Italian ryegrass (*Lolium multiflorum*) growth response to water and nitrogen

by

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Humility and the fear of the LORD bring wealth and honour and life.

(Proverbs 22:4)

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DECLARATION

I, Amanuel Bokhre Abraha, declare that the dissertation hereby submitted by me for the MSc (Agric) degree at the University of Pretoria is my own independent work and has not previously been submitted by me for a degree at this or any other university.

Signed______________________________

Amanuel Bokhre Abraha

May 2011

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ABSTRACT

At present, and more so in the future, irrigated agriculture will take place under water scarcity. Owing to the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimize water production and use efficiency (WUE). In South Africa, annual ryegrass (*Lolium multiflorum*) is one of the most widely grown cool season pasture species under irrigation. It is mainly used in dairy farming enterprises. Shortages of water and nitrogen can, however, be limiting factors for the production of this pasture. By using appropriate irrigation and nitrogen management tools, water and nitrogen productivity of the pasture can be improved. The objective of this study was, therefore, to determine the effects of different water levels in combination with different N fertiliser applications on the growth rate and dry matter production, quality, water use and water use efficiency of annual ryegrass. For two seasons, the trial was conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria. Higher frequency of irrigation coupled with high nitrogen application significantly improved the dry matter yield. Canopy size influenced the LAI and FI which in turn affects the yield. The study showed that the treatments that were irrigated twice weekly and top-dressed with 60 kg N ha^{-1} after each cut consumed the most water, and this resulted in the production of higher yield, maintenance of the

largest leaf area index and higher interception of the incoming solar radiation. The increase in these parameters may be due to the sufficient water and nitrogen fertiliser that induces rapid cell elongation as a result of higher water potential, higher turgor pressure and higher photosynthetic processes. As hypothesized, the decrease in the frequency of water application resulted in an increase in the DMC, digestibility, ME and CP values. Nitrogen application had an effect on the WU, as less water was used in the treatments that received no nitrogen. Highest K_C value recorded was in the optimal range and this indicates that the treatments were not over-irrigated. As the irrigation interval increased, more water was depleted from the soil profile. Depletion rates increased as the season progressed but generally it was minimal in the frequently irrigated treatments. Increase in WUE was achieved by reducing the frequency of irrigation from twice a week to once a week without causing significant yield loss. A possible reason for the increase in the WUE by reducing the irrigation frequency could be ascribed in part to reduced evaporation from the soil resulting from the lower wetting frequency of the deficit irrigation treatments. Within the same irrigation frequency, higher WUE was achieved by alleviating a limiting factor, N fertiliser, in this case, through increases in dry matter production. The highest WUE was achieved by irrigating once every two weeks. However, in some treatments, the WUE was not improved with the reduction in the frequency of irrigation as the water saved was overshadowed by yield loss. In summary, it can be said that the hypotheses that pasture production will be positively associated with soil moisture content, water stress can improve the quality of the pasture, N fertiliser will increase the DM response to soil moisture content and WUE will increase by alleviating a limiting factor, N fertiliser in this case were accepted. A logical extension of this work would be to do the trial in an open field to analyze the effect of irrigation and nitrogen fertilization on the growth, yield and quality of the pasture and then extrapolate the results to other sites and soil types using models.

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CHAPTER 1

GENERAL INTRODUCTION

In South Africa, annual ryegrass (*Lolium multiflorum*) is one of the most widely grown cool season pasture species under irrigation. It is grown by commercial farmers for intensive dairy, lamb and beef production. It is best adapted to areas with long seasons of cool, moist weather, well drained soils but can be tolerant to a wide range of soils and climates. The optimum planting date for irrigated annual ryegrass in South Africa is in February, hence it can be used as a source of feed in late autumn, winter, spring and early summer (Goodenough *et al*., 1984). It is a high yielding pasture with high nutritional qualities, high palatability, digestibility, metabolisable energy, protein and minerals (Hannaway *et al.,* 1999). It can be grazed and used for hay or silage. This characteristic plays an essential role in supplying better quality material between the winter and summer grazing. In South Africa an increase in irrigated pasture in both winter and summer rainfall regions (Tainton, 2000) has been reported. Supplementary irrigation in summer is usually used for tropical pasture crops, such as kikuyu, when spring rains are late or during periods of water stress. The production of annual ryegrass pastures during winter is generally under irrigation. Due to the high costs of irrigation water and fertilisers (Tainton, 2000) the production of pasture under irrigation is discouraging. Improved management systems for pastures are, therefore, required including irrigation scheduling and meeting the nutrient requirements of pastures, according to the intensity of utilization.

The primary cultural practices which affect growth and development of irrigated pastures (irrigation, fertilisation and defoliation management) ensure sustainable animal production. The rate of growth, leaf area index, canopy resistance and rooting conditions are affected directly by these cultural practices. Irrigation in particular plays an important role in pasture production, as it greatly affects the total yield and quality of the forage produced. Due to the wide variation in climatic conditions in different areas, it is not possible to have only one pasture management programme that can be directly applied to a specific site. To increase the quality and quantity of both annual and perennial pastures in intensive farming systems in times when rainfall is limiting, it is essential to irrigate these pasture species. Steynberg *et al.*, (1994) concluded that a single set of irrigation norms to schedule irrigation for pastures in South Africa was insufficient. Water use is seldom monitored by farmers and irrigation is generally only applied to prevent water stress. Limited research has been conducted to determine guidelines for irrigating different pastures widely used in agriculture, particularly in intensive animal production systems, such as dairy farming. To date, a few researchers have conducted detailed research on the water and management requirements of annual ryegrass in South Africa (Heard *et al.*, 1984; Goodenough *et al.*, 1984; Smith, 1985; Le Roux *et al.,* 1991; Eckard, 1994; Theron and Snyman, 2004). Detailed studies on the water use of temperate (Steynberg *et al.,* 1994), and tropical and sub tropical grasses and fodder crops (Marais *et al.,* 2002) were conducted. In these studies different pastures were compared and the main objective was to select the most drought tolerant and efficient temperate, tropical and sub tropical pasture crops. Detailed information on the water use and water use efficiency (in terms of quality and dry matter) together with economic analyses was reported. Limited water not only affected productivity but also altered the quality of the forage, in particular the protein content (Marais *et al.*, 2003). However, the use of intensive irrigation management systems on planted grass pastures with respect to the quantity of water applied, according to crop water requirements, needs further investigation.

