between treatments for the same crop. Therefore, decreasing average fixed water cost is the cause of a lower specified cost per millimetre water. The cash flow closing balance of the harvest months (last harvest months in the case of pearl millet and fodder sorghum) decreases from W1 to W4 for each crop as a result of variable irrigation costs. Those treatments for maize and fodder sorghum which have the lowest specified costs per ton dry matter have the highest crude protein content. The maize of W2 and fodder sorghum of W4 both contain seven percent crude protein. Soybeans W4, cowpeas W2 and pearl millet W4 contain 11, 17 and 9 percent respectively. These are either the lowest or second lowest crude protein content for the different crops. A higher crude protein content in the case of soybeans, cowpeas and pearl millet should, therefore, be weighed against higher costs.

Table 6. Specified costs, cash flow and crude protein content of annual fodder crops at four irrigation levels.

Crop	Irrigation level *	Specified costs per ton dry matter (R t^{-1})	Specified costs per millimetre water (R mm^{-1})	Cash flow closing balance (R ha^{-1})	Crude protein content (%)
Cowpeas	W1	1145	11.76	- 3 442	17
	W2	601	8.64	- 3 514	17
	W3	634	7.43	- 3 560	17
	W4	612	6.69	- 3 597	20
Pearl millet	W1	353	8.00	- 4 052	9
	W2	349	6.28	- 4 150	12
	W3	252	5.06	- 4 268	8
	W4	233	4.05	- 4 434	9
Fodder sorghum	W1	404	6.29	- 4 242	7
	W2	260	5.65	- 4 298	6
	W3	269	4.7	- 4 415	6
	W4	236	3.61	- 4 643	7
Maize	W1	625	12.16	- 4 523	7
	W2	228	8.33	- 4 641	7
	W3	272	6.9	- 4 717	7
	W4	314	6.62	- 4 745	5
Soybean	W1	745	11.30	- 3 952	14
	W2	446	8.18	- 4 044	11
	W3	357	6.42	- 4 141	12
	W4	344	5.35	- 4 235	11

* W1 -severely water stressed level, W4 - control

CHAPTER 5

CONCLUSIONS

The dry matter yields of soybeans and cowpeas are lower than those of maize, fodder sorghum and pearl millet. With the aim of producing higher yields per unit of water used, the cultivation of legumes for fodder purposes may, therefore, be questioned.

For the farmer, however, the quality, rather than the quantity, might be of greater importance. The dry matter digestibility of soybean, cowpeas, fodder sorghum and pearl millet did not differ significantly from each other. In addition cowpeas and soybean had the highest crude protein content over the two experimental seasons. The superior quality of the legumes should thus not be ignored, despite lower yields.

From the soil profile graphs it is evident that water was extracted from deeper soil layers as the water deficit was increased. A lack in significant differences in the dry matter yields between the W3 and W4, and sometimes W2 irrigation levels, indicates the ability of the plants to make efficient use of water from the soil profile where deficit irrigation was applied. The water holding capacity of different soil profiles will, therefore, play a decisive role when extrapolating these results to different sites.

The soil profile graphs of the W1 irrigation level further emphasise the importance of bringing the profile back to the upper limit of water availability at the start of the next growing season. This would prevent the plants experiencing water deficit conditions in the early growing stages.

With annual subtropical fodder crops, there is a choice between crops that can be harvested once only and crops which may be harvested repeatedly in a single growing season. The choice will depend on the farmers' needs. Maize, in combination with a legume, can produce a high quality silage, which may be available at times when the quality of other forages might be low. Fodder sorghum and pearl millet, on the other hand, can be harvested more than once, supplying a high quality fodder on a more regular basis. Results should not, therefore, be prescriptive, but rather supply information which can serve as basis for management decisions in each situation.

Tjandraatmadja, Macrae & Norton (1993) and Goodchild & McMeniman (1994) emphasize the advantage of using leguminous crops in communal farming systems where there is often no money available to buy protein or which experience transport problems. One should also keep the advantages of using leguminous crops in crop rotation systems in mind.

The cash flow closing balance per hectare of the harvest months decreases from W1 to W4. This is the result of higher variable irrigation costs. Specified costs per millimetre water, however, decrease from W1 tot W4. This decrease can be ascribed to decreasing average fixed water cost. Economic benefits from a higher crude protein content should be weighed against higher specified costs per ton dry matter for most of the annual fodder crops. The irrigation level for maize and fodder sorghum which had the lowest specified costs also realised the highest protein content. The crude protein content of these crops does not, however, vary more than two percent.

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APPENDIX

Table A1. Influence of irrigation level on the dry matter yield (t ha^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	4.2	6.0	5.2	4.5	5.1
Pearl millet	11.9	14.9	16.1	18.8	15.5
Fodder sorghum	12.7	17.2	15.1	20.4	16.3
Maize	12.5	22.5	21.2	19.9	19.0
Soybean	7.3	8.3	8.8	11.2	8.9
Mean	9.7	13.8	13.3	15.1	
LSD_T(C)= 3.1					
LSD_T(I) = 2.6					

* W1 -severely water stressed level, W4 - control

Table A2. Influence of irrigation level on the dry matter yield (t^{-1} ha) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	1.2	4.5	4.8	5.7	4.0
Pearl millet	8.2	9.8	13.7	17.2	11.6
Fodder sorghum	5.8	11.9	13.9	14.4	11.5
Maize	4.7	14.3	17.2	20.7	14.2
Soybean	4.6	7.9	12.0	10.9	8.9
Mean	4.9	9.7	12.3	13.3	
LSD_T(C*I) = 4.0					

* W1 -severely water stressed level, W4 - control

Table A3. Influence of irrigation level on the stem dry matter yield (t ha^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	2.6	4.1	3.7	3.4	3.5
Pearl millet	5.7	7.7	7.7	9.5	7.7
Fodder sorghum	8.2	11.6	9.9	13.9	10.9
Maize	3.3	6.8	6.3	6.1	5.6
Soybean	3.3	3.9	4.2	5.5	4.2
Mean	4.6	6.8	6.4	7.7	
LSD_T(C) = 2.1					
LSD_T(I) = 1.8					

* W1 -severely water stressed level, W4 - control

Table A4. Influence of irrigation level on stem dry matter yield (t ha^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.6	2.1	3.0	4.1	2.5
Pearl millet	2.9	3.9	6.6	9.2	5.3
Fodder sorghum	2.4	6.4	7.7	7.7	6.1
Maize	3.0	4.3	5.2	6.6	4.7
Soybean	1.9	2.7	4.6	4.2	3.4
Mean	2.2	3.9	5.4	6.4	
LSD_T(C) = 1.4					
LSD_T(I) = 1.2					

* W1 -severely water stressed level, W4 - control

Table A5. Influence of irrigation level on the leaf dry matter yield (t ha^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	1.2	1.7	1.5	1.0	1.3
Pearl millet	3.5	4.6	5.8	5.6	4.9
Fodder sorghum	3.5	4.6	4.6	5.3	4.5
Maize	1.4	2.4	2.8	2.7	2.3
Soybean	1.7	1.8	2.1	2.4	2.0
Mean	2.3	3.0	3.4	3.4	

$LSD_T(C) = 0.9$

$LSD_T(I) = 0.7$

* W1 -severely water stressed level, W4 - control

Table A6. Influence of irrigation level on the leaf dry matter yield (t ha^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.3	1.1	1.3	1.3	1.0
Pearl millet	5.0	5.5	6.9	8.0	6.1
Fodder sorghum	3.2	5.2	6.1	7.0	5.3
Maize	1.6	1.9	1.9	2.3	1.9
Soybean	1.2	1.4	2.7	2.2	1.9
Mean	2.3	3.0	3.8	3.9	

$LSD_T(C) = 0.8$

$LSD_T(I) = 0.6$

* W1 -severely water stressed level, W4 - control

Table A7. Influence of irrigation level on the reproductive component dry matter yield ($t\ ha^{-1}$) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.5	0.3	0.03	0.008	0.2
Pearl millet	2.7	2.5	2.7	3.8	3.0
Fodder sorghum	1.0	1.0	0.7	1.1	1.0
Maize	7.8	13.3	12.1	11.1	11.1
Soybean	2.4	2.6	2.5	3.4	2.7
Mean	2.9	3.9	3.6	3.9	

* W1 -severely water stressed level, W4 - control

Table A8. Influence of irrigation level on the reproductive component dry matter yield ($t\ ha^{-1}$) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.3	1.3	0.5	0.2	0.6
Pearl millet	0.3	0.4	0.3	0.2	0.3
Fodder sorghum	0.2	0.3	0.1	0.1	0.2
Maize	0.2	8.2	10.2	11.8	7.6
Soybean	1.5	3.8	4.6	4.6	3.6
Mean	0.5	2.8	3.2	3.4	
$LSD_T(C) = 0.7$					
$LSD_T(I) = 0.6$					

* W1 -severely water stressed level, W4 - control

Table A9. Influence of irrigation level on the water use (mm) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	235.0	342.0	341.0	368.0	322.0
Pearl millet	536.0	678.0	809.0	1168.0	798.0
Fodder sorghum	857.0	817.0	943.0	1413.0	1008.0
Maize	419.0	536.0	592.0	636.0	546.0
Soybean	324.0	406.0	484.0	660.0	469.0
Mean	474.0	556.0	634.0	849.0	
$LSD_T(C*I) = 19.8$					

* W1 -severely water stressed level, W4 - control

Table A10. Influence of irrigation level on the water use (mm) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	284.0	381.0	511.0	591.0	442.0
Pearl millet	351.0	482.0	676.0	823.0	583.0
Fodder sorghum	345.0	522.0	716.0	867.0	612.0
Maize	255.0	473.0	643.0	789.0	539.0
Soybean	299.0	536.0	668.0	811.0	578.0
Mean	307.0	478.0	643.0	776.0	
$LSD_T(C*I) = 82.7$					

* W1 -severely water stressed level, W4 - control

Table A11. Influence of irrigation level on the *in vitro*- dry matter digestibility (%) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	62.0	60.0	68.0	72.0	65.0
Pearl millet	69.0	62.0	69.0	65.0	66.0
Fodder sorghum	66.0	64.0	75.0	73.0	69.0
Maize	75.0	73.0	72.0	74.0	74.0
Soybean	58.0	54.0	65.0	52.0	58.0
Mean	66.0	62.0	69.0	67.0	
$LSD_T(C) = 8.5$					

* W1 -severely water stressed level, W4 - control

Table A12. Influence of irrigation level on the *in vitro*- dry matter digestibility (%) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	77.0	66.0	65.0	59.0	67.0
Pearl millet	72.0	70.0	69.0	66.0	70.0
Fodder sorghum	73.0	70.0	69.0	65.0	69.0
Maize	78.0	84.0	82.0	80.0	81.0
Soybean	63.0	68.0	69.0	68.0	67.0
Mean	73.0	72.0	71.0	68.0	
LSD_T (G*W) = 8.0					

* W1 -severely water stressed level, W4 - control

Table A13. Influence of irrigation level on the crude protein content (%) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	18.1	18.5	17.8	17.0	17.9
Pearl millet	10.8	10.5	8.3	9.7	9.8
Fodder sorghum	9.6	8.9	9.6	10.5	9.6
Maize	9.0	7.4	8.0	6.7	7.8
Soybean	13.5	16.8	14.2	17.0	15.4
Mean	12.2	12.4	11.5	12.1	

* W1 -severely water stressed level, W4 - control

Table A14. Influence of irrigation level on the crude protein content (%) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	20.0	17.0	17.0	17.0	18.0
Pearl millet	9.0	11.0	12.0	9.0	10.0
Fodder sorghum	7.0	9.0	6.0	7.0	7.0
Maize	5.0	7.0	7.0	7.0	6.0
Soybean	10.0	12.0	11.0	14.0	12.0
Mean	10.0	11.0	11 .0	11.0	
$LSD_T(C)$ = 2.5					

* W1 -severely water stressed level, W4 - control

Table A15. Correlation (r^2) between plant yield components and *in vitro* dry matter digestibility of five annual fodder crops in 1993/94.

Yield component	*In vitro* dry matter digestibility				
	Cowpeas	Pearl millet	Fodder sorghum	Maize	Soybean
Leaf	0.8	- 0.6	0.4	0.2	- 0.21
Stem	0.8	- 0.2	- 0.2	0.3	- 0.3
Reproductive component	- 0.2	0.1	- 0.6	0.2	- 0.6

Table A16. Correlation (r^2) between plant yield components and *in vitro* dry matter digestibility of five annual fodder crops in 1994/95.

Yield component	*In vitro* dry matter digestibility				
	Cowpeas	Pearl millet	Fodder sorghum	Maize	Soybean
Leaf	- 0.7	- 0.3	- 0.4	- 0.1	0.4
Stem	- 0.9	- 0.6	- 0.3	0.2	0.5
Reproductive component	- 0.1	0.1	0.1	0.3	0.6

Table A17. Correlation (R^2) between plant yield components and crude protein content of five annual fodder crops in 1994/95.

Yield component	Crude protein content				
	Cowpeas	Pearl millet	Fodder sorghum	Maize	Soybean
Leaf	- 0.2	0.2	0.1	0.5	0
Stem	- 0.3	0.1	- 0.1	0.6	0.1
Reproductive component	- 0.3	0.2	- 0.1	0.8	0.4

Table A18. Influence of irrigation level on the WUE_{DM} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	17.8	17.4	15.4	13.1	15.9
Pearl millet	22.2	22.0	19.9	16.0	20.0
Fodder sorghum	14.8	21.0	16.0	14.6	16.6
Maize	29.9	41.9	35.9	31.3	34.7
Soybean	22.4	20.4	18.3	17.0	19.5
Mean	21.4	24.5	21.1	18.4	

$LSD_T(C) = 4.7$

$LSD_T(I) = 3.0$

* W1 -severely water stressed level, W4 - control

Table A19. Influence of irrigation level on the WUE_{DM} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	4.1	11.6	9.3	9.6	8.7
Pearl millet	23.2	20.2	20.3	18.1	20.5
Fodder sorghum	17.0	22.9	19.5	16.6	19.0
Maize	18.6	31.1	26.7	26.4	25.7
Soybean	15.5	14.6	18.1	13.1	15.3
Mean	15.7	20.1	18.8	16.8	
$LSD_T(CxI) = 6.2$					

* W1 -severely water stressed level, W4 - control

Table A20. Influence of irrigation level on the digestible dry matter yield (t ha^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	2.6	3.6	3.6	3.5	3.3
Pearl millet	8.2	9.2	11.1	12.3	10.2
Fodder sorghum	8.4	11.0	12.1	14.9	11.6
Maize	9.4	16.4	15.3	14.7	13.9
Soybean	4.2	4.5	5.7	5.8	5.1
Mean	6.6	8.9	9.6	10.2	

* W1 -severely water stressed level, W4 - control

Table A21. Influence of irrigation level on the digestible dry matter yield (t ha^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.9	2.9	3.1	3.4	2.6
Pearl millet	6.0	6.6	9.6	9.8	8.0
Fodder sorghum	4.2	8.3	9.6	9.5	7.9
Maize	3.7	12.1	14.0	16.6	11.6
Soybean	2.9	5.3	8.2	7.3	5.9
Mean	3.5	7.1	8.9	9.3	
$LSD_T(CxI) = 0.8$					

* W1 -severely water stressed level, W4 - control

Table A22. Influence of irrigation level on the WUE_{DDM} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	11.0	10.4	10.4	9.4	10.3
Pearl millet	15.3	13.6	13.8	10.5	13.3
Fodder sorghum	9.8	13.5	12.8	10.6	11.7
Maize	22.4	30.6	25.8	23.1	25.5
Soybean	13.0	11.0	11.8	8.9	11.2
Mean	14.3	15.8	14.9	12.5	

* W1 -severely water stressed level, W4 - control

Table A23. Influence of irrigation level on the WUE_{DDM} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	3.2	7.7	6.0	5.7	5.7
Pearl millet	16.9	13.8	14.2	12.	14.2
Fodder sorghum	12.5	16.0	13.4	10.9	13.2
Maize	14.5	25.5	21.7	21.2	20.7
Soybean	9.7	10.1	12.3	9.1	10.3
Mean	11.4	14.6	13.5	11.8	
LSD_T(CxI) = 0.4					

* W1 -severely water stressed level, W4 - control

Table A24. Influence of irrigation level on the crude protein dry matter yield (t ha^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.8	1.1	0.9	0.8	0.9
Pearl millet	1.3	1.6	1.3	1.8	1.5
Fodder sorghum	1.2	1.5	1.4	2.1	1.6
Maize	1.1	1.7	1.7	1.3	1.5
Soybean	1.0	1.4	1.3	1.9	1.4
Mean	1.1	1.5	1.3	1.6	

* W1 -severely water stressed level, W4 - control

Table A25. Influence of irrigation level on the crude protein dry matter yield (t ha^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.2	0.8	0.8	1.0	0.7
Pearl millet	0.8	1.1	1.6	1.3	1.2
Fodder sorghum	0.4	1.1	0.9	1.0	0.8
Maize	0.2	1.0	1.3	1.4	1.0
Soybean	0.5	0.9	1.3	1.5	1.0
Mean	0.4	1.0	1.2	1.2	
$LSD_T(C) = 0.3$					
$LSD_T(I) = 0.3$					

* W1 -severely water stressed level, W4 - control

Table A26. Influence of irrigation level on the WUE_{CP} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1993/94.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	3.2	3.2	2.7	2.2	2.9
Pearl millet	2.4	2.3	1.7	1.6	2.0
Fodder sorghum	1.4	1.9	1.5	1.5	1.6
Maize	2.7	3.1	2.9	2.1	2.7
Soybean	3.0	3.4	2.6	2.9	3.0
Mean	2.6	2.8	2.3	2.1	

* W1 -severely water stressed level, W4 - control

Table A27. Influence of irrigation level on the WUE_{CP} (kg ha^{-1} mm^{-1}) of five annual fodder crops in 1994/95.