After moisture, nitrogen is the most important determinant factor affecting the growth and yield of planted grass pastures. Irrigated ryegrass or kikuyu and ryegrass mixtures form an important component of intensive fodder production in South Africa. These pastures are established on marginal soils not suitable for agronomic, vegetable or horticultural crops (van Heerden and Du Rand, 1994). Despite the cost factor the application of nitrogen is still widely recommended for these pastures, although the use of inexpensive sources of N such as manure and/or legumes may become economically viable in the future. The most common N fertilisers used in South Africa are urea, limestone ammonium nitrate (LAN) and ammonium sulphate (Rethman, 1987). No differences in the dry matter responses were reported between different N sources by Rethman (1987), Eckard (1989) or McKenzie and Tainton (1993), although, Miles and Hardy (1999) reported the highest yields from LAN, followed by urea and the lowest from ammonium sulphate. In addition, the acidification associated with N fertilisation was higher when 400 to 600 kg N ha^{-1} $year^{-1}$ was used, especially with the ammonium sulphate (Miles and Hardy, 1999). The proper timing of application of N and irrigation also increased the efficiency of use of fertilisers and reduced the rate of volatilization. Because N plays such a key role in determining the yield and quality of planted grass pastures, important decisions on how much and when to apply N must be made. The main effect of N fertilisation on grasses is to increase the yield and quality of harvestable material. The benefits of N fertiliser may, however, be limited when other macro and micronutrients are limited. The response to N fertiliser can also be influenced by other environmental factors such as water, temperature (McKenzie and Tainton, 1993) and other nutrients (Miles and Hardy, 1999). Therefore, the optimum N will vary from season to season, year to year and from site to site, depending on weather conditions, soil fertility and age of the stand. With adequate soil moisture, planted grass pastures can make greater use of available N than under dry conditions. As a result, different soil moisture levels are likely to cause high fluctuations in yield and quality of pasture especially at higher rates of N. In general, when using N fertiliser farmers should ensure that the price is right, N use efficiency is promoted and that low environmental impact is targeted. Detailed studies on the effect of different levels of nitrogen and water availability on annual ryegrass had not yet been done. These factors will be addressed with the main objectives of the experiments to test the hypotheses:

1) pasture production will be positively associated with soil moisture content,

2) water stress can improve the quality of the pasture,

3) N fertiliser will increase the DM response to soil moisture content,

4) the grass will use water more efficiently under water limiting than under non-limiting conditions and

5) WUE will increase by alleviating a limiting factor, N fertiliser in this case.

Bearing these in mind, the experiment was done in 2007 and 2008. The main aspects of pasture production under irrigation and N fertilisation of annual ryegrass (*Lolium multiflorum* cv. Agriton) including yield, growth, quality, water use and water use efficiency will be discussed in the following chapters. All the chapters are written according to the African Journal of Range and Forage Science.

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CHAPTER 2

DRY MATTER YIELD AND GROWTH RESPONSE OF RYEGRASS AT THREE WATER AND NITROGEN LEVELS

Abstract

Annual ryegrass (*Lolium multiflorum*) is one of the most widely grown cool season pasture species under irrigation. It is mainly used in dairy farming enterprises. Water and nitrogen shortage is a limiting factor for the production of this pasture. This can be improved by using a proper irrigation and nitrogen scheduling method. Therefore, in this experiment, the effect of frequency of irrigation and nitrogen availability on the yield of annual ryegrass was evaluated to achieve an optimal production. To exclude rainfall effects on the irrigation treatments, the trial was conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria over a period of two growing seasons. The aim of the experiment was to analyse the effect of water stress and nitrogen application on annual ryegrass growth rate and dry matter production. The plots were arranged in a randomised complete block design with three replications. Treatments consisted of three water and three nitrogen levels. Water application to field capacity was scheduled twice a week, once a week or once every two weeks and nitrogen was top-dressed after each harvest at a rate of 0, 30 or 60 kg N per hectare. In each plot, an access tube was installed and the soil water content was measured with a Neutron Probe to a depth of 1.2 m. After calculating the deficit, plots were irrigated to field capacity. Ryegrass was harvested to 50 mm above ground on a 28 day cycle. Dry matter (DM) yield, leaf area index (LAI) and fractional interception of photosynthetically active radiation (PAR) were measured during the two growing seasons. Dry matter (DM) yield of the two seasons was significantly influenced ($P<0.05$) by treatment interactions between the amount of water and nitrogen fertiliser application. In both seasons, yield increased as a function of the amount of water and nitrogen fertiliser applied. Highest cumulative yield of 10.98 t ha^{-1} over four harvests was obtained in the second season from the highest water and nitrogen treatment (W3N3). Leaf area index (LAI) of the two seasons was also significantly influenced ($P<0.05$) by the treatment interactions except for the second sampling date in the second season. Highest LAI of 5.19 m^2 m^{-2} was recorded for the treatment with the highest yield, while highest fractional interception of 94% was recorded for the same treatment. These results conclude that the response of yield and LAI to irrigation and nitrogen fertiliser were positive as higher yield and LAI was recorded when nitrogen fertiliser was applied provided that more water was available in the soil.