Crop (C)	Irrigation level (I) *				Mean
	W1	W2	W3	W4	
Cowpeas	0.8	2.0	1.6	1.7	1.5
Pearl millet	2.2	2.2	2.4	1.5	2.1
Fodder sorghum	1.2	2.1	1.3	1.1	1.4
Maize	0.8	2.1	2.0	1.9	1.7
Soybean	1.5	1.8	1.9	1.9	1.8
Mean	1.3	2.0	1.8	1.6	

$LSD_T(C) = 0.5$

$LSD_T(I) = 0.4$

* W1 -severely water stressed level, W4 - control

WATER USE AND WATER USE EFFICIENCY OF FODDER CROPS UNDER IRRIGATION: PART 2 – PERENNIAL SUBTROPICAL CROPS.

BY

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EXECUTIVE SUMMARY

Natural resources should be managed in a responsible way to ensure sustainable production of food, feed and other crops. In South Africa, prior to 1988, little was known of the water requirements of planted pastures. Applicable norms for irrigation scheduling were not in place and this often resulted in ineffective use of irrigation water. To get a better idea of planted pasture water use, a project was started in 1988 with temperate fodder crops followed by tropical and subtropical fodder crops in 1993. This study was made possible with financial support from the Water Research Commission.

The objectives of this project were to compare different pastures to determine whether a single set of irrigation guidelines could be used for all pastures; to determine yield and quality base water production functions as a tool to determine the economic optimum irrigation level for the different crops and to identify alternative crops, best suited for dryland and irrigation conditions.

The water use of five perennial subtropical crops was determined in two consecutive seasons in a trial conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria, Pretoria. The crops used were *Cenchrus ciliaris*, *Panicum maximum*, *Digitaria eriantha* sups eriantha, *Pennisetum clandestinum* and a *Cynodon* hybrid. Each grass was subjected to four irrigation levels, ranging from a stressed (W1) to a well watered control (W4).
Above-ground dry matter yields tended to decrease with less water being applied,

but due to the ability of the perennial grasses to extract water to a 1 400 mm soil depth, significant differences were only found between the control (W4) and severely water stressed (W1) conditions.

A comparison of the dry matter yields of the different grasses, indicated that *Cenchrus* was the highest yielding grass under these conditions. *Cynodon* also produced a high yield in the 1997/98 season, and yielded much more than the other creeping grass namely *Pennisetum*. *Panicum* had the most stable yields but yields were close to the bottom of the range.

Although there was no grass x irrigation level interaction, one of the project objectives was to determine which of the grasses is better adapted to irrigation or dry land conditions. In both seasons, *Cenchrus* yielded between three and seven tons more dry matter per hectare, under the severely water stressed conditions, than the other four grasses. This species, however, also yielded the highest in the 1996/97 season and second highest in the 1997/98 season under well watered conditions. This indicates that *Cenchrus* has the ability to do well under irrigated conditions, while under dryland conditions it had no equal.

It is difficult to choose one of the remaining species as being ideal for irrigated conditions (W4) on the basis of dry matter yields only. *Digitaria* and *Cynodon* had the highest yields in the 1996/97 season, with *Cynodon* and *Pennisetum* having the highest yields in the 1997/98 season. The only conclusion that may be drawn from this information is that *Cynodon* is one of the best options under irrigation.

In both seasons, water was used more efficiently under water limiting than under well watered conditions. All plots were irrigated weekly. Irrigating at different frequencies might affect the results and this has to be kept in mind when comparing these with other data.

The water use efficiency data confirms that there was no equal to *Cenchrus* under dryland conditions. *Cenchrus* was able to use water far more efficiently under dryland than under well watered conditions in comparison to the other grasses.

From the water use efficiency data, it is not clear which of *Cynodon*, *Digitaria* or *Pennisetum* would be recommended for use under well watered conditions. *Cynodon* and *Pennisetum* are often irrigated, whilst *Digitaria* is not generally recommended for irrigated conditions. These data indicate that *Digitaria* should be considered as a viable alternative where irrigation is available.

The dry matter digestibility was quite variable between seasons and no general conclusions could be drawn. There were, however, clear differences in the crude protein content of the grasses. The two creeping grasses, *Cynodon* and *Pennisetum*, tended to have the highest crude protein content. The protein contents reported in the literature also indicate a high crude protein content for these two grasses and indicate that these results are not exceptionally high.

With the application of new technologies in agriculture it is evident that a single set of guidelines for the irrigation of forages, or other crops, will not have universal application. There are clear indications that considerable variation in both yield and quality occurs between different regions and between seasons at the same location. By combining crop factors with comprehensive soil and climate parameters in simple, or complex predictive models, it should be possible to ensure the best possible yields (and quality) under specific conditions.

According to an economic analysis, done with the models IrriCost and FARMS, it is cheaper to produce a ton of dry matter under severe moisture stress (W1) than control (W4) conditions.

The cash flow closing balance for all the treatments was negative due to a starting balance of zero. Despite this, the cash flow for producing the grasses under severe moisture stress (W1) conditions were far better than under control (W4) conditions.

CHAPTER 1

INTRODUCTION AND LITERATURE STUDY

1.1 Introduction

On intensive livestock farms, subtropical grasses are being used extensively to fulfill the fodder needs of the animals (Heard, Tainton & Edwards, 1984a and 1984b). A large percentage of these pastures are under irrigation, due to the high production potential of the subtropical grasses. Subtropical grasses can, for example, produce two to three times as much dry matter as temperate grasses (Grunow & Rabie, 1985). An additional advantage of irrigating subtropical grasses is that peak production and a good quality fodder can be produced earlier in the season (Grunow & Rabie, 1985).

In a discussion document on Agricultural Policy in South Africa by the Ministry of Agricultural and Land Affairs (1998) it is stated that 50% of water in South Africa is already used for irrigation purposes, but the demand for more water from urban and industrial users is growing rapidly. Limited water availability suggests that at most an additional 200 000 ha could be brought under irrigation. The document goes further by saying that only crops that have a high cash value should be considered for use in irrigation schemes. Researchers and farmers will thus have to ensure that meat, milk and fibre from irrigated pastures are produced as efficiently as possible.

To increase biological water use efficiency all the determining factors have to be taken in consideration. These include soil, climate, plant and economic considerations. Knowing the plant and its response to a given water supply is a major step towards using water more efficiently, and the rest of this chapter will concentrate on the five grass species nl. *Cenchrus ciliaris, Cynodon dactylon, Digitaria eriantha* sups. *eriantha, Pannicum maximum* and *Pennisetum clandestinum*, used in this trial.

1.2. Literature study

The background information gives an overview on the use of the five grasses in different parts of the world, as well as the variability of production due to different growing conditions as well as water supply.

1.2.1. *Cenchrus ciliaris* L.

Cenchrus (Bluebuffel or buffel grass) is an indigenous perennial with well developed short rhizomes, while certain cultivars (e.g. Molopo) have creeping stems with roots developing at the lower nodes which are in contact with the soil (Rattray, 1960; Tainton, 1988; Dickinson, Hyam & Breytenbach, 1990; Gibbs-Russel, Watson, Koekemoer, Smook & Barker, 1991; Van Outshoorn, 1991). The genus *Cenchrus* is commonly found in hot dry areas of the world (Rattray, 1960; Tainton, 1988; Dickinson *et al.* ,1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991; Moolman, 1993) receiving as little as 254 mm a^{-1} (Rattray, 1960), while *Cenchrus ciliaris* is generally associated with rainfall between 400 and 600 mm (Rattray, 1960; Tainton, 1988). It has been found to be extremely drought tolerant, which might be due to a strong, deep (1.5 m) root system (Dickinson *et al.*, 1990). In the literature there is no consensus on the soil preferences of *Cenchrus*, which might indicate adaptability to a variety of soil types ranging from gravelly, sandy soils to heavy clay soils (Rattray, 1960; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991) but restricted to well drained conditions. In its natural state, it can be found in the Savanna, Grassveld and Nama-Karroo biomes (Rattray, 1960; Van Outshoorn, 1991; Moolman, 1993).

According to Dickinson *et al.* (1990), *Cenchrus* is used mainly for beef production, but it can also play an important role in the fodder flow of dairy cattle, sheep and horses. The material can be grazed or used as hay (Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991). Planted *Cenchrus* pastures are ready for grazing early in the season and can help relieve pressure on natural veld during the early summer months (Tainton, 1988; Dickinson *et al.*; 1990), but can also provide good grazing material during autumn (Tainton, 1988).

Some of the cultivars to be found in South Africa include Molopo and Gayndah, with Biloela and West Australian being less well known (Dickinson *et al.*, 1990; Moolman, 1993). Molopo was selected in South Africa, while Gayndah was imported from Australia, where it was selected from material originating from Kenya (Dickinson *et al.*, 1990; Moolman, 1993). Gayndah is a low growing non-creeping cultivar (Moolman, 1993) that has softer leaves than Molopo (Dickinson *et al.*, 1990) and should thus be better suited for sheep grazing. Molopo is a creeping tall growing cultivar (Moolman, 1993), which is considered to be more drought tolerant than Gayndah (Dickinson *et al.*, 1990). *Cenchrus* can be propagated by means of seed or vegetative material.

The crude protein content of *Cenchrus* has been found to be as low as 3.8% (no nitrogen applied) or 4.8%, if left on the field until frosted, and as high as 18.6% when grazed at a young stage (Tainton, 1988; Dannhauser, 1991). According to Dickinson *et al.* (1990) the protein content of hay can be between 7.0 and 8.9%. Dry matter digestibility of the whole plant can be between 55 and 65% (Dannhauser, 1991) or that of the leaves alone around 64% (Moolman, 1993). Under low rainfall conditions (< 650 mm a^{-1}) 1.8 to 4.1 t dry matter ha^{-1} can be produced (Dannhauser, 1991), while the yields can be as high as 11.4 t ha^{-1} (Moolman, 1993) and 12.0 t ha^{-1} (Dannhauser, 1991) under higher rainfall conditions. Under the same conditions cultivar Molopo produced about 6 to 7 t ha^{-1} more than Gayndah and the West Australian cultivars (Moolman, 1993).

1.2.2. *Digitaria eriantha* subsp *eriantha* Steud.

Digitaria (Smutsfinger grass) is an indigenous, palatable, perennial grass with tufted rhizomatous or stoloniferous growth forms (Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991), that can be found in areas with rainfall as low as 400 mm a^{-1} but also as high as 1 000 mm a^{-1} (Tainton, 1988; Dickinson *et al.*, 1990; Van Outshoorn, 1991). Despite its adaptability to high rainfall conditions, it is seldom found under irrigation (Dickinson *et al.*, 1990). Although it can be found under low rainfall conditions, the best production will occur in situations where the annual rainfall is 500 mm or more (Tainton, 1988; Dannhauser, 1991). It is not generally regarded as being as drought resistant as *Cenchrus*. *Digitaria* although, adapted to a wide variety of soil types, does best on gravelly and light sandy soils (Dickinson *et al.*, 1990; Dannhauser, 1991; Van Outshoorn, 1991). This species also does not tolerate waterlogged conditions for extended periods. In veld, *Digitaria* is an indicator of good veld condition and can be found in the Transvaal mixed and sweet bushveld, Savanna and Nama Karroo biomes (Tainton, 1988; Van Outshoorn, 1991).

In semi-intensive and intensive meat (cattle and sheep) production systems, *Digitaria* can play an important role (Dickinson *et al.*, 1990). *Digitaria* can be used for grazing or kept for later use in the form of hay and foggage (Tainton, 1988;Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991). The latter is due to the fact that it remains relatively palatable throughout the year (Dickinson *et al.*, 1990; Van Outshoorn, 1991). According to Tainton (1988) and Dickinson *et al.* (1990), *Digitaria* should be used mainly for grazing, from late spring to autumn, and as foggage, during the winter. Although *Digitaria* will yield some grazing in the early spring, using it later in the season will give better production results.

With the start of this project there was only one cultivar available in South Africa, namely Irene (Dickinson *et al.*, 1990; Dannhauser, 1991). A new cultivar, TipTop, has been developed by the Agricultural Research Council (Roodeplaat), and will be available soon (A. Smith, personal communication, 1999)[1].

Irene is very variable, but gives good results (Dannhauser, 1991). *Digitaria* can be propagated by means of seed.

Although *Digitaria* remains palatable in the winter, the crude protein content can drop to 5%, in comparison to 17 to 22 % during the growing season (Dickinson *et al.*, 1990; Dannhauser, 1991). A drop in digestibility from 60 to 65% in the growing season to as low as 40% in the winter can also be expected (Dannhauser, 1991). Yields are influenced by not only the amount of rain, but also the amount of nitrogen applied. Without any nitrogen the yields may be as low as 2.2 t ha^{-1} or as high as 5.8 t ha^{-1} with 140 kg N ha^{-1} (Dannhauser, 1991) or 6.5 t ha^{-1} with 100 kg N ha^{-1} (Dickinson *et al.*, 1990).

1.2.3. *Panicum maximum* Jacq.

Panicum (Whitebuffel or Guinea grass) is a large and important genus in Africa. *Panicum maximum* is a perennial, occasionally annual, tufted grass with rooting taking place at lower nodes, which come in contact with the soil (Rattray, 1960; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991). It prefers moist and shady places, especially under canopies of trees or brush and bushes, but is, however, adapted to a variety of conditions from

[1]Roodeplaat Range & Forage Institute, Private Bag X05, Lynn East, 0039.

the Eastern Cape Province to the Northern Province (Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991). *Panicum* can be produced with as little as 380 mm a^{-1}, or as much as 1 700 mm rain a^{-1} (Rattray, 1960; Dickinson *et al.*, 1990; Dannhauser, 1991), although the best results can be expected with 500 mm a^{-1} or more. According to Dickinson *et al.* (1990), *Panicum* has a relatively shallow root system. This specie prefers fertile soils with good drainage but should preferably not be established on very sandy or heavy clay soils (Dickinson *et al.*, 1990; Van Outshoorn, 1991). It can tolerate light frost and in frost free areas has the ability to grow year round. *Panicum* is usually associated with the sour, sweet or mixed bushveld biomes, but also with the Nama Karroo and Fynbos biomes (Tainton, 1988; Van Outshoorn, 1991).

Panicum is very palatable throughout the year and can be used for summer grazing or foggage as well as for hay making (Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991). Both game and livestock have been found to use *Panicum* for grazing (Rattray, 1960). Much of the carbohydrates are stored in the tiller bases above the soil surface during the winter months, and grass should be allowed to recuperate in the spring if it was heavily utilized as foggage in the winter.

Some of the cultivars known in South Africa include Green Panic, Gatton, Sabi and Mutale (Pretorius, 1973; Dickinson *et al.*, 1990; Dannhauser, 1991). Green Panic is sensitive to cold, but is drought resistant with the ability to also produce under extremely wet conditions (1 700 mm a^{-1}) as long as the soil is not waterlogged. Gatton grows under much the same conditions as Green Panic, but is less sensitive to cold. Gatton seed is imported from Australia. Sabi, a cultivar from Zimbabwe, is also sensitive to cold but less sensitive to drought conditions than any of the other cultivars mentioned. This cultivar is resistant to root-knot nematodes and can be used in a rotation system with tobacco. Sabi can be cut for silage and is adapted to many soil types. Mutale produces a lot of leaf material and is not very sensitive to cold conditions. *Panicum* is usually established with seed.