Key words: irrigation, leaf area index, photosynthetically active radiation

2.1. Introduction

The growth of plants is determined by the accumulation of matter from the environment. Three important processes regulating the growth of plants are uptake of water, photosynthesis and uptake of minerals (Dovrat, 1993). Water and mineral uptake occur by a transfer across the soil-root interface. Although water accumulation is a major contribution to growth, photosynthesis (i.e. CO_2 assimilation) is quantitatively the limiting process on which accumulation of water and minerals depend. Photosynthetic transfer of CO_2 from the air to the leaves is therefore the basic rate determining process for advanced systems of crop production (Dovrat, 1993). The exposure of grass species to variable climatic conditions determines if the growth of the species vary within a season and amongst seasons. Knowledge of the physiological responses of any particular species to the environment is required to determine practical management practices. Management practices should thus be based on the stage of development and on the physiological condition of the plant. To understand the growth of a grass, it is essential to note the differences that exist in the physiological responses of annual and perennial species and also temperate and sub tropical species (Ball *et al.*, 2002). Generally light, temperature and moisture are important environmental factors that influence the vegetative development and maturation of forage specie (Kramer, 1983). These environmental factors however, determine the major processes responsible for the production potential of a plant, which include the interception of solar radiation by the leaf canopy, conversion of the intercepted radiant energy to plant dry matter (DM), and partitioning of the DM produced between plant components (Dovrat, 1993).

A study to determine the effect of over-seeding of kikuyu pastures with annual and perennial ryegrass, and annual and perennial clovers, and its effect on the production rate of kikuyu, was conducted at the Outeniqua Research farm in the Western Cape, South Africa. Low production rates of 33.9 kg DM ha^{-1} day^{-1} in spring and during the summer and autumn higher yields of 67 kg DM ha^{-1} day^{-1} and 71 kg ha^{-1} day^{-1} (Botha *et al.*, 2005) were obtained, respectively. In general the dry matter yield tends to increase as the moisture availability in the soil increases. Similarly, a linear increase in DM is expected up to the maximum threshold, from which a quadratic increase will be shown under optimum environmental and soil moisture conditions.

Irrigated annual ryegrass is capable of producing very high forage yields with excellent nutritional values (Dovrat, 1993). In research carried out at Cedara, KwaZulu Natal, South Africa, the dry matter yield of annual ryegrass ranged from 11.6 - 15.6 t DM ha^{-1} (Marais *et al.*, 2003). Various dry matter yields of ryegrass were obtained for the experimental work conducted by Eckard (1989) for two growing seasons on four different water stress treatments. These yields were 13.5 t ha^{-1} and 9.5 t ha^{-1} for the control treatment; 7.7 t ha^{-1} and 8.2 t ha^{-1} for the 75% water availability of the control; 6.1 t ha^{-1} and 6.2 t ha^{-1} for the 50 % of the control and 5.6 t ha^{-1} and 4.1 t ha^{-1} for the 25% of the control respectively. These yields compared well with the yields obtained by Le Roux *et al.,* (1991) who reported 9 t ha^{-1} and 13 t ha^{-1} for ryegrass established in October and February respectively. Slightly higher yields were achieved by Smith *et al.,* (1986), a season cumulative of 17 t ha^{-1}. Eckard (1989), however, concluded that the area of production and the type of soil could affect the yield of annual ryegrass, and may vary by 5 t ha^{-1}.

It is not always clear how much water and fertiliser to apply to obtain an optimum yield. Therefore the objective of this study was focused on quantifying the yield response of annual ryegrass to variable water and nitrogen levels and to test the hypotheses that:

- the DM yield will be positively associated with soil water content and N fertilisation and
- higher LAI and radiation interception will be obtained from the non-stressed treatments.

2.2. Materials and methods

2.2.1. Experimental site

To exclude rainfall effects on the proposed irrigation treatments, the experiment was conducted under a rain shelter at the Hatfield Experimental Farm of the University of Pretoria. The area has an elevation of 1327m above sea level, co-ordinates of 25º45'S and 28º16'E with an average annual rainfall of 670 mm (Annandale *et al.*, 1999). The soil of the experimental site is classified as a silt clay loam of the Hutton form that belongs to the Suurbekom family with a clay content of 26 – 37% (Soil Classification Working Group, 1991). To create suitable conditions for good soil and seed contact, the field was ploughed with a disc plough and rotavated. Prior to the commencement of the study, 12 soil samples were taken randomly from the top 0.15 m from the experimental site and were analysed in the Soil Science Laboratory of the University of Pretoria for pH (H_2O) and electrical conductivity (EC). A composite of the 12 samples was then analysed for C, NH_4, NO_3, SO_4, P and exchangeable cations (Ca, K, Mg and Na) using the ammonium acetate extractable technique. The analysis indicated that the site was slightly saline, so the salt was leached before planting. The chemical analyses of the soil at the experimental site are displayed in Appendix B.

2.2.2. Experimental layout

A 149.5 m^2 (6.5 m x 23.0 m) block was divided into 27 plots of 3.0 m^2 (1.5 m x 2.0 m) each, with an interspacing of 0.5 m between each plot. In both seasons, superphosphate and potassium chloride were applied at planting. In the first week of June 2007, annual ryegrass (*Lolium multiflorum* cv. Agriton) was planted at a seeding rate of 30 kg ha^{-1}. Sprinkler irrigation was used for seven weeks until the grass was well established, and thereafter to control the water use more efficiently drip irrigation commenced. In the 2008 season, the grass was planted in April and sprinkler irrigation was used for eight weeks before the commencement of drip irrigation. The lateral spacing between the dripper lines and the distance between drippers in the line was 0.3 m. Irrigation was applied to individual plots depending on the soil water deficit to field capacity. Weeding was conducted manually during the course of the trial.

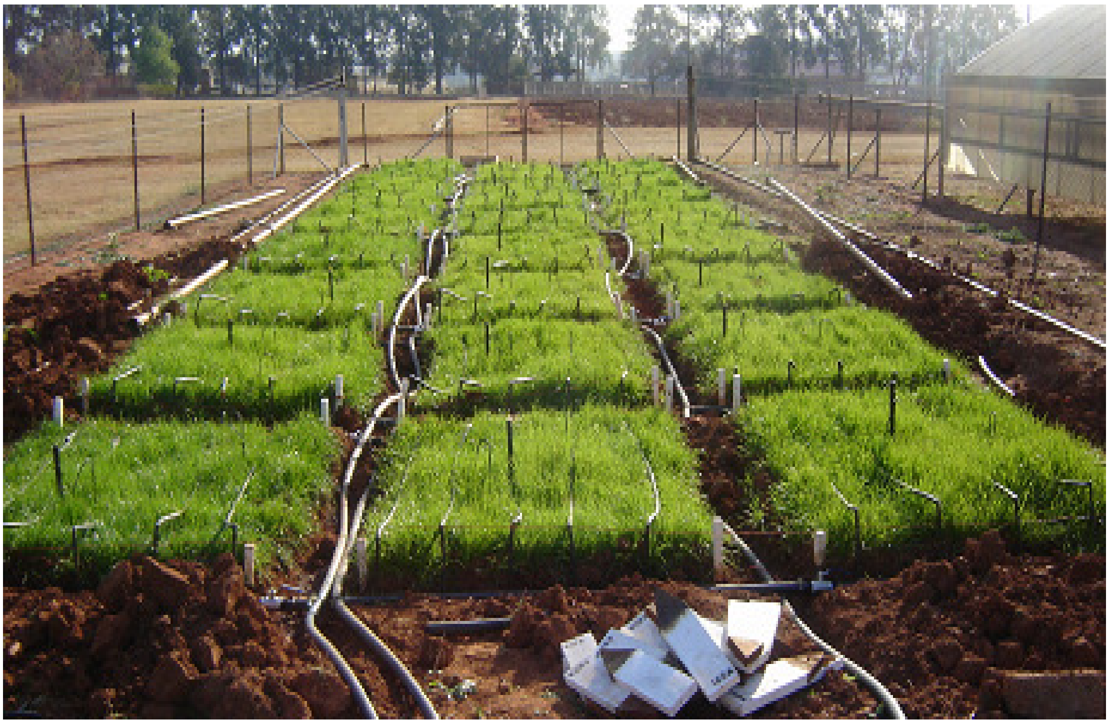

Figure 2.1: Panoramic view of annual ryegrass (*Lolium multiflorum* cv. Agriton) experimental layout at the Hatfield Experimental Farm (July 2007)

2.2.3. Treatments

In each plot, a neutron probe access tube was installed and the soil water content was calculated using a neutron water meter. Three levels of irrigation were applied, namely W1: irrigation of once every two weeks to field capacity, W2: irrigation of once weekly to field capacity and W3: irrigation of twice a week to field capacity. At the beginning of each season, the soil profiles of all the plots were brought to field capacity. Soil water deficit measurements were made using a neutron water meter model 503 DR CPN Hydroprobe (Campbell Pacific Nuclear, California, USA). The cumulative water deficit of the profile was calculated over a soil depth of 1.2 m, but irrigation was based on the upper 0.8 m of the soil profile as the roots of the grass were concentrated in the top 0.7 m. Three nitrogen treatments, namely N1: 0 kg N ha^{-1}, N2: 30 kg N ha^{-1} and N3: 60 kg N ha^{-1} were applied after each cut. The nitrogen was applied as a top dressing in the form of limestone ammonium nitrate (LAN) – 28% N.

2.2.4. Weather

Weather data was collected from an automatic weather station located near the experimental site. The automatic weather station consisted of an LI 200X pyranometer (LiCor, Lincoln, Nebraska, USA) for measuring solar radiation, an electronic relative humidity and temperature sensor installed in a Gill screen, an electronic cup anemometer (MET ONE, Inc. USA) to measure wind speed, an electronic rain gauge (RIMCO, R/TBR tipping bucket rain gauge, Rauchfuss Instruments Division, Australia) and a CR 10X data-logger (Campbell Scientific Inc., USA). All of the above data were monitored and recorded every 10 seconds with the data-logger. The logged data was downloaded once in a month. Table 2.1 shows a summary of the monthly rainfall, maximum and minimum temperatures of 2007 and 2008 for the experimental site downloaded from the automatic weather station.