According to Dannhauser (1991), yields as high as 20 t ha^{-1} have been reported for *Panicum*, but 4 to 12 t ha^{-1} is more the norm for fertilized pastures. In the Eastern Cape Province with 400 to 700 mm rain a^{-1} , yields of 6.4 - 14.5 t ha^{-1} were harvested (Dannhauser, 1991). Cultivar Sabi reacted well to N, P and K fertilisers and gave yields of 9.9 t ha^{-1} with, and 3.6 t ha^{-1} without, nitrogen (Pretorius, 1973). In the summer the crude protein content ranged from 6.0 to 22.6%, while the dry matter digestibility ranged from 53 to 62% (Dannhauser, 1991).

1.2.4. *Cynodon dactylon* (L.) Pers.

Cynodon (Couch or Bermuda grass) is a perennial, sward forming, rhizomatous and stoloniferous grass species (Archer & Bunch, 1953; Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Van Outshoorn, 1991). Coastcross II (K II), the hybrid used in these trials, is a cross between a Bermuda grass (*Cynodon dactylon)* and another *Cynodon* specie from Kenya (Dickinson *et al.*, 1990; Dannhauser, 1991). *Cynodon* can be found world wide in warm and temperate regions and with rainfall ranging from 400 mm upwards, this species should give good yields (Tainton, 1988; Dickinson *et al.*, 1990; Dannhauser, 1991). It can withstand short periods of drought (Hughes, Heath & Metcalfe, 1966). Any type of soil can be used for planting *Cynodon* pastures (Dickinson *et al.*, 1990; Dannhauser, 1991) but in general it has a better production on fertile and heavy clay soils rather than sandy soils (Hughes *et al.*, 1966; Van Outshoorn, 1991). *Cynodon* is usually associated with the Grassveld, Savanna, Nama Karroo and Fynbos biomes.

Cynodon is a grass with diverse usages which range from grazing (Archer & Bunch, 1953; Hughes *et al.*, 1966; Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991), hay (Hughes *et al.*, 1966; Archer & Bunch, 1953; Tainton, 1988; Dickinson *et al.*, 1990) and silage making (Dickinson *et al.*, 1990), to erosion control (Archer & Bunch, 1953; Tainton, 1988; Gibbs-Russel *et al.*, 1991; Van Outshoorn, 1991) and recreation (Tainton, 1988; Gibbs-Russel *et al.*, 1991). *Cynodon* is also an important weed (Gibbs-Russel *et al.*, 1991) along roads, near dams or in cultivated fields. Due to a deep rhizome (up to 1.0 m deep) it is rather difficult to control the spread of this grass. As fodder, *Cynodon* can be used by both sheep and cattle during the spring, summer and autumn months. In frost free areas it can grow throughout the year and winter grazing might also be possible (Van Outshoorn, 1991).

Coastcross II is a sterile *Cynodon* hybrid and can only be propagated by means of vegetative material (Dickinson *et al.*, 1990; Dannhauser, 1991). It has the ability to grow very rapidly and will establish and spread easily, covering the soil surface in a short time (Dickinson *et al.*, 1990). Coastcross II is also resistant to root-knot nematode attacks.

In a trial, reported by Dickinson *et al.* (1990), higher yields were obtained with longer harvest intervals (17.6 to 23.2 t ha^{-1}), but the dry matter digestibility (65.2 to 51.0%), crude protein content (18.5 to 9.0%) and leaf percentages (83 to 51%) decreased with longer harvest intervals. Archer & Bunch (1953) have reported hay yields of 1 to 3 t ha^{-1}. In Natal yields of 12 to 18 t ha^{-1} have been reported while 3 to 6 t ha^{-1} were harvested in the Potchefstroom area (Dannhauser, 1991), with crude protein contents of 9 to 18% and dry matter digestibilities of 51 to 65%.

1.2.5. *Pennisetum clandestinum* Chiov.

Pennisetum (Kikuyu) originated in Kenya and is a perennial sod forming grass which spreads vigorously by means of rhizomes and stolons (Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Dannhauser, 1991; Van Outshoorn, 1991). This species is adapted to the East African Highlands (> 1 200 m) with rainfall ranging from 760 mm to 2 300 mm per annum (Rattray, 1960; Gibbs-Russel *et al.*, 1991; Van Outshoorn, 1991). Dickinson *et al.* (1990) and Dannhauser (1991) recommend planting *Pennisetum* under irrigation or in areas where the annual rainfall is above 700 mm, while Rattray (1960) and Tainton (1988) advise rainfall above 750 mm. It can tolerate moderate frost conditions, which make it a better species to use than *Cynodon* if frost is common in the area (Dickinson *et al.*, 1990). On the other hand *Cynodon* is much more drought tolerant than *Pennisetum* and this should be kept in mind when deciding between the two species

(Dannhauser, 1991). *Pennisetum* will do well on fertile soils with a high organic matter content (Tainton, 1988; Dickinson *et al.*, 1990; Dannhauser, 1991; Van Outshoorn, 1991). Any type of soil, with the application of the necessary nutrients, can thus be used, as long as it does not get too waterlogged. *Pennisetum* is usually associated with the Grassveld and Fynbos biomes.

Pennisetum is not only known as a palatable fodder crop (Rattray, 1960;Tainton, 1988; Dickinson *et al.*, 1990; Gibbs-Russel *et al.*, 1991; Van Outshoorn, 1991; Dannhauser, 1991), but is also widely used as a lawn grass (Tainton, 1988; Gibbs-Russel *et al.*, 1991; Van Outshoorn, 1991; Dannhauser, 1991), while it can also become a weed in cultivated areas (Gibbs-Russel *et al.*, 1991). According to Tainton (1988), *Pennisetum* is grazed mainly in spring and autumn and utilized as foggage in the winter in the cool inland regions, while in the warmer coastal regions it can be used throughout the year for grazing, as hay or foggage. *Pennisetum* can be grazed by milk cows and sheep in the summer or utilized as foggage or silage in the winter months (Dannhauser, 1991).

The two *Pennisetum* cultivars used in South Africa are Whittet and Common (Dannhauser, 1991). Not much is known about the difference between the two, except that Whittet can be propagated by means of seed or vegetative material, while Common is propagated with vegetative material.

The crude protein content given for *Pennisetum* is quite high , 29 - 32% (Tainton, 1988), 17.3 - 25.6% (Dickinson *et al.*, 1990) and 15 - 22% (Dannhauser, 1991). The total digestible nutrients are between 54 and 67% (Tainton, 1988 ; Dickinson *et al.*, 1990, Dannhauser, 1991). According to Tainton (1988), yields of up to 15.6 t ha^{-1} were harvested in the Natal area, while up to 18 t ha^{-1} has been harvested in the summer rainfall area (Dannhauser, 1991).

1.3. Motivation and Objectives

In 1988 a lack of information about the water requirements of planted pastures was identified as a major problem. If norms for irrigation scheduling are not available this can result in ineffective use of water. To obtain a better idea of planted pastures water use, a long term project was started in 1988 (Steynberg, Nel & Rethman, 1993) with temperate fodder crops followed by tropical and subtropical crops in 1993.

In a small plot irrigation trial annual (Part 1) and perennial fodder crops (Part 2) were cultivated from 1993 till 1998. The objectives for both groups were to:

- develop irrigation norms for perennial subtropical planted pasture crops;
- develop water production functions as a tool in the planning of economic optimum irrigation levels and size of plantings;
- identify alternative crops with high water use efficiencies for use under both dryland and irrigated conditions.

CHAPTER 2

GENERAL PROCEDURE

2.1. Trial area, material and design

A randomized block design trial with five species, four levels of irrigation and three replications was established under an automatic rain shelter. This area was divided into 60 plots, each 2.0 m x 2.5 m. The roots in each plot were separated from adjacent plots using asbestos sheets to a depth of 1.2 m. Each plot had a neutron probe access tube to a depth of 1.8 m. These access tubes were situated in approximately the centre of each plot. The soil is a Hutton form, Shorrock series with about 30% clay in the top soil (MacVicar *et al.*, 1991). The soil is uniform for the first 1.2 m, at which depth a characteristic gravel layer is evident.

Five perennial subtropical grasses were used as trial material. The planting densities of the grasses are presented in Table 1.

Table 1. Planting details of the different subtropical grasses under the automatic rain shelter.

Grass	Cultivar	Planting density (plants ha^{-1})	Row spacing (m)
Cenchrus	Molopo	300 000	0.2
Panicum	Gatton	300 000	0.2
Digitaria	Irene	300 000	0.2
Pennisetum	Whittet	160 000	0.3
Cynodon	K II	160 000	0.3

Cultivars of the different grasses were chosen mainly on the grounds of previous experience. In the case of *Digitaria* and *Pennisetum*, there was not a large group of cultivars to choose from and available seed had to be used. A limited number of plots were, however, available and more than one cultivar per species could not, therefore, be accommodated. New cultivars might be better yielding than the ones used in this trial and one should keep this in mind when comparing performance.

The seed of *Cenchrus*, *Panicum*, *Digitaria* and *Pennisetum* was sown in seedling trays. This was done during the winter of 1995 and the seedling trays were kept in a greenhouse. *Cynodon* was established using vegetative material, collected on the experimental farm. The *Digitaria* had a low germination percentage and had to be re-seeded. As a result the *Digitaria* seedlings were only planted on the 25th of January 1996, 10 weeks after the other species (3-6 November 1995). During the first year (1995/96 season), the grasses were not subjected to differential irrigation treatments to ensure good establishment. It has been found that most of these grasses only produce optimally from the second year of establishment. To ensure a fair comparison, treatments were thus only applied from the second year.

2.2. Soil water monitoring and irrigation treatments

1995/96 Season

The soil profile was brought to field capacity, to a depth of 1.8 m, at planting. The soil water content of this profile was determined on a weekly basis using a Campbell Pacific Nuclear neutron probe (503 DR). The field capacity readings for nine 0.2 m depth increments were determined beforehand. The difference between field capacity and the weekly readings then represented the soil water deficit for that layer. Readings were taken for each plot, but only the control plot readings were used to calculate the irrigation amounts. The soil water deficit for the whole 1.8 m soil profile was then determined and the water applied. To encourage good establishment, differential irrigation was not implemented during this season and only a well watered irrigation treatment was used.

1996/97 and 1997/98 seasons

The soil profiles of each plot were brought to field capacity at the start of each growing season. There-after the soil water content of the whole 1.8 metre profile was determined on a weekly basis with a neutron probe. Unlike the previous season, differential irrigation was applied on a weekly basis. The irrigation treatments (henceforth referred to as irrigation levels) used were:

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

W2 - apply 50% of the average amount given to W4

W3 - apply 75% of the average amount given to W4

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

The control plots (W4) received water in accordance to individual profile water deficits. For the other three irrigation levels, the control amounts, for the specific grass species, were averaged to determine the irrigation amounts.

Between the summer growing seasons, the species received no water, but the water deficit was monitored on a regular basis.

2.3. Fertiliser application

The fertilisers used were limestone ammonium nitrate (LAN) (28% N); superphosphate (8.3% P) and potassium chloride (KCl) (50% K).

A soil analysis (Table 2) served as the basis for the following fertilizer programme. The objective was to attain a soil status of 40 mg P kg^{-1} and 150 mg K kg^{-1}. Both the phosphorus and potassium content in the top layer is higher than that of the sub-soil layers (Table 2). The soil pH is close to neutral and lime application was, therefore, unnecessary. The grasses were not grazed, but clippings were removed, resulting in large quantities of N, P and K being removed from the soil system.

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 a top dressing, during the summer growing season resulting in total applications of 450 kg N ha^{-1} a^{-1} and 400 kg K ha^{-1} a^{-1}. In the 1996/97 and 1997/98 seasons, nitrogen and potassium were applied to the different irrigation levels as top dressings at rates of 225, 337.5, 393.8 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 irrigation levels respectively.

Table 2. Soil analysis for the plots under the rain-shelter on the Hatfield Experimental Farm (1996).

Soil depth (mm)	pH (H_2O)	Bray II P ($mg\ kg^{-1}$)	NH_4-acetate seperation K ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)
0 - 21	7.3	30	108	595	279
21 - 42	7.0	8	67	540	184
42 - 63	6.7	3	49	501	175

2.4. Harvest and further analysis of the dry matter produced

The crops were harvested with the aim of producing high quality fodder. The *Cenchrus*, *Panicum* and *Digitaria* were harvested in the early flowering stage, while the *Cynodon* and *Pennisetum* were harvested as soon as they reached a height of approximately 30 cm. The tufted grasses were clipped to a height of 10 cm and the creeping grasses to a height of 5 cm. The harvest dates for the two seasons are presented in Table 3.

Table 3. Harvesting dates for five perennial grasses under an automatic rain shelter.

Grass	Harvest dates			
	1	2	3	4
Cenchrus	4/12/96	17/2/97	23/5/97	-
	22/10/97	17/12/97	4/02/98	1/04/98
Cynodon	20/11/96	21/1/97	14/3/97	18/6/97
	4/12/97	5/02/98	21/04/98	-
Digitaria	5/12/96	6/2/97	18/4/97	-
	24/10/97	8/01/98	15/04/98	-
Panicum	8/1/97	25/4/97	-	-
	18/11/97	9/02/98	19/05/98	-
Pennisetum	9/1/97	24/3/97	20/6/97	-
	17/12/97	5/2/98	24/4/98	-

From each 5 m^2 plot, a 1 m^2 quadrant was harvested to determine the dry matter yield. After these samples had been taken, the remainder of each plot was also cut. Four tufts per plot of *Cenchrus*, *Panicum* and *Digitaria* and four 0.25 x 0.25 m samples of *Cynodon* and *Pennisetum* were harvested and divided into leaf, stem and reproductive components to determine the dry matter contribution of each to the above-ground plant dry mass. The stems were taken as the stems and leaf sheaths, while the leaf blades were taken as the leaf. Reproductive components were taken as the inflorescence.

Intact plants as well as the different yield components, for each grass, were milled after drying. The material was dried at 60°C till a constant weight was reached. 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 as well as the crude protein content of the crops.

2.5. Fodder quality

2.5.1. *In vitro* digestibility

The dry matter, organic matter and ash contents of the samples were determined by drying 2 g of each sample for 24 hours at 60°C (dry matter content), before incinerating at 600°C for 4 hours (ash content). The organic matter content could be 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 & Terry (1963).

2.5.2. Crude protein content

The milled plant samples were analysed for nitrogen content (%) using the Kjeldahl technique (Association of Official Analytical Chemists, 1984). These values were multiplied by 6.25 (Van der Merwe & Smith, 1991) to determine the crude protein content (%) of the samples.

2.6. Root study

In 1999, a root study was conducted on the W1 and W4 plots. Three replicate cores per plot were taken in an attempt to account for variability in research results. Soil samples were taken with a soil auger to a depth of 1.05 or 1.26 m. Deeper samples were made difficult by the presence of a gravel layer which tended to compact the samples or even prevented penetration of the auger.

After sampling, the soil samples were washed under running water, the roots dried, and the root lengths determined with a Geotron Root Length Meter (Model WLM1).

2.7. Statistical analysis

The material of each plot was kept apart to facilitate statistical analysis. With the aid of Statomet, a division of the Department of Statistics of the University of Pretoria, the data were analysed with the statistical software programme, SAS (Statistical Analysis System).

The least significant difference of Tukey (LSD_T), at the 95% probability level was used to determine significant differences between means.