Table 2.1: Monthly rainfall, maximum and minimum temperatures of the Hatfield Experimental Farm, Pretoria for 2007 – 2008

	2007			2008		
	Rainfall (mm)	T_{max} (°C)	T_{min} (°C)	Rainfall (mm)	T_{max} (°C)	T_{min} (°C)
Jan	56.4	31.0	15.8	228.7	26.8	15.9
Feb	38.3	32.5	16.3	59.5	29.7	15.7
Mar	14.3	31.1	15.3	144.3	27.0	14.5
Apr	19.2	27.4	12.3	18.1	25.0	9.6
May	0.0	23.9	6.2	37.6	23.0	8.1
Jun	34.1	20.3	4.8	8.7	21.1	4.8
Jul	2.8	20.4	3.8	1.6	20.2	4.0
Aug	0.0	23.5	6.1	0.0	24.2	7.5
Sep	31.2	26.9	9.4	0.0	29.3	12.7
Oct	142.0	29.9	14.2	33.1	28.6	12.5
Nov	48.9	28.1	15.6	165.7	29.1	14.7
Dec	170.3	30.2	17.1	74.1	29.8	15.3

T_{max} = maximum monthly average temperature,

T_{min} = minimum monthly average temperature

2.2.5. Yield and growth

Every 28 days yield was measured by sampling plant material from a 0.09 m^2 area from each of the 27 plots to a height of 50 mm above the soil surface. In each season the pasture was harvested four times. In the first season (2007), the first growth cycle was harvested on August 23, the second growth cycle on September 20, the third growth cycle on October 18 and the fourth growth cycle on November 15. In the second season (2008), the first growth cycle was harvested on July 15, the second growth cycle on August 12, the third growth cycle on September 9 and the fourth growth cycle on October 7. The sample was partitioned into stem and leaves and for dry matter yield determination, the sample was oven dried for 72 hours at 67 °C to a constant mass. Leaf area index (LAI) was a growth parameter measured using an LI 3100 belt driven leaf area meter (LiCor, Lincoln, Nebraska, USA) every two weeks. The first sampling date, Day 14 (D14), was taken two weeks after the cutting date and the second sampling date, Day 28 (D28), was taken two weeks later. Fractional interception of photosynthetically active radiation (PAR) was another growth parameter used to illustrate ryegrass growth response to treatment, and was measured using a sunfleck ceptometer (Decagon Devices, Pullman, Washington, USA) by measuring alternately above the canopy and 5 cm above the ground in the respective plot every week. The first sampling date, Day 7 (D7), was taken one week after the cutting date and subsequently Day 14 (D14), Day 21 (D21) and Day 28 (D28) followed at a weekly interval. Five sequential measurements were made in each plot. The measurements were made between 1100 and 1300 hours.

2.2.6. Statistical analyses

Nine treatment combinations of three water levels and three nitrogen levels were replicated three times. The plots were in a complete ramdomised block design and the data was analysed using the Statistical Analysis System (SAS) program for Windows v9.2 (Statistical Analysis System Institute Inc., 2002). Least significant difference (LSD) was calculated at the 5% significance level to compare the treatment means using the Student's t-test.

2.3. Results and discussion

2.3.1. Dry matter yield

The dry matter (DM) yield of the first season was significantly ($P<0.05$) influenced by treatment interactions between the amount of water and N fertiliser applied except for the first growth cycle. Within each growth cycle the treatments had significant differences in the dry matter yields. W3 was higher ($P<0.05$) in yield than W2 and W1, while the yield of W2 was also higher ($P<0.05$) than that of W1. The same is also true for the nitrogen treatment. The highest yield obtained averaged over nitrogen treatment was from the W3 treatment, the highest being 2.26 t ha^{-1} in the third growth cycle. The lowest yield of 1.09 t ha^{-1} was recorded in the W1 treatment in the first growth cycle. With respect to the nitrogen treatment, the highest yield of 2.64 t ha^{-1} was produced in the N3 treatment of the second growth cycle while the lowest of 0.71 t ha^{-1} was produced from the N1 treatment. From Table 2.2 it is shown that production increased significantly with an increase in the frequency of irrigation and fertiliser application. This could be due to the favourable conditions associated with the grass not being stressed, as the yield was lower ($P>0.05$) from the stressed plots. In the first season (2007), the highest yield in most of the treatments was achieved in the second regrowth cycle which was in September. This could mainly be attributed to the fertiliser carry-over from the first growth cycle and the time of harvest. The time of harvest for the highest yield corresponds well with the results obtained by Le Roux *et al.*, (1991) and Pieterse *et al.,* (1988). They reported that the peak production rate of annual ryegrass is in August/September.

Table 2.2: Dry matter yield (t ha^{-1}) of annual ryegrass (*Lolium multiflorum* cv. Agriton) for the first growing season (2007)

Main Effect	Growth cycle 1 (Aug 23)	Growth cycle 2 (Sep 20)	Growth cycle 3 (Oct 18)	Growth cycle 4 (Nov 15)	Total
Water (W)					
W1	1.09c‡	1.91c	1.88c	1.69c	6.57c
W2	1.20b	2.12b	2.02b	1.86b	7.20b
W3	1.36a	2.24a	2.26a	2.13a	7.99a
LSD	***0.072***	***0.078***	***0.074***	***0.075***	***0.194***
Nitrogen (N)					
N1	0.71c	1.43c	1.30c	1.24c	4.70c
N2	1.42b	2.19b	2.26b	1.99b	7.87b
N3	1.52a	2.64a	2.58a	2.45a	9.19a
LSD	***0.072***	***0.078***	***0.074***	***0.075***	***0.194***
Significance					
W	**	**	**	**	**
N	**	**	**	**	**
WxN	Ns	**	*	*	*

‡Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; W= water treatment; N= nitrogen treatment; WxN= water and nitrogen interaction; Ns= non significant; LSD= least significant difference

The DM yield of the second season was significantly ($P<0.05$) influenced by WxN treatment interactions. Table 2.3 shows that within each regrowth cycle, some of the treatment combinations had significant differences in the dry matter yields while there was no significant difference between others. The highest cumulative total yield of 10.98 t ha^{-1} and 10.64 t ha^{-1} over four harvests was achieved by W3N3 and W2N3, treatments receiving water twice and once a week with the highest nitrogen application, respectively. There was no significant difference ($P>0.05$) between these two treatments but they differ significantly from the other treatments. The lowest yield, a total of 3.61 t ha^{-1} was produced from W1N1, the treatment that was irrigated once every two weeks with no nitrogen application. The response to irrigating once or twice a week at N3 was non significant as there was no difference in the yield between W2N3 and W3N3. These results indicate that the soil was wet enough to fulfil the demand, hence increasing the water use efficiency by applying once a week. The highest yield in the second season was achieved in the third regrowth cycle which was in September, and this again, agrees with the results obtained by Le Roux *et al.*, (1991) and Pieterse *et al.,* (1988) as they reported the peak production rate of annual ryegrass in August/September.

Table 2.3: Interaction between water and nitrogen treatments on the individual and total DM yield (t ha^{-1}) for the second season (2008)

Treatment	Growth cycle 1 (15 Jul)	Growth cycle 2 (12 Aug)	Growth cycle 3 (09 Sep)	Growth cycle 4 (07 Oct)	Total
W1N1	0.90e[‡]	0.93e	0.97e	0.81e	3.61f
W1N2	2.01b	1.96bc	2.02c	1.91cd	7.90c
W1N3	2.13b	2.26b	2.36b	2.20bc	8.95b
W2N1	1.15d	1.15e	1.19e	1.08e	4.57e
W2N2	1.96b	1.93c	2.05c	2.07c	8.01c
W2N3	2.58a	2.71a	2.70a	2.65a	10.64a
W3N1	1.60c	1.60d	1.67d	1.64d	6.51d
W3N2	2.16b	2.20bc	2.40b	2.45ab	9.21b
W3N3	2.70a	2.73a	2.83a	2.72a	10.98a
LSD	***0.244***	***0.305***	***0.277***	***0.294***	***0.875***

[‡]Means within columns with the same letter do not differ significantly (P>0.05)

The cumulative dry matter productions of the treatments for both seasons are shown in Figure 2.2. The highest yield was obtained from the treatment with the high water and high nitrogen application. As the season changed from winter to summer there was a decrease in the growth of the pasture and thus a decrease in the dry matter production. Figure 2.3 illustrates the DM production pattern for the treatments fertilised with the highest nitrogen with different irrigation frequencies in the second season. Peak production was attained in September and after that the production started to decrease as the temperature became warmer. This is mainly attributed to the grass being a cool season pasture. The effect of increased irrigation and nitrogen application had a positive effect on the total yield produced. Generally, for the same level of water availability, yield increased with increasing nitrogen application. However, from the unfertilised plots the highest yield was obtained when plots were irrigated twice a week.

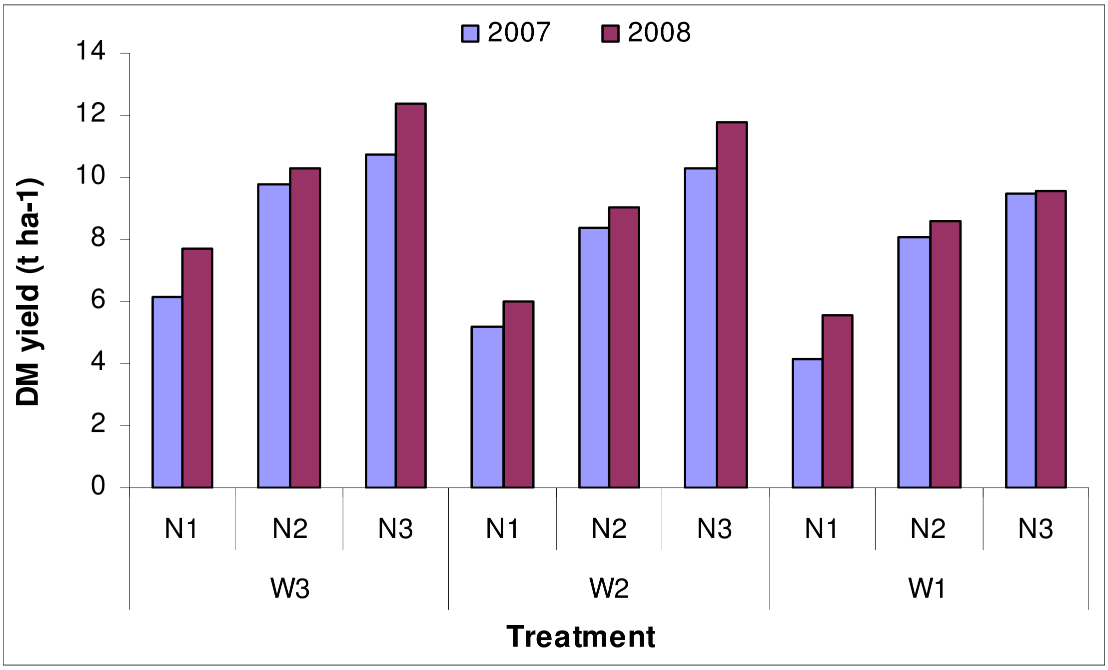

Figure 2.2: Total DM yield for both seasons (2007 and 2008)