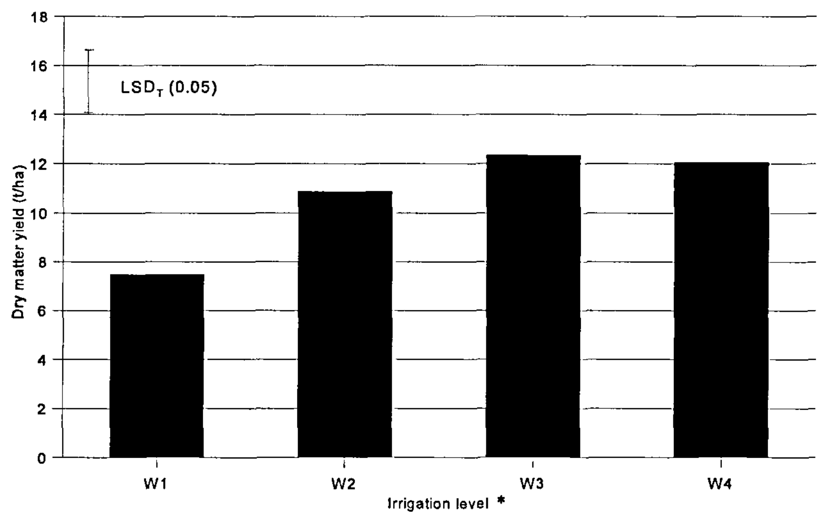
CHAPTER 3

RESULTS AND DISCUSSION

3.1. Dry matter yield

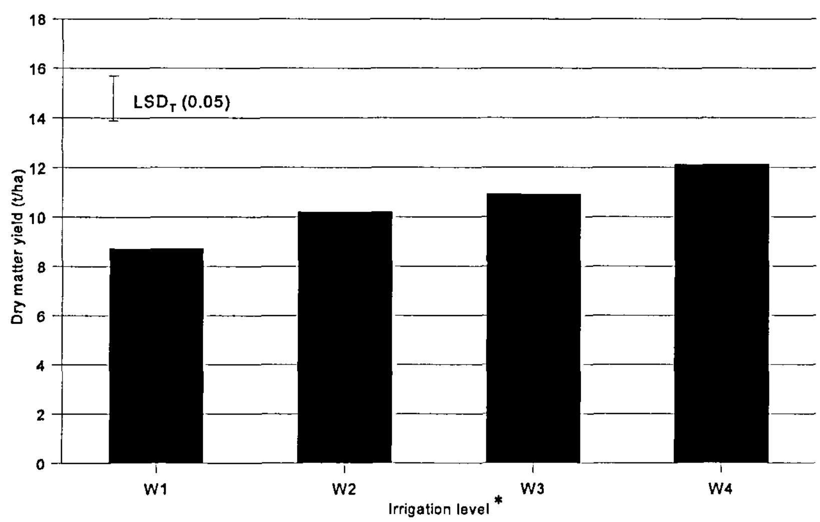
The dry matter yields presented in Figures 1 to 4, represent the total above-ground yield for the whole season. There was no significant grass species x irrigation level interaction in either the 1996/97 or the 1997/98 seasons. The yields at certain irrigation levels (Figure 1 and 2) did, however, differ significantly from each other in both seasons. In the 1996/97 season (Figure 1) the W1 irrigation level resulted in a significantly lower yield than the remaining three irrigation levels. In the following season (Figure 2) both the W1 and W2 irrigation levels resulted in significant lower yields than under control conditions (W4).

In the 1996/97 season (Figure 3) the yields of the two creeping grasses were quite low in comparison to the yields found in the literature (Van Heerden, 1986; Burton, Butler & Hellwig, 1987; Pieterse, Grunow & Rethman, 1988; Pieterse, Grunow, Rethman & van Niekerk, 1989). Despite these initial low yields *Pennisetum* and *Cynodon* did quite well in the 1997/98 season (Figure 4), with *Cynodon* producing higher yields than *Pennisetum*. The same was found in Pietermaritzburg (Hefer & Tainton, 1990) where *Cynodon* yielded about 3.5 to 4.5 t ha^{-1} in comparison with the 3.0 to 4.3 t ha^{-1} of *Pennisetum* in the same trial.



* W1 -severely water stressed level, W4 - control

Figure 1. The average total above-ground dry matter yield of five grass species for four irrigation levels in the 1996/97 season.



* W1 -severely water stressed level, W4 - control

Figure 2. The average total above-ground dry matter yield for five grass species for four irrigation levels in the 1997/98 season.

The yields of *Panicum*, under these conditions (Figures 3 and 4), were below 10 t ha^{-1}, Dannhauser (1991) stated that 4 to 12 t ha^{-1} would be the norm for *Panicum* yields. There might, however, be differences in yield potential between different cultivars as found by Singh, Singh & Sale (1995). These researchers reported yields ranging from 10.1 to 26.6 t ha^{-1} with 1 728 mm rain and enough N, P and K to prevent deficiencies.

The grass species that did the best under the rain-shelter was *Cenchrus*, producing the highest average dry matter in both seasons (Figures 3 and 4). *Digitaria* yielded well in the 1996/97 season (Figure 3), but in the following season the yield did not differ significantly from *Panicum* or *Pennisetum* (Figure 4). Under dryland conditions on the Highveld, *Digitaria* yielded between 7.1 and 12.0 t ha^{-1} (Pieterse *et al.*, 1989), while a predictive map drawn by Dannhauser, Van Rensburg, Opperman & Van Rooyen (1987) indicated a potential yield of 7 t ha^{-1}, with 800 mm precipitation and 240 kg N ha^{-1}.

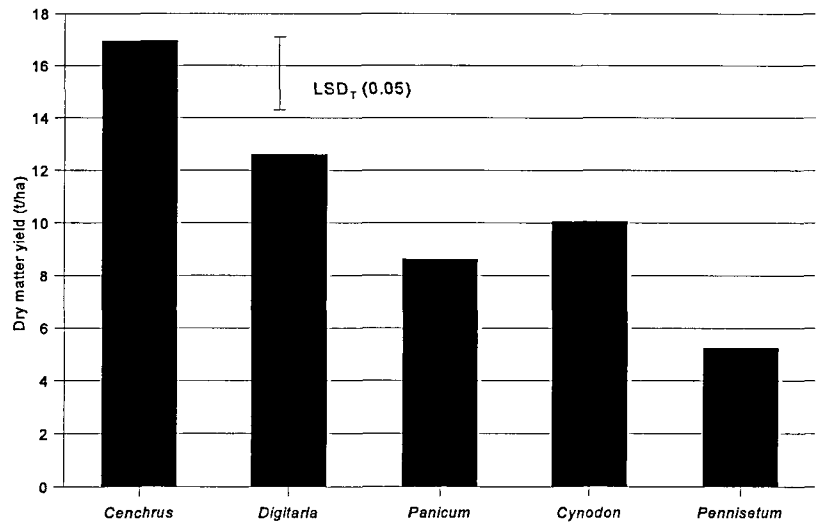


Figure 3. Total above-ground dry matter yield for five perennial grass species, averaged over four irrigation levels, in the 1996/97 season.

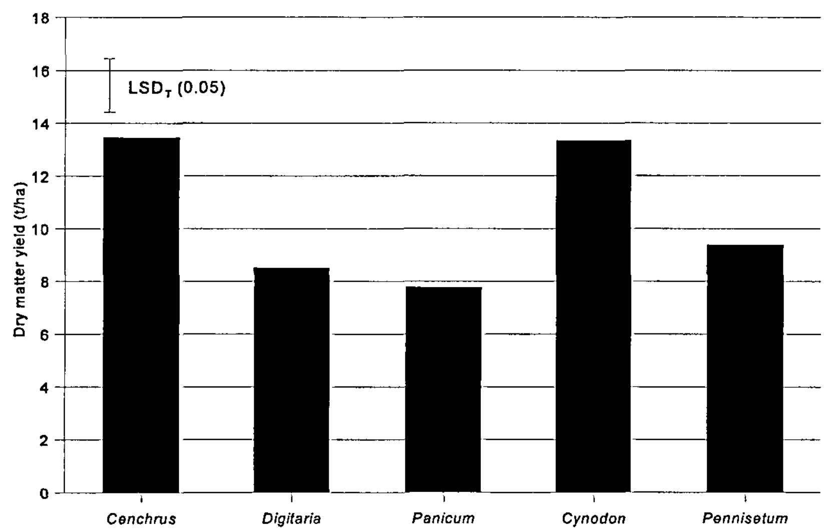


Figure 4. Total above-ground dry matter yield for five perennial grass species, averaged over four irrigation levels, in the 1997/98 season.

Although there were no significant interactions, the following can be said of the five grass species under the four irrigation levels (Tables 4 and 5). *Cenchrus* yielded between 13 and 20 t ha^{-1} in the two seasons under W2, W3 and W4 irrigation conditions. Although the yield under the severely stressed irrigation level (W1) was lower than under the other irrigation levels, *Cenchrus* was still able to produce higher yields under the W1 irrigation level than any of the other grasses, and was better than some of the grasses under control conditions (W4).

As stated earlier, *Cynodon* did not yield as expected in the first season, but in the second season it outyielded *Cenchrus* under the W3 and W4 irrigation levels, although the average yield of *Cenchrus* was higher. In comparison to *Pennisetum*, *Cynodon* was more drought tolerant which is in agreement with results obtained by Dannhauser, 1991.

In the 1997/98 season the yields of *Pennisetum* practically doubled for all the irrigation levels in comparison to the previous seasons yields. In 1997/98 *Pennisetum* and *Panicum* yields under control conditions (W4) were much higher than under the other irrigation levels. These two species appear to be better adapted to cooler and more moist conditions, and water stress resulted in large yield decreases. Snyman (1994) also stated that *Panicum* was not adapted to drought conditions and had a better potential under better water supply conditions.

Table 4. Influence of irrigation level on the dry matter yield (t ha^{-1}) of five perennial grasses in the 1996/97 season.

Grass	Irrigation level				Mean
	W1	W2	W3	W4	
Cenchrus	11.7	17.0	20.0	19.2	17.0
Cynodon	7.4	8.8	12.1	12.0	10.1
Digitaria	8.2	14.9	14.1	13.2	12.6
Panicum	6.2	8.7	9.2	10.4	8.6
Pennisetum	4.0	5.1	6.3	5.6	5.3
Mean	7.5	10.9	12.4	12.1	

* W1 -severely water stressed level, W4 - control

Table 5. Influence of irrigation level on the dry matter yield (t ha^{-1}) of five perennial grasses in the 1997/98 season.

Grass	Irrigation level				Mean
	W1	W2	W3	W4	
Cenchrus	12.4	13.9	13.9	13.7	13.5
Cynodon	9.7	13.2	14.7	15.8	13.3
Digitaria	6.9	8.2	9.0	9.9	8.5
Panicum	7.0	7.0	7.7	9.4	7.8
Pennisetum	7.7	8.7	9.3	11.8	9.4
Mean	8.7	10.2	10.9	12.1	

* W1 -severely water stressed level, W4 - control

3.2. Contribution of the yield components to the above-ground dry matter yield

During the harvesting process, sub-samples of 0.25 x 0.25 m were taken of the creeping grasses, while tufts were regarded as sub-samples of the tufted grasses. A direct comparison between these two sub-samples could thus not be made. To make comparison possible, the dry matter contribution per area was determined and is presented in Figures 5 and 6.

Due to the cutting regime followed, the reproductive component made up a very small proportion of the above-ground dry matter yield, which consisted mainly of leaves and stem.

Cynodon, *Digitaria* and *Pennisetum* were similar in following the same trend. These grasses had more leaf than stem in both seasons. Dannhauser (1991) also mentions a high leaf : stem ratio for *Cynodon* as well as a large amount of leaf material being produced by *Digitaria*. From the literature it is also evident that *Pennisetum* produces an abundance of leaves (Gibbs-Russel *et al.*, 1991) while *Digitaria* can easily be ensilaged due to its leafiness (Dickinson *et al.*, 1990).

Panicum and *Cenchrus* were not consistent in the two seasons. In the 1996/97 season the stem dry matter of the two species was respectively 0.9 and 1.3 t ha^{-1} more than for the leaves. In the following season, however, the leaf dry matter was 1.0 and 1.2 t ha^{-1} more than the stem dry matter respectively. In the 1996/97 season, *Panicum* was only cut twice and *Cenchrus* three times, while three cuttings were taken for *Panicum* and four cuttings for *Cenchrus*, in the 1997/98 season resulting in shorter regrowth periods, with less accumulation of stem material.

The only notable results with respect to yield of reproductive material was that of *Digitaria* in the 1996/97 season.

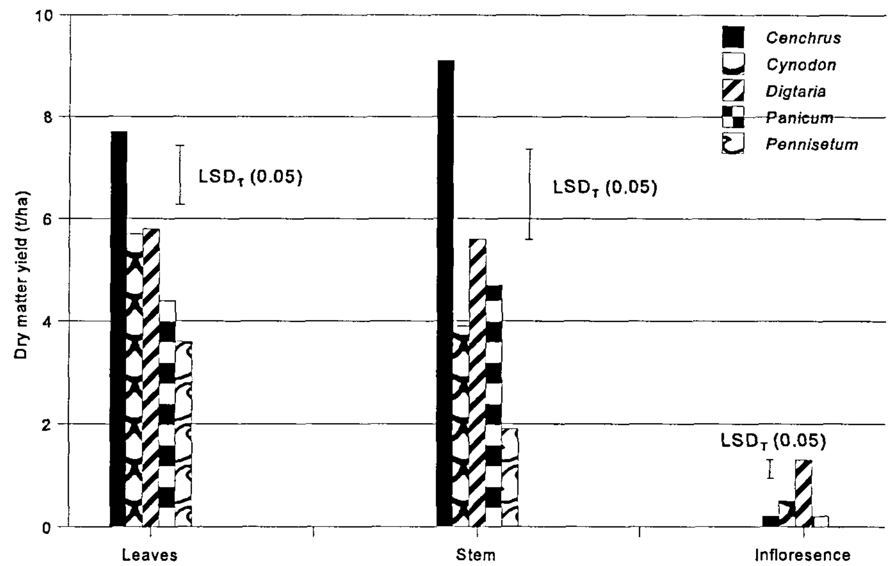


Figure 5. The contribution of different plant components for five perennial grasses in the 1996/97 season.

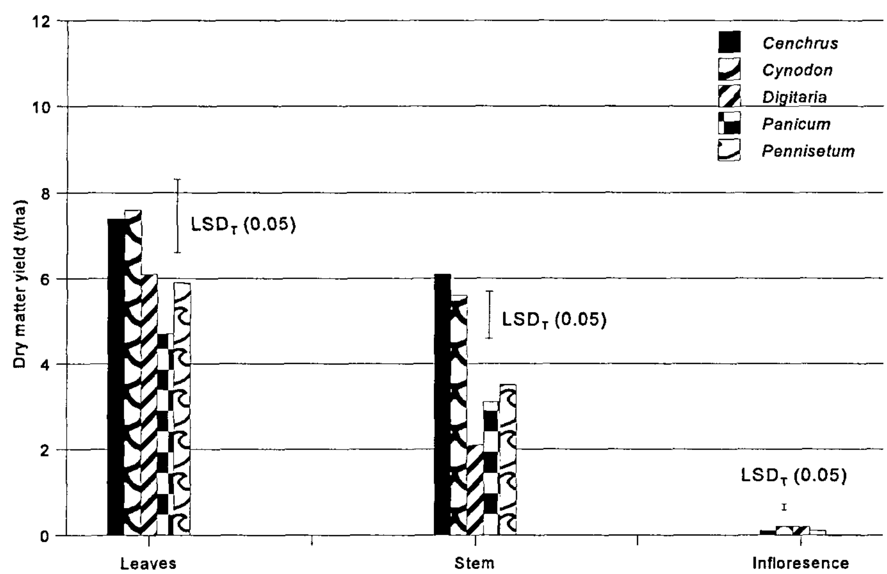


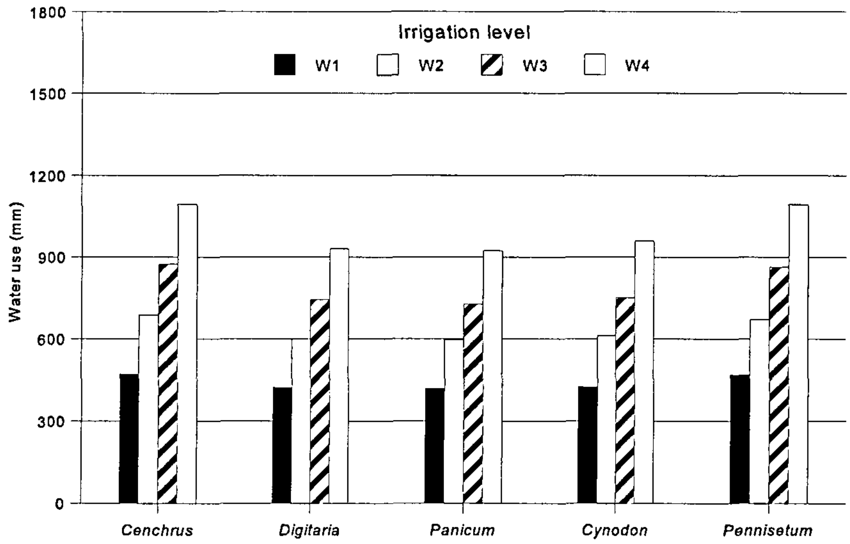
Figure 6. The contribution of different plant components for five perennial grasses in the 1997/98 season.

3.3. Water use

The water use values represent the sum of the weekly irrigation amounts as well as the difference in water shortage in the soil profile between the beginning and the end of the season. In Figures 7 and 8 the total water use for the five grasses in the two experimental seasons are given. In the 1996/97 season (Figure 7) there was no significant grass species x irrigation level interaction, but their was a significant interaction in the 1997/98 season (Figure 8). In both seasons the grasses, however, used more water as the irrigation amount increased.

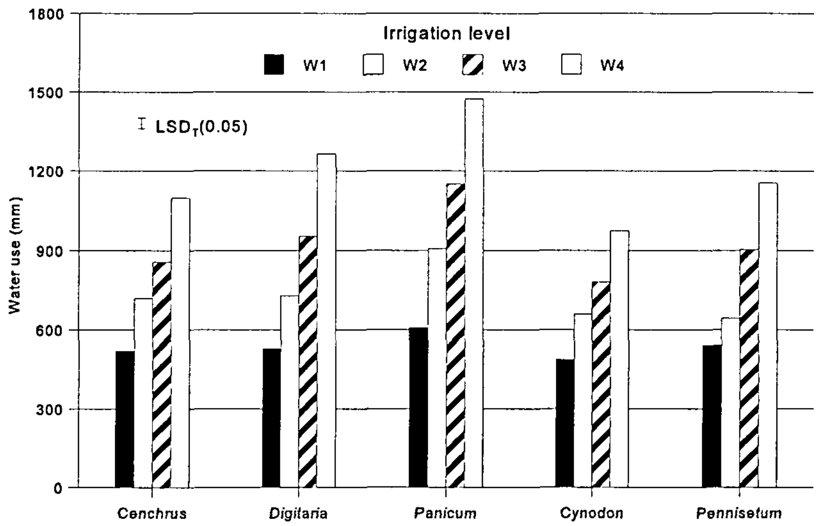
Although the W1 plots received 75% , W2 plots 50% and W3 plots 25% less water over the season than the W4 plots, these percentages are not reflected in the water use of those treatments. By comparing the soil water deficits for the different irrigation levels at the end of the season (Figures 10 - 14), the reason for this becomes evident.

While the soil water extraction of the W4 plots was approximately 5 mm per soil layer, that of the W1 plots was about 15 mm per soil layer at the end of the growing season. Thus more of the soil water reserve was utilized under W1 than under W4 irrigation conditions. The implication of this for water management in the next season becomes clear. Growing a crop on the W1 plots without supplying additional water can cause serious yield losses early in the following season, while a crop on the W4 plots, also without additional water, might still be able to produce some yield at this time. It is clear from this, that the monitoring of soil water content is not a



* W1 -severely water stressed level, W4 - control

Figure 7. Water use of five perennial grasses as influenced by four irrigation levels in the 1996/97 season.



* W1 -severely water stressed level, W4 - control

Figure 8. Water use of five perennial grasses as influenced by four irrigation levels in the 1997/98 season.

luxury, but a necessity. The more often soil water monitoring can be done during the growing season the better, but at the very least it should be assessed at the beginning of the season.

Results from a root study, done for the W1 and W4 irrigation levels are presented in Figure 9. From this it is evident that *Cenchrus* tended to have the same total root length regardless of irrigation treatment. This might shed some light on the fact why *Cenchrus* produced good yields (Table 5) under W1 irrigation level conditions despite it receiving far less water than the control (W4).

The root lengths (Figure 9) of the other four grass species tended to be higher for the control plants (W4) than for the water stressed plants (W1). This is also reflected in the yields (Table 5) for *Cynodon, Digitaria, Panicum* and *Pennisetum*, where the difference in yield between the W1 and W4 irrigation levels is far greater than that of *Cenchrus.*

As expected, about 40 - 60% of the species's roots (Figure 9) could be found in the top layer (0 - 0.21 m). The root lengths found in each of the other 0.21 m soil increments, were between 5 and 19% of the total root length for the different species and irrigation treatments. It appears that the balance of the roots were equally distributed in the deeper (> 0.21 m) horizons. This implies that, although the bulk of roots are located in the top soil, there is also a mass of roots deeper in the soil that could explain the extraction pattern as observed in Figures 10 - 14, where water as deep as 1.8 m was used.

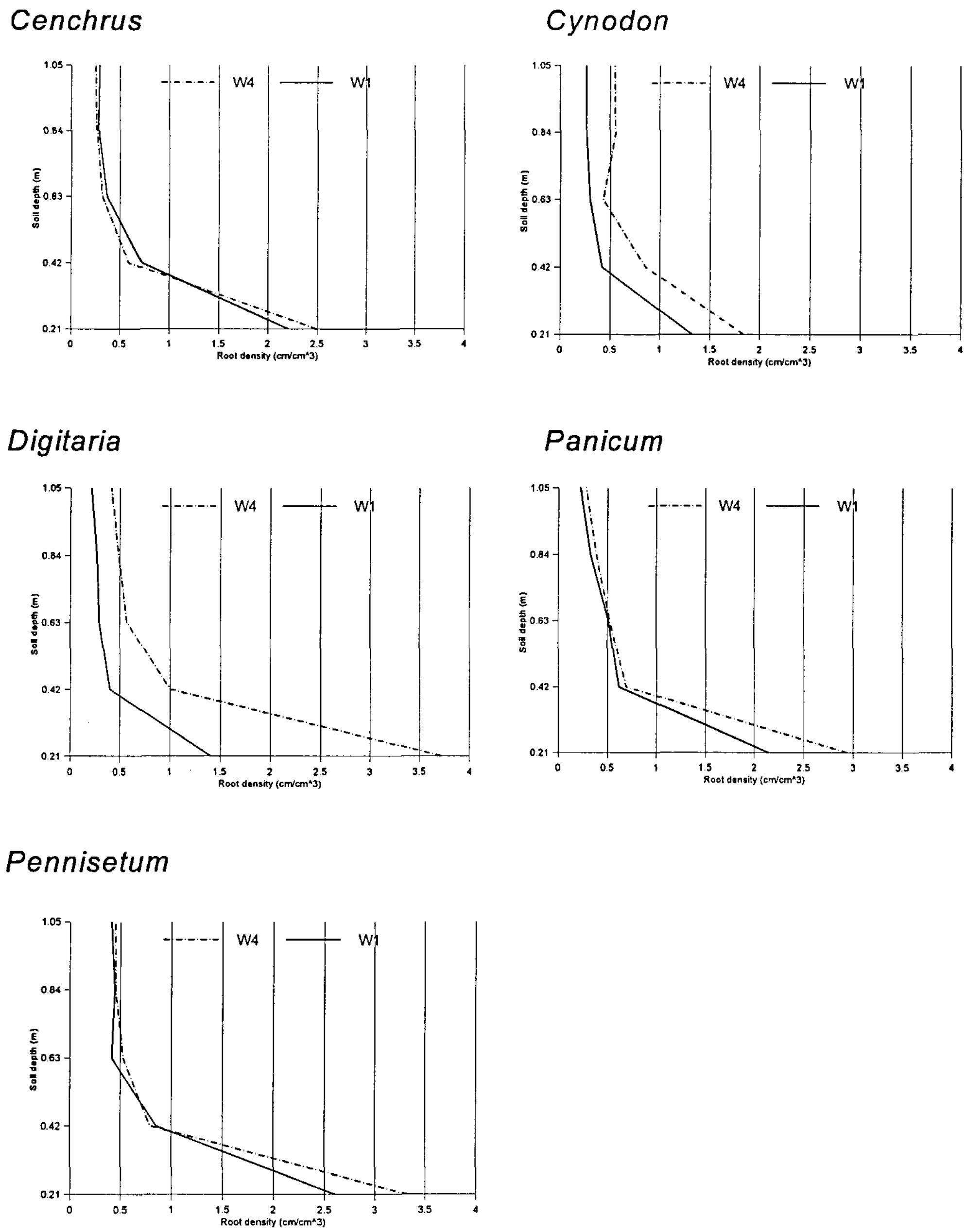
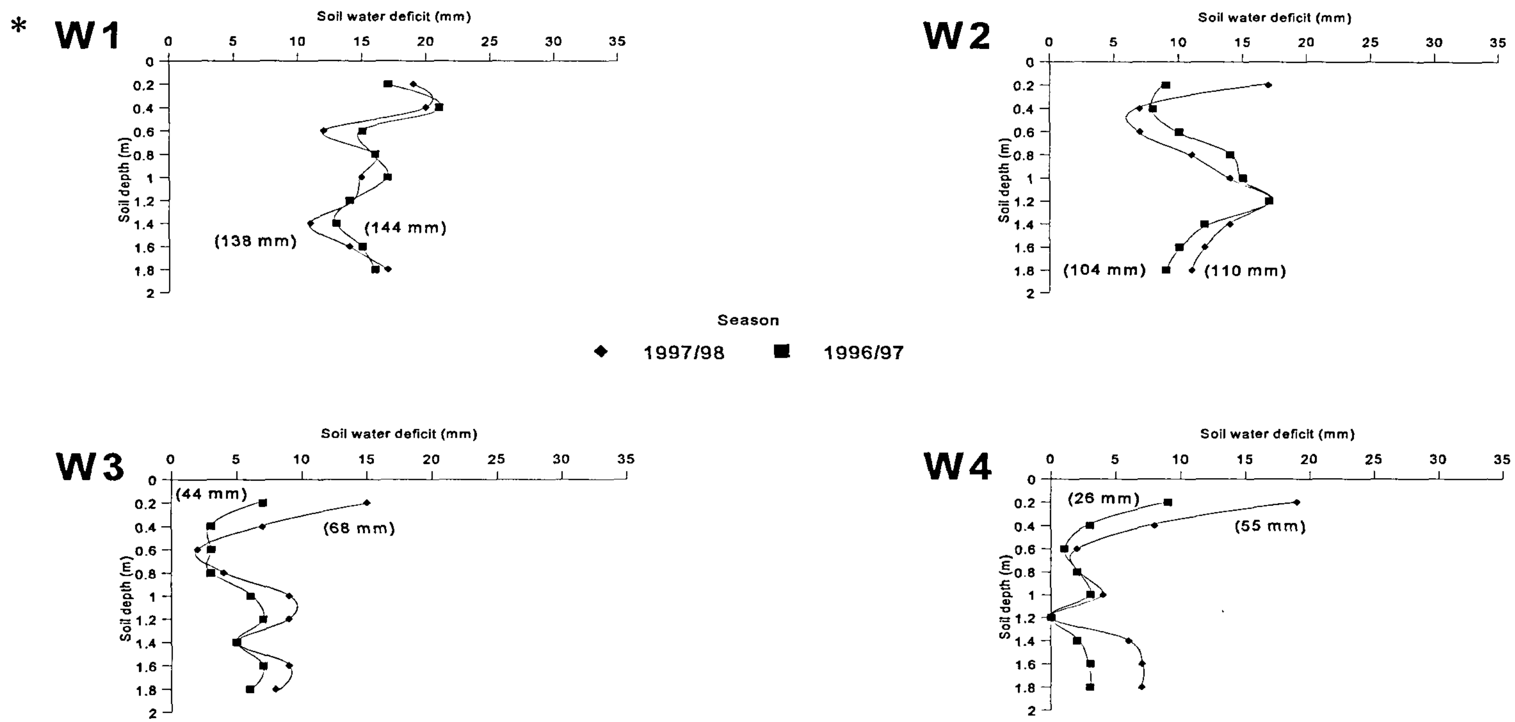


Figure 9. Root density for the wll wateted control (W4) and the water limited treatment (W1) of five grass species.

Before this study was undertaken, the recommendation for irrigating grasses was to use a single set of criteria for all types of grasses in all the different production regions (Steynberg *et al.*, 1994). From Figures 10 - 14 it should be clear that using a single set of criteria for these subtropical grasses might lead to ineffective use of water by *Cenchrus* (Figure 10) and *Panicum* (Figure 13) due to their lower water use under W3 and W4 irrigation conditions, than *Cynodon* (Figure 11), *Digitaria* (Figure 12) and *Pennisetum* (Figure 14). The same may be true for *Cynodon* (Figure 11), *Digitaria* (Figure 12) and *Pennisetum* (Figure 14) under W2 irrigation conditions.

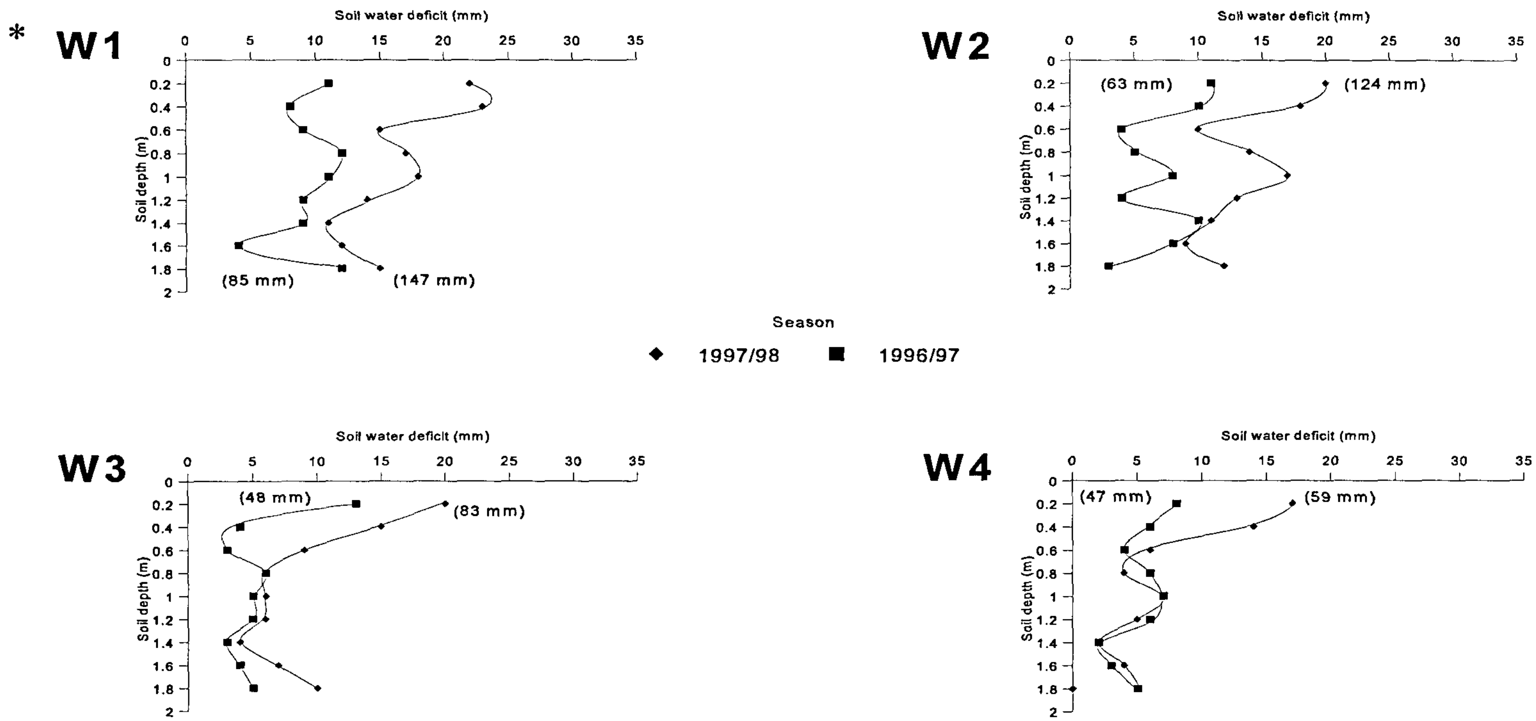
The soil water deficit values of all five grass species for the W1 irrigation level are very close. This might, however, be an indication of the maximum plant extractable water for the specific profile, rather than the maximum water use by the plants. This should be kept in mind when drawing further conclusions.

One of the aims of this study was to give irrigation guidelines to the farmer. Exact values cannot and should not be expected from this data, because the plant is not the only role player in the water use system . The soil acts as a reservoir, of which the capacity will be determined by soil properties, while the climate, together with the management of the leaf area, determines evapotranspiration. These data do, however, supply a rough figure to start with, which can be refined when the climate, soil and management for a specific area are determined.