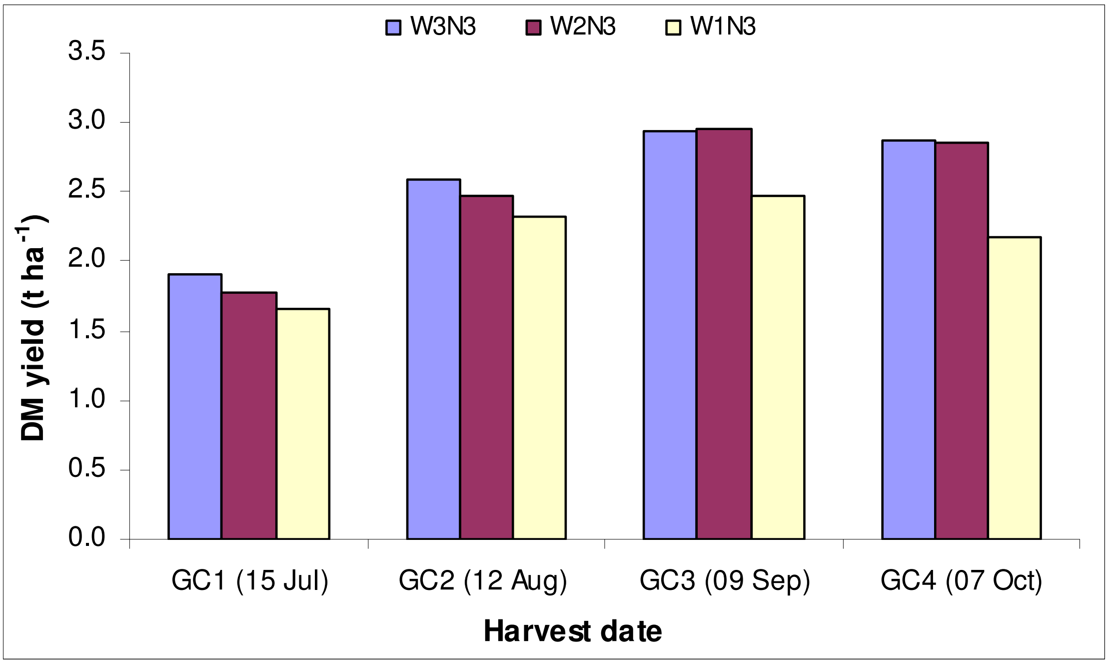

Figure 2.3: DM yield over the season of N3 treatment with different irrigation frequencies in the second season

2.3.2. Leaf area index

Leaf area index (LAI) is the leaf area of plants per unit surface area. It is one of the physical parameters that indicate the growth of the crop. The presence of sufficient plant available soil water throughout the growing season helps plants to maintain higher leaf water potential and at the same time increase the period over which the canopy remains functional (Akmal and Janssens, 2004). Both during 2007 and 2008 (Table 2.4) the leaves of the treatments without water and nitrogen stress grew vigorously and retained the highest LAI throughout the growing season. In D14 of the first season (Table 2.4) LAI was significantly affected by the main effects and WxN treatment interactions. However, figure 2.4 shows that LAI was not significantly different amongst the W2 and W3 treatments in the high nitrogen application (N3) and also between W1 and W2 treatments in the medium nitrogen application (N2). Highest

(P<0.05) LAI of 3.42 m^2 m^{-2} was recorded from the W3N3 treatment (Figure 2.4), but this was similar (P>0.05) to that of W2N3 treatment. The lowest LAI of 1.58 m^2 m^{-2} was recorded from the treatments that received water every two weeks with no nitrogen application (W1N1). The higher LAI values may be due to the sufficient water and N fertiliser application that induce rapid cell elongation due to the higher water potential and, therefore, higher turgor pressure, better interception of PAR and thus increased DM production.