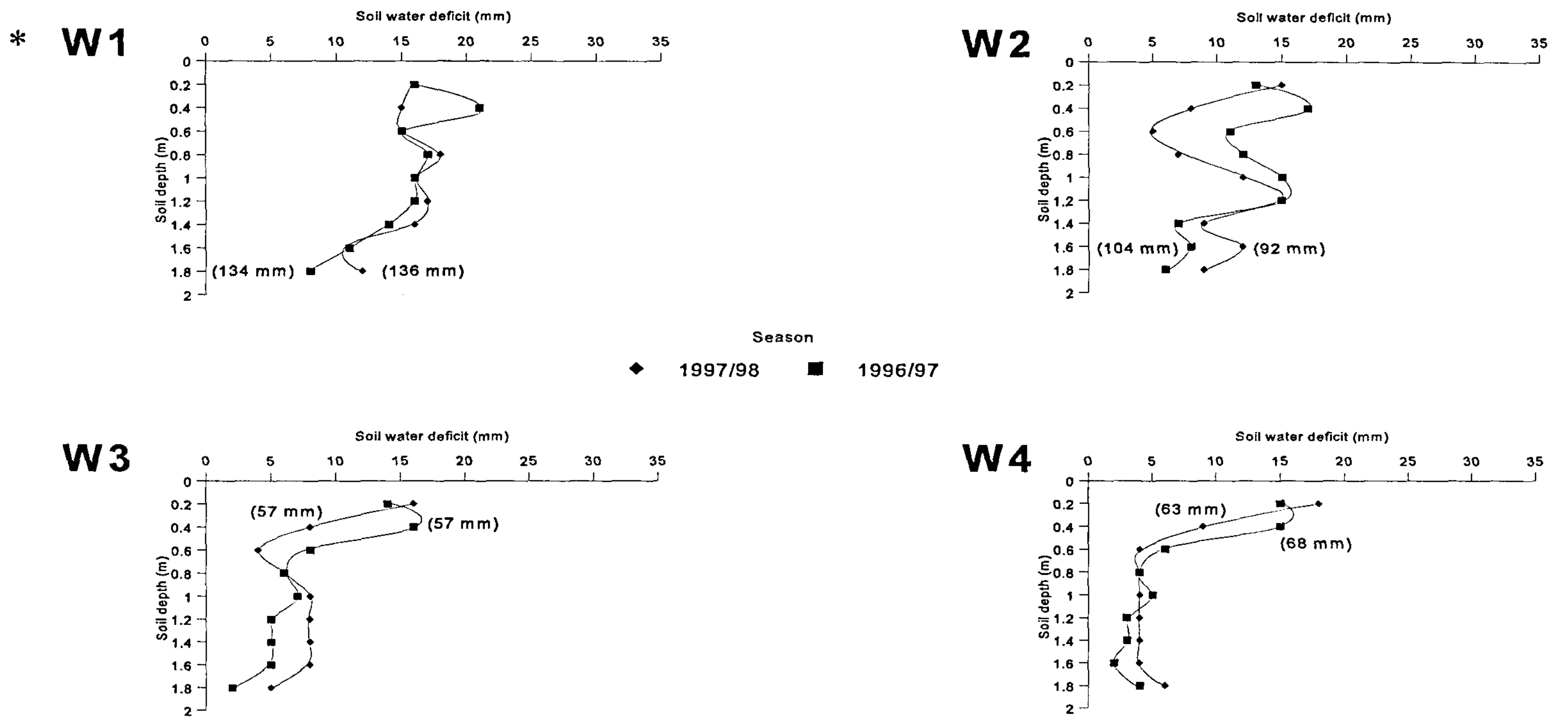
* W1 - severely water stressed level, W4 - control

Figure 10. Water deficit at the end of the growing season for *Cenchrus* at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



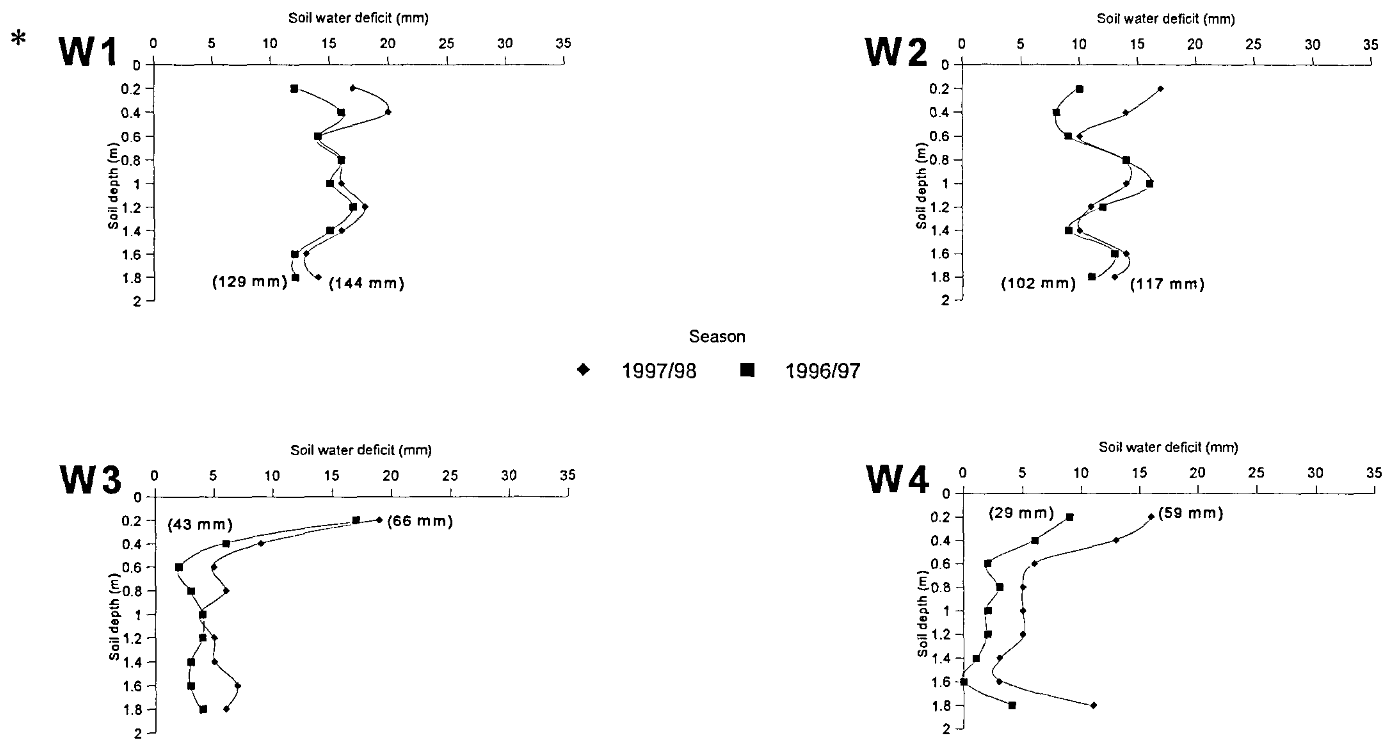
* W1 - severely water stressed level, W4 - control

Figure 11. Water deficit at the end of the growing season for *Cynodon* at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



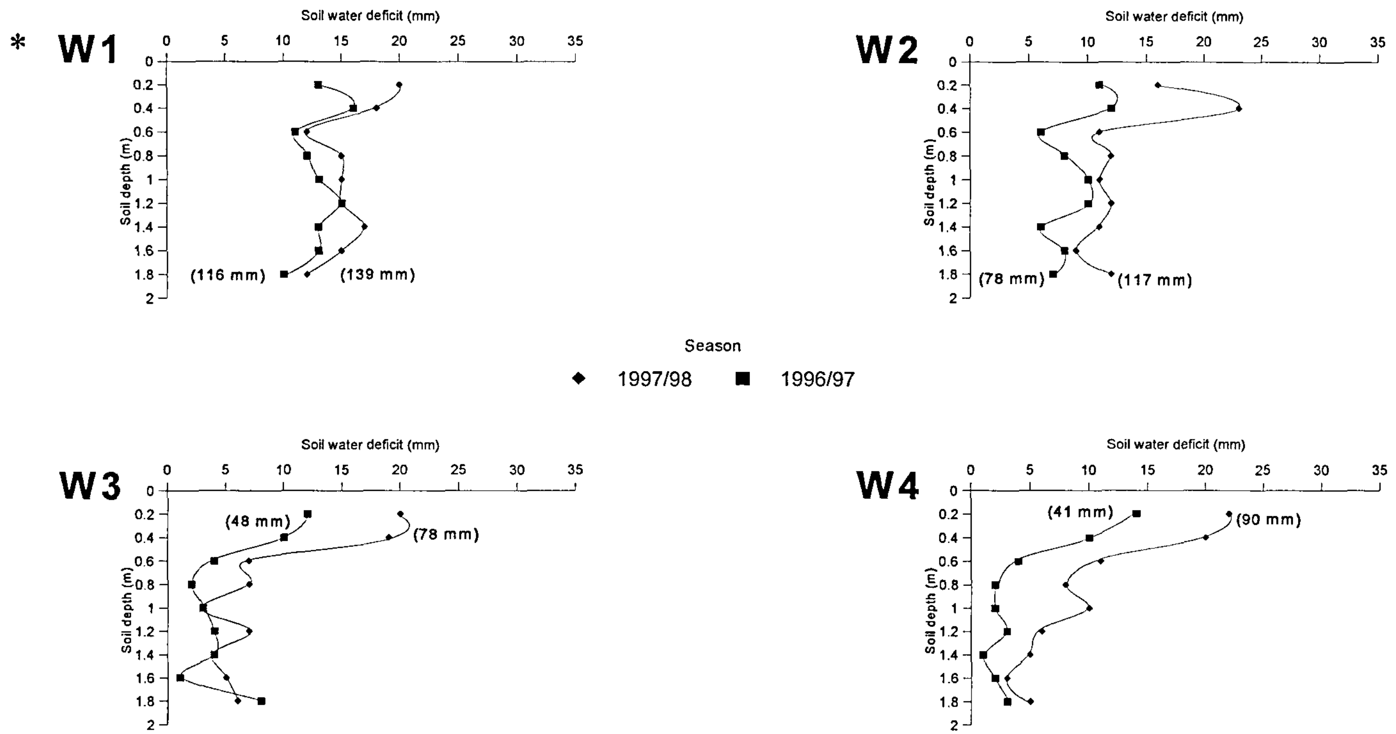
* W1 - severely water stressed level, W4 - control

Figure 12. Water deficit at the end of the growing season for *Digitaria* at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



* W1 - severely water stressed level, W4 - control

Figure 13. Water deficit at the end of the growing season for *Panicum* at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)



* W1 - severely water stressed level, W4 - control

Figure 14. Water deficit at the end of the growing season for *Pennisetum* at four irrigation levels over two seasons. (Total soil water deficit for 1.8 m is given in brackets)

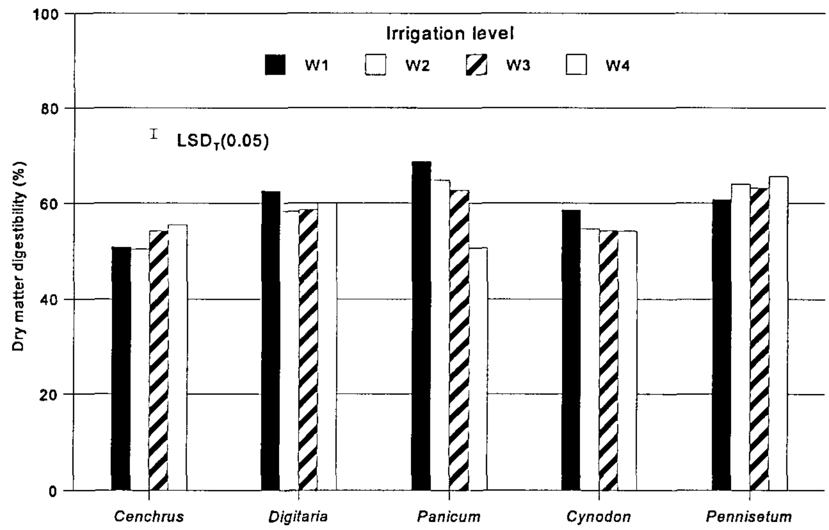
3.4. Fodder quality

3.4.1. Dry matter digestibility

The *in vitro* digestibilities of whole plants are presented in Figures 15 and 16. In the 1996/97 season (Figure 15) there was a significant grass x irrigation level interaction which was, however, not present in the following season (Figure 16).

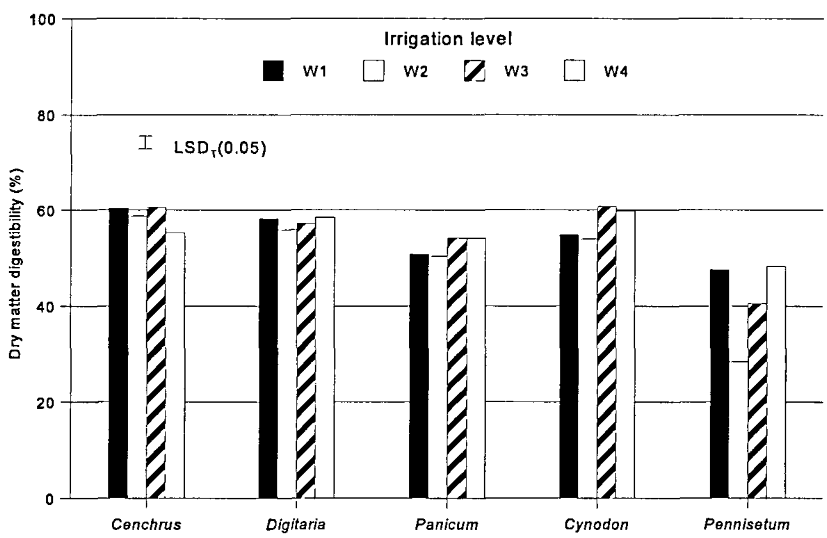
Panicum has the strongest interaction, illustrating an increase in the digestibility of plants with increasing water stress (Figure 15). Whilst the plants under water stress conditions (W1) were the most digestible for *Panicum, Cynodon* and *Digitaria*, the opposite tended to be true for *Cenchrus* and *Pennisetum.*

In the 1997/98 season there was no significant interaction (Figure 16), nor were there any similarities between the two seasons. In the first season *Cenchrus* and *Cynodon* were the least digestible, while in the following season they tended to be the most digestible, with *Pennisetum* declining considerably in digestibility (Figures 15 and 16). Pieterse *et al.* (1989) concluded that *Digitaria* is more digestible than *Cynodon* under Highveld conditions. The same can not, however, be said for these grasses in this trial. In the 1996/97 season, *Digitaria* tended to be more digestible than *Cynodon* (Figure 15), while this difference was not evident in the following season (Figure 16).



* W1 - severely water stressed level, W4 - control

Figure 15. Dry matter digestibility of five grasses as affected by four irrigation levels in the 1996/97 season



* W1 -severely water stressed level, W4 - control

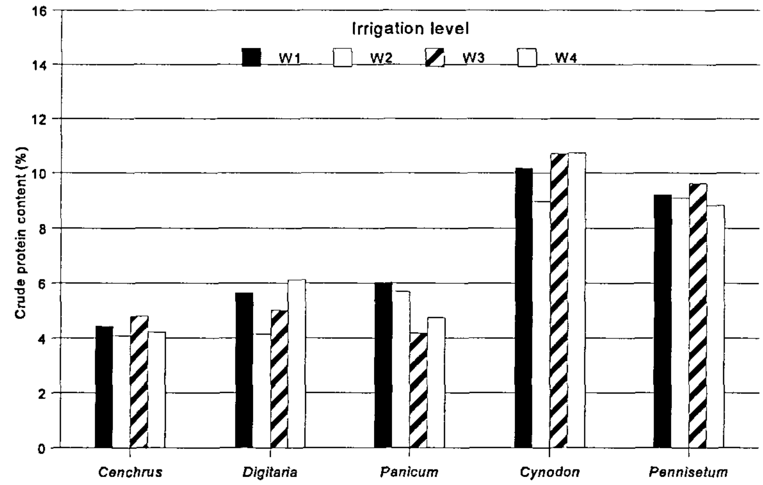
Figure 16. Dry matter digestibility of five grasses influenced by four irrigation levels in the 1997/98 season.

3.4.2. Crude protein content

A comparison of the whole plant crude protein (CP) content for the two seasons indicates slightly higher CP contents in the 1997/98 season (Figure 18) for *Cenchrus*, *Panicum* and *Cynodon*, while that of *Digitaria* was almost the same and that of *Pennisetum* was slightly lower.

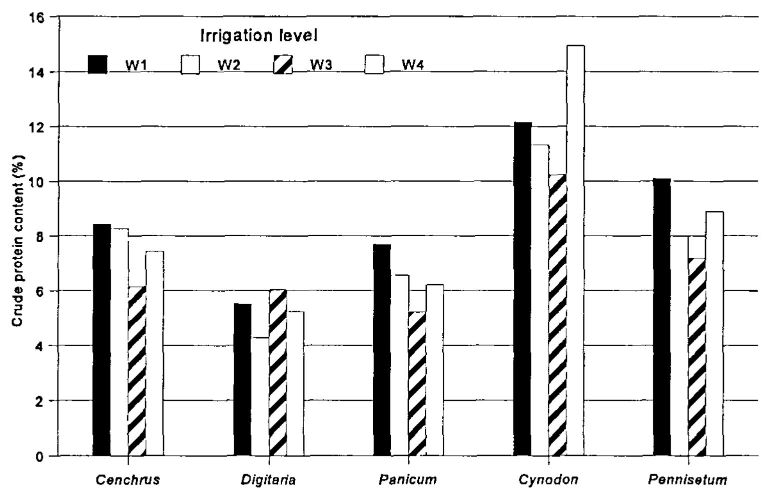
The CP content of *Panicum* tended to be higher under water stressed (W1) than well watered conditions (W4) while the plants with very little or no water stress (W3 and W4) of *Digitaria* and *Cynodon* had a higher content than the other irrigation levels. In the 1996/97 season there was very little difference in crude protein content for the *Cenchrus* and *Pennisetum* plants for all four irrigation levels. In the following season, however, the crude protein contents under water limiting conditions (W1) was slightly higher than that of the well watered control plants (W4).

In both seasons (Figures 17 and 18) the CP content of *Cynodon* and *Pennisetum* was higher than that of the other three grasses . Hefer and Tainton (1990) found that *Pennisetum* had a higher CP content than *Cynodon* under growing conditions in Natal. The opposite was, however, true in this trial. The CP contents as reported by Pieterse *et al.* (1989), on the Highveld, for *Digitaria* (15 - 17%) and *Cynodon* (18 - 21%) were much higher than the results reported here. The CP contents for *Cenchrus* (3 - 5%), *Digitaria* (3.5 - 7.0%) and *Panicum* (3 - 8%) as reported by Snyman (1994) were more in agreement with the range reported here. Singh *et al.* (1995) also reported CP contents for *Panicum* of 6.1 and 8.3% which is close to the range in Figures 17 and 18.



* W1 -severely water stressed level, W4 - control

Figure 17. Crude protein content of five grasses as influenced by four irrigation levels in the 1996/97 season.



* W1 -severely water stressed level, W4 - control

Figure 18. Crude protein content of five grasses as influence by four irrigation levels in the 1997/98 season.

3.5. Water use efficiency (WUE)

Water use efficiency (WUE) is usually expressed as a mass per area per depth of water used by the crop. As in Part 1 of this report, the WUE will again be given in terms of dry matter yield, digestible dry matter yield or crude protein dry matter yield.

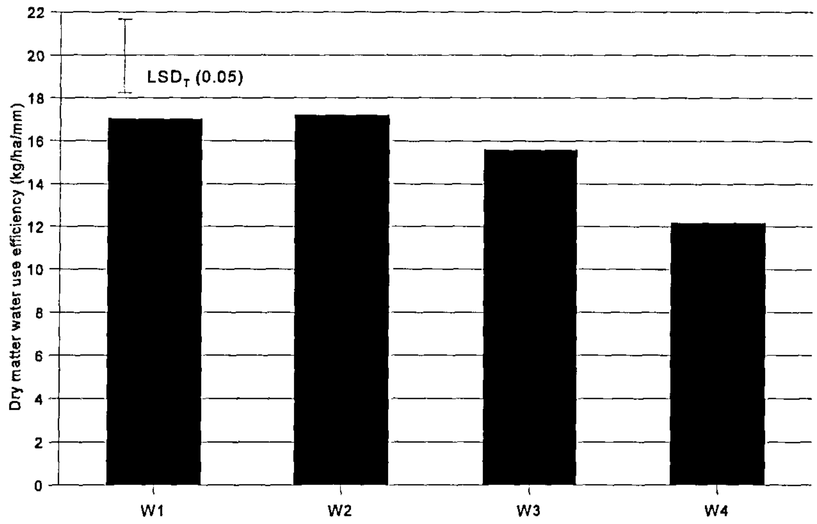
3.5.1. Water use efficiency in terms of dry matter yield (WUE_{DM})

In both seasons there were significant differences in the WUE_{DM} of the different irrigation levels. Water was used more efficiently under "non-control" conditions (Figures 19 and 20). In the 1996/97 season (Figure 19) it was only the control (W4) treatment that used water less efficiently than the other three treatments (W1, W2 & W3), but in the following season (Figure 20) both the well watered treatments (W3 and W4) used water less efficiently than under severe water limiting conditions (W1).

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

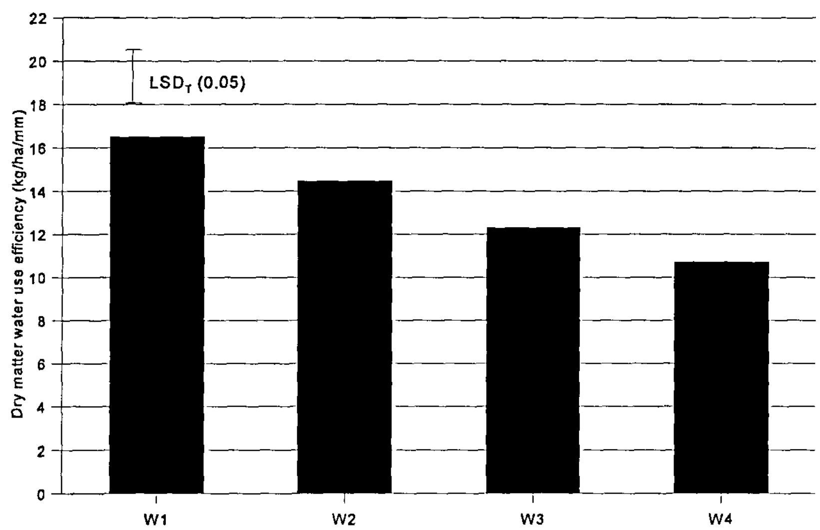
In both seasons *Cenchrus*, *Panicum* and *Pennisetum* used water the most efficiently under W1 irrigation conditions, while *Cynodon* and *Digitaria* used water more efficiently under W1, W2 and W3 irrigation conditions (Tables 6 and 7). All five grasses, however, used water the least efficiently under well watered control conditions (W4).

In this trial *Cenchrus and Cynodon* were the more efficient water users and cultivation of these grasses under a wide range of irrigation conditions can be recommended. The same can, however, not be said about *Panicum* and *Pennisetum* which were the least efficient water users for this trial and their use under irrigation can be questioned. From this trial, no definite conclusions can be drawn about *Digitaria*, except that water was more efficiently used under water limiting (W1) than control conditions (W4).



* W1 -severely water stressed level, W4 - control

Figure 19. The average dry matter water use efficiency of five grass species for four irrigation levels for the 1996/97 season.



* W1 -severely water stressed level, W4 - control

Figure 20. The average dry matter water use efficiency of five grass species for four irrigation levels for the 1997/98 season.

Table 6. Influence of irrigation level on the WUE_{DM} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	24.9	24.7	22.8	17.6	22.5
Cynodon	17.4	14.3	16.2	12.4	15.1
Digitaria	19.4	24.9	19.0	14.3	19.4
Panicum	14.9	14.6	12.7	11.4	13.4
Pennisetum	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					

* W1 -severely water stressed level, W4 - control

Table 7. Influence of irrigation level on the WUE_{DM} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	23.9	19.3	16.3	12.7	18.0
Cynodon	19.9	20.0	18.8	16.3	18.7
Digitaria	13.0	11.3	9.5	7.9	10.4
Panicum	11.6	8.5	6.7	6.4	8.3
Pennisetum	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

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

The digestible dry matter yield of *Cenchrus*, *Panicum* and *Digitaria*, was higher in the 1996/97 than the 1997/98 season (Tables 8 and 9). This is in accordance with the dry matter yields (Figures 3 and 4), where *Cynodon* and *Pennisetum* were the only two grasses that produced higher yields in the 1997/98 than the 1996/97 season. In the 1996/97 season only *Cenchrus* produced significantly higher digestible dry matter yields than the other grasses (Table 8). In the following season (Table 9), *Cynodon* also produced significantly higher digestible dry matter yields than *Digitaria*, *Panicum* and *Pennisetum*. In terms of irrigation level (Tables 8 and 9), the digestible dry matter yield was significantly higher under W3 and W4 than under W1 conditions, in both seasons. This was also true for the dry matter yields represented in Figures 1 and 2.

There was a significant irrigation level x grass species interaction in the 1997/98 season (Table 11) for WUE_{DDM}. During that season, *Cenchrus* and *Digitaria* tended to use water more efficiently with an increase in water deficit. For *Panicum*, *Cynodon* and *Pennisetum* water was used more efficiently under W1 and sometimes W3 conditions, than under control conditions (W4). The difference in WUE_{DDM} between W2, W3 and W4 was, however, not always significant for the latter three grasses. As with WUE_{DM}, WUE_{DDM} was again better under water stressed than under control conditions (Tables 10 and 11). In both seasons, *Panicum* and *Pennisetum* used water the least efficiently.

Table 8. Influence of irrigation level on the digestible dry matter yield (t ha^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	5.9	8.5	10.8	10.6	9.0
Cynodon	4.3	4.8	6.6	6.5	5.6
Digitaria	3.1	5.6	5.5	7.9	5.6
Panicum	4.3	5.7	5.8	5.1	5.2
Pennisetum	2.5	3.3	4.0	3.7	3.4
Mean	4.0	5.6	6.5	6.8	

$LSD_T(G) = 2.4$

$LSD_T(I) = 2.0$

* W1 -severely water stressed level, W4 - control

Table 9. Influence of irrigation level on the digestible dry matter yield (t ha^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	7.5	8.1	8.4	7.6	7.9
Cynodon	5.3	6.7	8.6	9.4	7.5
Digitaria	4.0	4.6	5.2	5.8	4.9
Panicum	3.6	3.5	4.2	5.1	4.1
Pennisetum	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 10. Influence of irrigation level on the WUE_{DDM} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	12.6	12.4	12.3	9.7	11.8
Cynodon	10.2	7.8	8.8	6.7	8.4
Digitaria	12.1	14.5	11.1	8.5	11.6
Panicum	9.1	9.3	7.9	7.4	8.4
Pennisetum	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					

* W1 -severely water stressed level, W4 - control

Table 11. Influence of irrigation level on the WUE_{DDM} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	14.4	11.3	9.8	6.9	10.6
Cynodon	11.0	10.1	11.3	9.7	10.5
Digitaria	7.8	6.3	5.4	4.6	6.0
Panicum	5.9	3.9	3.6	3.5	4.2
Pennisetum	6.0	4.5	4.2	5.0	4.9
Mean	9.0	7.2	6.9	5.9	
$LSD_T(GxI)$ = 0.7					

* W1 -severely water stressed level, W4 - control

3.5.3. Water use efficiency in terms of crude protein dry matter yield (WUE_{CP})

The crude protein dry matter yield of all the grasses, except that of *Digitaria*, tended to be higher in the 1997/98 than 1996/97 season (Tables 12 and 13). In both seasons, *Cenchrus* and *Cynodon* produced higher crude protein dry matter yields than the other grasses. The crude protein dry matter yield 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 dry matter yield was far better under severe water limiting (W1) than under control conditions (W4) (Tables 14 and 15). *Cynodon, Cenchrus* and *Digitaria* used water the most efficiently in the 1996/97 season while the WUE_{CP} of *Cynodon* and *Cenchrus* were the best in the following season. *Panicum* and *Pennisetum* were highly variable in this respect.

Table 12. Influence of irrigation level on the crude protein dry matter yield (t ha^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	0.5	0.7	1.0	0.9	0.8
Cynodon	0.8	0.8	1.3	1.3	1.0
Digitaria	0.3	0.4	0.5	0.8	0.5
Panicum	0.4	0.5	0.4	0.5	0.4
Pennisetum	0.4	0.5	0.6	0.5	0.5
Mean	0.5	0.6	0.7	0.8	
$LSD_T(G) = 0.3$					
$LSD_T(I) = 0.2$					

* W1 -severely water stressed level, W4 - control

Table 13. Influence of irrigation level on the crude protein dry matter yield (t ha^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	1.1	1.6	0.9	1.0	1.1
Cynodon	1.3	1.4	1.4	2.2	1.6
Digitaria	0.4	0.4	0.5	0.5	0.5
Panicum	0.5	0.5	0.4	0.6	0.5
Pennisetum	0.8	0.7	0.7	1.0	0.8
Mean	0.8	0.9	0.8	1.1	
$LSD_T(GxI) = 0.1$					

* W1 -severely water stressed level, W4 - control

Table 14. Influence of irrigation level on the WUE_{CP} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	1.1	1.0	1.1	0.9	1.0
Cynodon	1.8	1.3	1.7	1.3	1.5
Digitaria	1.1	1.0	1.0	0.9	1.0
Panicum	1.4	1.3	1.2	1.0	1.2
Pennisetum	0.8	0.7	0.7	0.5	0.7
Mean	1.2	1.1	1.1	0.9	
$LSD_T(G) = 0.3$					
$LSD_T(I) = 0.3$					

* W1 -severely water stressed level, W4 - control

Table 15. Influence of irrigation level on the WUE_{CP} (kg ha^{-1} mm^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	2.2	2.2	1.0	1.0	1.6
Cynodon	2.7	2.1	1.8	2.3	2.2
Digitaria	0.7	0.5	0.6	0.4	0.6
Panicum	0.9	0.5	0.3	0.4	0.5
Pennisetum	1.4	1.1	0.7	0.9	1.0
Mean	1.6	1.3	0.9	1.0	
$LSD_T(GxI) = 0.1$					

* W1 -severely water stressed level, W4 - control

CHAPTER 4

ECONOMIC ANALYSIS

4.1 Methodology

A hypothetical centre pivot irrigation system was used for the economic analyses because systems employed in the trial are not used for fodder crops under commercial conditions. The virtual centre pivot covered 30.58 hectares. It was assumed that the site fell within the Roodeplaat Dam Government Water Scheme. The annual quota for this scheme is 6 500 m^3 per hectare and the tariff R 670.10 per hectare. An extra 4 000 m^3 per hectare can be purchased under surplus conditions at the same rate per m^3 as the initial 6 500 m^3. The centre pivot was provided with a 50 kVA electricity supply (Landrate 2 tariff). Depreciation of the irrigation system and the opportunity cost of capital used to purchase the system (interest) were not taken into account.

The trial was carried out underneath an automatic rain shelter preventing the crops from receiving any rain. However, the analyses will then only be relevant to the specific area. Consequently the water application levels of the trial were used to estimate irrigation costs.

Weed control was done by hand in the trial, whereas herbicides had to be added to the crop enterprise budgets for commercial conditions. Land preparation actions were not recorded during the trial but were done by hand as well. Therefore, assumptions had to be made regarding cultivation actions. The most cost effective possible mechanisation system was compiled for each crop. As in the case of the irrigation system, depreciation and interest of the mechanisation system were not taken into account. One permanent labourer was assumed employed at R 750 per month.

Approximately one and a half hectare should be re-established every year if the perennial grasses are productive for 20 years. In practice, however, no farmer will re-establish such a small area at a time. Therefore, the establishment costs of perennial grasses were not taken into account. Only the pre-harvest costs of each crop treatment combination were estimated because all the crops cannot be harvested commercially. The utilisation of the crops by a livestock enterprise was not considered because too little information regarding the nutritional value of these crops was available. Irrigation costs were calculated with the aid of the IrriCost programme (Irrigation Cost programme) whereas the FARMS programme (Firm level Agricultural Management Simulator programme) was employed to generate enterprise budgets and cash flow statements. Both programmes form a part of the FARMS system (Firm level Agricultural Risk Management Simulator system).

4.2 Results

Table 16 summarises the specified costs per ton dry matter as well as per millimetre water, cash flow closing balance and crude protein content of the perennial grasses at four irrigation levels. The quantity of water needed for irrigation exceeded the quantity available (the quota and extra pruchases) for W4 of *Cenchrus, Panicum, Digitaria* and *Pennisetum.* As in the case of annual fodder crops, irrigation costs were still estimated for these impractical treatments (not feasible in consequence of high water application levels and not taking summer rainfall into account). *Cenchrus* W1, *Panicum* W1, *Digitaria* W2 and *Pennisetum* W1 have a specified cost R 85, R 156, R 120 and R 175 per ton dry matter respectively. The costs of *Cynodon* W1 and W3 were both R 119. These specified costs were the lowest for each grass. However, specified cost per ton dry matter results are biased as a result of high fertilisation levels and consequent high operating costs. Specified costs per millimetre water do not decrease from *Pennisetum* W1 to W2 and *Cynodon* W3 to W4. In these two instances the increase in fertilisation costs was higher than the decrease in average fixed water cost. Therefore, the specified cost per millimetre water of W4 are the lowest for all the grasses except *Cynodon.* With the latter grass W3 was the best in this regard.

Cash balances per hectare at the end of the harvest months decrease from W1 to W4 for the different grasses. This decrease is the result of fertilisation and variable irrigation costs. *Cenchrus* realises a three percent and *Panicum* a four percent crude protein content with treatment W1. These percentages were the lowest for the different grasses. *Digitaria* W2 contains six percent and *Pennisetum* W1 nine percent crude protein. These were the second lowest contents for the different grasses. *Cynodon* realises a highest crude protein content of 10 percent with treatment W1. Therefore, W1 has the joint lowest specified costs per ton dry matter as well as the highest crude protein content for *Cynodon*.

Table 16. Specified costs, cash flow and crude protein content of perennial grasses at four irrigation levels.

Grass	Irrigation level*	Specified costs per ton dry matter ($R\ t^{-1}$)	Specified costs per millimetre water ($R\ mm^{-1}$)	Cash flow closing balance ($R\ ha^{-1}$)	Crude protein content (%)
Cenchrus	W1	85	6.34	- 3 506	3
	W2	90	5.95	- 4 681	5
	W3	93	5.5	- 5 262	6
	W4	110	4.96	- 5 984	5
Cynodon	W1	119	6.68	- 3 520	10
	W2	126	6.51	- 4 678	9
	W3	119	5.04	- 5 381	8
	W4	128	5.53	- 5 950	9
Digitaria	W1	135	6.41	- 3 502	5
	W2	120	6.36	- 4 645	6
	W3	136	5.58	- 5 253	9
	W4	157	4.96	- 5 988	6
Panicum	W1	156	6.02	- 3 560	4
	W2	179	5.62	- 4 763	5
	W3	190	5.12	- 5 371	6
	W4	186	4.6	- 6 122	7
Pennisetum	W1	175	6.17	- 3 551	9
	W2	202	6.32	- 4 694	8
	W3	203	5.4	- 5 329	9
	W4	209	4.85	- 6 066	10

* W1 -severely water stressed level, W4 - control

CHAPTER 5

CONCLUSIONS

The pre-judgement of grasses in terms of water use is dangerous. The inclusion of *Cenchrus* and *Digitaria* in this trial was contentious because neither of them are commonly used under irrigation. If one, however, examines the WUE of *Cenchrus* under well watered conditions, it appears that *Cynodon,* or even *Digitaria* might be comparable. Under severe water limiting conditions, however, *Cenchrus* is unequalled in terms of dry matter production as well as WUE.

To choose between *Digitaria*, *Panicum*, *Cynodon* and *Pennisetum* in terms of average dry matter yield is difficult. *Panicum* was assessed as the one with the lowest production potential, but over the two experimental seasons it was the most stable with respect to production under all treatments. The difference in *Panicum* yields, for the two seasons at the four irrigation levels was no more than two tons per hectare in comparison to the three to six ton per hectare differences for the other four grasses. One should, however, bear in mind that *Panicum* used far more water in the 1997/98 season with a decrease in dry matter yield, resulting in very poor WUE values.

As with the annual fodder crops, water was again used most efficiently under moderate to severe water stress. This might imply that irrigation scheduling should not aim to bring the soil profile to field capacity with each irrigation, but rather to apply less, depending on climatic and soil conditions, and thus increase especially the applied water use efficiency of a production system, as rainfall will be more effective. Having made this statement it should also be noted that the soil profiles for this trial were brought to field capacity at the start of each season. If this had not been done, the picture might have looked different.

Water use efficiency was also calculated in term of digestible and crude protein dry matter yield. In terms of these factors, water was again used most efficiently under water limiting (W1) than control (W4) conditions. *Panicum* (WUE_{DDM} and WUE_{CP}) and *Pennisetum* (WUE_{DDM}) tended to use water the least efficiently in the two seasons. *Cenchrus* (1996/97 and 1997/98), *Digitaria* (1996/97) and *Cynodon* (1996/97 and 1997/98) tended to use water more efficiently, in terms of crude protein dry matter yield, than the other grasses. In terms of digestible dry matter yield, Cenchrus (1996/97 and 1997/98), Digitaria (1996/97) and Cynodon (1997/98) were the more efficient water users.

Another important aspect of the trial was to examine the quality of fodder being produced by the five species. From these results it was evident that the whole plant dry matter digestibility ranged from as low as 40 to as high as 70%. As found in the literature, there is no consensus on the influence of moisture stress on the digestibility of crops. Some have stated (also to be found for the annual fodder crops in Part 1 of this report) that crops grown under water stressed conditions are often more digestible than those grown under well watered conditions. This, however, was not the finding of all researchers.

It is apparent that *Cynodon* and *Pennisetum* had the highest CP content of the five species in both seasons. The CP content of these two species varied between 8 and 15% while it varied between 4.0 and 8.5% for the tufted species. The CP content also varied between seasons and irrigation levels, although that of *Digitaria* averaged the same in both seasons.

The cash flow closing balance per hectare of the harvest months decreases from W1 to W4. This is the result of higher variable irrigation and higher fertilisation costs. Specified costs per millimetre water decrease from W1 to W4 except for two grasses. This decrease can be ascribed to decreasing average fixed water cost. The increase in fertilisation costs is higher than the decrease in average fixed water cost for *Pennisetum* and *Cynodon*. Economic benefits from a higher crude protein content should be weighed against higher specified costs per ton dry matter. The irrigation level for *Cynodon* which has the lowest specified costs also realises the highest protein content. However, the crude protein content of these crops does not vary more than two percent.

In summary the following can be said:

1. The dry matter yield of *Panicum* varied between 6.2 (W1) and 10.4 t ha^{-1} (control) over the two seasons. In both seasons *Panicum* was the poorest in terms of yield and WUE. The yields were, however, relatively stable despite more water being used in the second than in the first season. *Panicum* tended to produce more stem material during the first than the second season, although this was not reflected in a better digestibility. The CP

content was, however, a little higher in the second season when there were proportionately more leaves.

2. For *Digitaria* the dry matter yields varied between 6.9 (W1) and 14.9 t ha^{-1} (control), with more water being used in the second season without a concomitant increase in yield resulting in a poor WUE in that season. *Digitaria* in general was able to use less water more efficiently. The dry matter digestibilities of *Digitaria* did not differ by more than six percent in the two seasons and were approximately 58%, while the CP content was between four and six percent. *Digitaria* had more leaf than stem in both seasons, which might explain why the digestibility and CP content did not differ much between seasons.

3. *Cenchrus* produced more dry matter under water stressed conditions (W1), than any of the other crops and even more than some crops under well watered conditions. The yield varied between 11.7 (W1) and 20.0 t ha^{-1} (W3). The water use of *Cenchrus* did not differ much between the seasons, but the yield was lower in the second season resulting in lower WUE values. Despite this, it still had the highest WUE (24.9 and 23.9 kg ha^{-1} mm^{-1}) of all the crops under water stressed conditions and compared well with *Digitaria* and *Cynodon* under well watered conditions. Both the digestibility and CP content of this species was lower in the first than in the second season, and varied between 50 and 60% for the digestibility and 4.0 and 8.5% for the CP content. The CP content was relatively low in comparison to that of the two creeping grasses.

4. *Pennisetum* also used a little more water in the second than in the first

season. The yields, however, also increased, resulting in a far better water use in the second than in the first season. The yields of *Pennisetum* were as low as 4 (W1) and as high as 11.8 t ha^{-1}, under control conditions, resulting in WUE values of 5.2 kg ha^{-1} mm^{-1} (control conditions) and as high as 14.2 for water stressed conditions. Despite a higher dry matter yield, and more leaf material being produced, the dry matter digestibility and CP content decreased drastically from the first to the second season. *Pennisetum* was, however, still one of the grasses with a high CP content of between 7.2 and 10.1%.

5. Although *Cynodon* did not produce well in the first season, it was still amongst the top three in terms of production. In the second season it was in first place (15.8 t ha^{-1}) with about two tons more dry material than *Cenchrus*. Under water stressed conditions, however, it was not as good as *Cenchrus*. *Cynodon* was able to use water efficiently over the whole range of water availabilities, increasing WUE with less water being applied. The digestibility and CP content of *Cynodon* were higher in the second than the first season, with the CP content the highest of all the grasses in both seasons.

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APPENDIX

Table A1. Influence of irrigation level on the stem dry matter yield (t ha^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	5.9	9.2	11.1	10.3	9.1
Cynodon	2.6	3.0	5.0	4.9	3.9
Digitaria	3.2	7.0	6.4	5.7	5.6
Panicum	3.1	4.4	5.4	5.9	4.7
Pennisetum	1.3	1.9	2.4	2.0	1.9
Mean	3.2	5.1	6.1	5.8	
$LSD_T(G)$ = 1.8					
$LSD_T(I)$ = 1.5					

* W1 -severely water stressed level, W4 - control

Table A2. Influence of irrigation level on stem dry matter yield (t ha^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	4.8	6.5	5.7	7.2	6.1
Cynodon	4.5	5.9	4.9	6.9	5.6
Digitaria	2.0	1.8	2.3	2.4	2.1
Panicum	2.6	3.1	3.3	3.3	3.1
Pennisetum	2.3	2.2	4.5	4.8	3.5
Mean	3.2	3.9	4.1	4.9	
$LSD_T(G)$ = 1.1					
$LSD_T(I)$ = 0.9					

* W1 -severely water stressed level, W4 - control

Table A3. Influence of irrigation level on the leaf dry matter yield (t ha^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	5.7	7.6	8.9	8.6	7.7
Cynodon	4.2	5.1	6.7	6.6	5.6
Digitaria	4.3	6.7	6.1	6.0	5.8
Panicum	3.1	4.2	3.6	4.4	3.8
Pennisetum	2.7	3.2	3.9	3.6	3.3
Mean	4.0	5.3	5.8	5.8	
$LSD_T(G) = 1.2$					
$LSD_T(I) = 1.0$					

* W1 -severely water stressed level, W4 - control

Table A4. Influence of irrigation level on the leaf dry matter yield (t ha^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	7.5	7.2	8.2	6.5	7.3
Cynodon	5.1	7.1	9.3	8.9	7.6
Digitaria	4.7	6.2	6.4	7.2	6.1
Panicum	4.4	3.9	4.4	6.2	4.7
Pennisetum	5.4	6.4	4.8	7.0	5.9
Mean	5.4	6.9	6.6	7.1	
$LSD_T(G) = 1.7$					
$LSD_T(I) = 1.4$					

* W1 -severely water stressed level, W4 - control

Table A5. Influence of irrigation level on the reproductive component dry matter yield (t ha^{-1}) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	0.1	0.3	0.0	0.2	0.2
Cynodon	0.5	0.7	0.4	0.5	0.5
Digitaria	0.7	1.2	1.6	1.6	1.3
Panicum	0.1	0.2	0.2	0.1	0.1
Pennisetum	0.0	0.0	0.0	0.0	0.0
Mean	0.3	0.5	0.4	0.5	
$LSD_T(G) = 0.4$					

* W1 -severely water stressed level, W4 - control

Table A6. Influence of irrigation level on the reproductive component dry matter yield (t ha^{-1}) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	0.1	0.1	0.0	0.0	0.1
Cynodon	0.1	0.2	0.5	0.1	0.2
Digitaria	0.2	0.1	0.3	0.3	0.2
Panicum	0.1	0.1	0.1	0.1	0.1
Pennisetum	0.0	0.0	0.0	0.0	0.0
Mean	0.1	0.1	0.2	0.1	
$LSD_T(GxI) = 0.1$					

* W1 -severely water stressed level, W4 - control

Table A7. Influence of irrigation level on the water use (mm) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	470.0	688.0	874.0	1095.3	781.8
Cynodon	423.0	612.0	752.3	960.3	686.9
Digitaria	421.0	600.3	745.0	931.3	674.4
Panicum	417.3	596.0	727.7	923.7	666.2
Pennisetum	468.7	672.3	863.7	1094.7	774.8
Mean	440.0	633.7	792.5	1001.1	

$LSD_T(G) = 46.8$

$LSD_T(I) = 39.3$

* W1 -severely water stressed level, W4 - control

Table A8. Influence of irrigation level on the water use (mm) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	521.2	719.5	856.6	1096.9	798.6
Cynodon	488.1	659.5	781.1	975.3	726.0
Digitaria	530.4	729.1	953.8	1265.1	869.6
Panicum	606.8	906.7	1149.8	1475.2	1034.6
Pennisetum	542.0	643.2	902.8	1154.0	810.5
Mean	537.7	731.6	928.8	1193.3	

$LSD_T(G*I) = 43.4$

* W1 -severely water stressed level, W4 - control

Table A9. Influence of irrigation level on the root length (cm cm^{-3}) of five perennial grasses.

Grass (G)	Irrigation level (I)*	Soil depth increment (m) (D)				
		0 - 0.21	0.21 - 0.42	0.42 - 0.63	0.63 - 0.84	0.84 - 1.05
Cenchrus	W1	2.50	0.59	0.32	0.27	0.25
	W4	2.21	0.74	0.37	0.28	0.29
Cynodon	W1	1.33	0.42	0.30	0.26	0.27
	W4	1.84	0.86	0.43	0.56	0.55
Digitaria	W1	1.40	0.40	0.30	0.27	0.21
	W4	3.72	1.00	0.57	0.49	0.42
Panicum	W1	2.15	0.52	0.51	0.33	0.23
	W4	2.95	0.70	0.53	0.39	0.28
Pennisetum	W1	2.61	0.85	0.42	0.45	0.41
	W4	3.33	0.79	0.53	0.46	0.45
LSD_T(GxIxD) = 0.22						

* W1 -severely water stressed level, W4 - control

Table A10. Influence of irrigation level on the *in vitro*- dry matter digestibility (%) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	50.8	50.4	54.2	55.5	52.7
Cynodon	58.6	54.7	54.3	54.2	55.4
Digitaria	62.6	58.3	58.6	60.0	59.9
Panicum	68.7	64.9	62.7	50.6	61.7
Pennisetum	60.8	64.0	63.2	65.6	63.4
Mean	60.2	58.6	58.5	57.2	
$LSD_T(GxI)$ = 2.2					

* W1 -severely water stressed level, W4 - control

Table A11. Influence of irrigation level on the *in vitro*- dry matter digestibility (%) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	60.4	58.7	60.6	55.3	58.7
Cynodon	54.9	54.0	60.8	59.8	57.4
Digitaria	58.2	56.0	57.2	58.5	57.5
Panicum	50.8	50.4	54.2	54.2	52.4
Pennisetum	47.6	36.0	40.5	48.3	41.2
Mean	54.4	48.5	54.6	55.2	
LSD_T (G) = 4.7					

* W1 -severely water stressed level, W4 - control

Table A12. Influence of irrigation level on the crude protein content (%) of five perennial grasses in 1996/97.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	4.4	4.1	4.8	4.2	4.4
Cynodon	10.2	9.0	10.7	10.7	10.2
Digitaria	5.6	4.2	5.0	6.1	5.2
Panicum	6.0	5.7	4.2	4.7	5.2
Pennisetum	9.2	9.1	9.6	8.8	9.2
Mean	7.1	6.4	6.9	6.9	
LSD_T(GxI) = 0.5					

* W1 -severely water stressed level, W4 - control

Table A13. Influence of irrigation level on the crude protein content (%) of five perennial grasses in 1997/98.

Grass (G)	Irrigation level (I)*				Mean
	W1	W2	W3	W4	
Cenchrus	8.4	8.3	6.1	7.4	7.6
Cynodon	12.2	11.3	10.2	14.9	12.2
Digitaria	5.5	4.3	6.0	5.2	5.2
Panicum	7.7	6.6	5.2	6.2	6.4
Pennisetum	10.1	8.0	7.2	8.9	8.5
Mean	8.8	7.7	7.3	8.5	
LSD_T(G) = 1.7					

* W1 -severely water stressed level, W4 - control

Table A14. Correlation (r^2) between plant yield components and *in vitro* dry matter digestibility of five annual fodder crops in 1996/97.

	In vitro dry matter digestibility of				
Yield component	Cenchrus	Cynodon	Digitaria	Panicum	Pennisetum
Leaf	0.1	- 0.3	- 0.4	- 0.7	0.6
Stem	0.2	- 0.3	- 0.6	- 0.6	0.5
Inflorescence	- 0.2	0.3	- 0.3	- 0.2	-

Table A15. Correlation (r^2) between plant yield components and *in vitro* dry matter digestibility of five annual fodder crops in 1997/98.

	In vitro dry matter digestibility of				
Yield component	Cenchrus	Cynodon	Digitaria	Panicum	Pennisetum
Leaf	- 0.01	0.4	0.1	0.2	- 0.03
Stem	- 0.6	0.1	- 0.2	0.4	0.4
Inflorescence	0.03	0.3	0.7	-	-

Table A16. Correlation (r^2) between plant yield components and crude protein content of five annual fodder crops in 1996/97.

Yield component	Crude protein content of Cenchrus	Cynodon	Digitaria	Panicum	Pennisetum
Leaf	0.3	0.1	- 0.6	0	0.4
Stem	0.4	0.4	- 0.6	- 0.5	0.5
Inflorescence	- 0.2	- 0.5	- 0.1	- 0.1	-

Table A17. Correlation (r^2) between plant yield components and crude protein content of five annual fodder crops in 1997/98.

Yield component	Crude protein content of Cenchrus	Cynodon	Digitaria	Panicum	Pennisetum
Leaf	0.5	0.4	0.1	0.1	0.03
Stem	0.6	0.1	- 0.2	- 0.6	- 0.3
Inflorescence	- 0.1	0.3	0.7	-	-