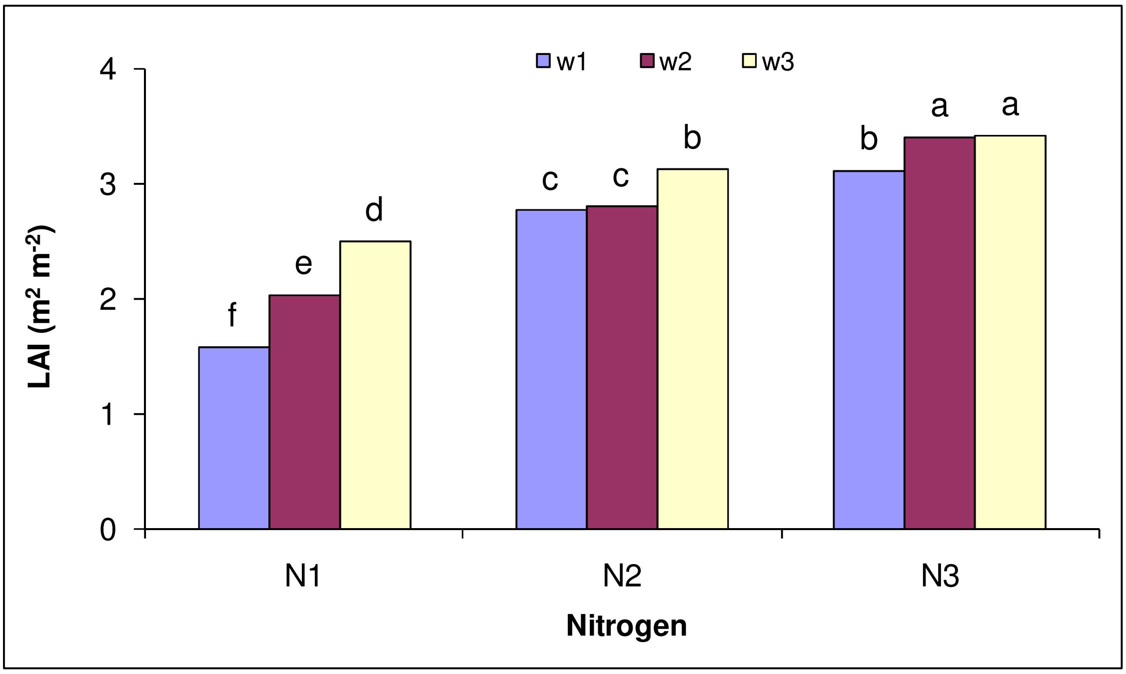

Figure 2.4: D14 Leaf area index (LAI) of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the first season (2007)

Table 2.4: Mean leaf area indices (LAIs) of annual ryegrass (*Lolium multiflorum* cv. Agriton) for the two growing seasons (2007 and 2008)

Main effect	2007		2008	
	D14	D28	D14	D28
Water (W)				
W1	2.49c‡	3.17c	2.84c	4.33b
W2	2.75b	4.21b	3.02b	4.49b
W3	3.01a	4.71a	3.44a	4.93a
LSD	***0.076***	***0.093***	***0.127***	***0.159***
Nitrogen (N)				
N1	2.04c	3.22c	2.40c	3.80c
N2	2.90b	4.36b	3.28b	4.76b
N3	3.32a	5.06a	3.62a	5.19a
LSD	***0.076***	***0.093***	***0.127***	***0.159***
W	**	**	**	**
N	**	**	**	**
WxN	**	*	**	Ns

‡Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; Ns= not significant W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction; D14 and D28= sampling dates

In D28 of the first season (Table 2.4) LAI was significantly affected by the main effects and WxN treatment interactions. Figure 2.5 shows that LAI of 5.45 m^2 m^{-2} from W3N3 was significantly higher ($P<0.05$) from the other treatments while the lowest LAI of 2.67 m^2 m^{-2} was recorded from the treatments that received water every two weeks with no nitrogen application. From these results, it can clearly be seen that the impact of water and nitrogen shortages had a main effect for the reduction of the LAI and also reduced DM production from these treatments.

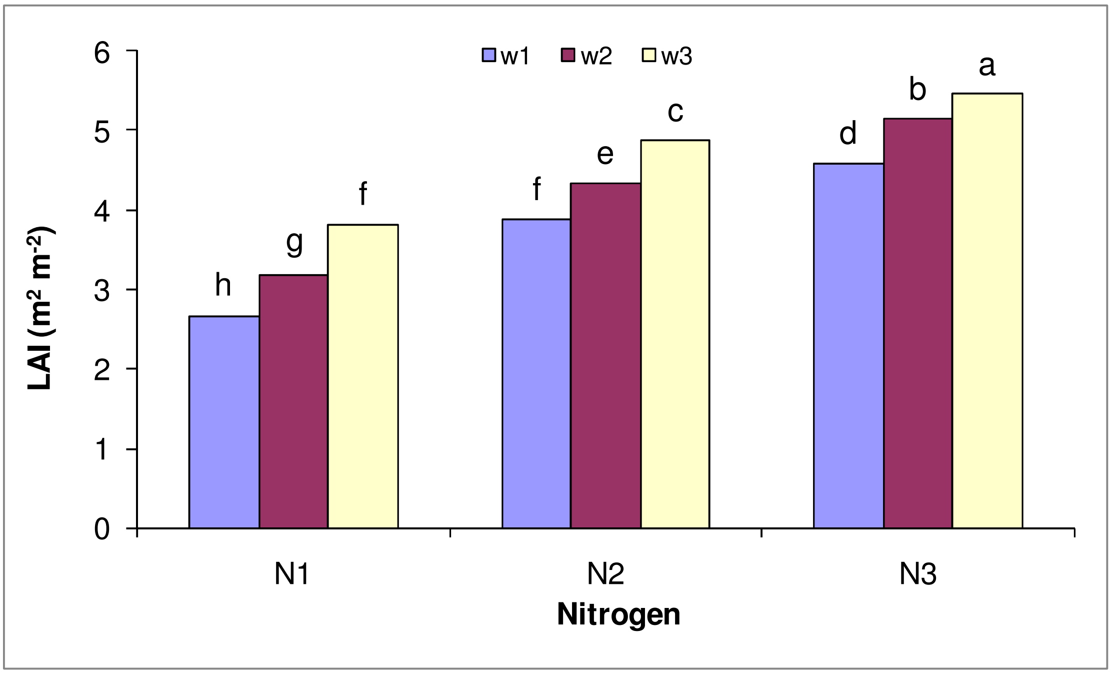

Figure 2.5: D28 Leaf area index (LAI) of annual ryegrass (*Lolium multiflorum* cv. Agriton) the first season (2007)

The same trend was also observed in D14 of the second season. The LAI was significantly affected by the main effects and by WxN treatment interactions (Table 2.4). Figure 2.6 shows highest LAI of 3.82 m^2 m^{-2} was obtained from the W3N3 treatment. However, this was not significantly different from W2N3 treatment. The lowest value of 1.82 m^2 m^{-2} was recorded for W1N1 treatment. The low values of LAI may be due to the shortages of water and fertiliser on these treatments.

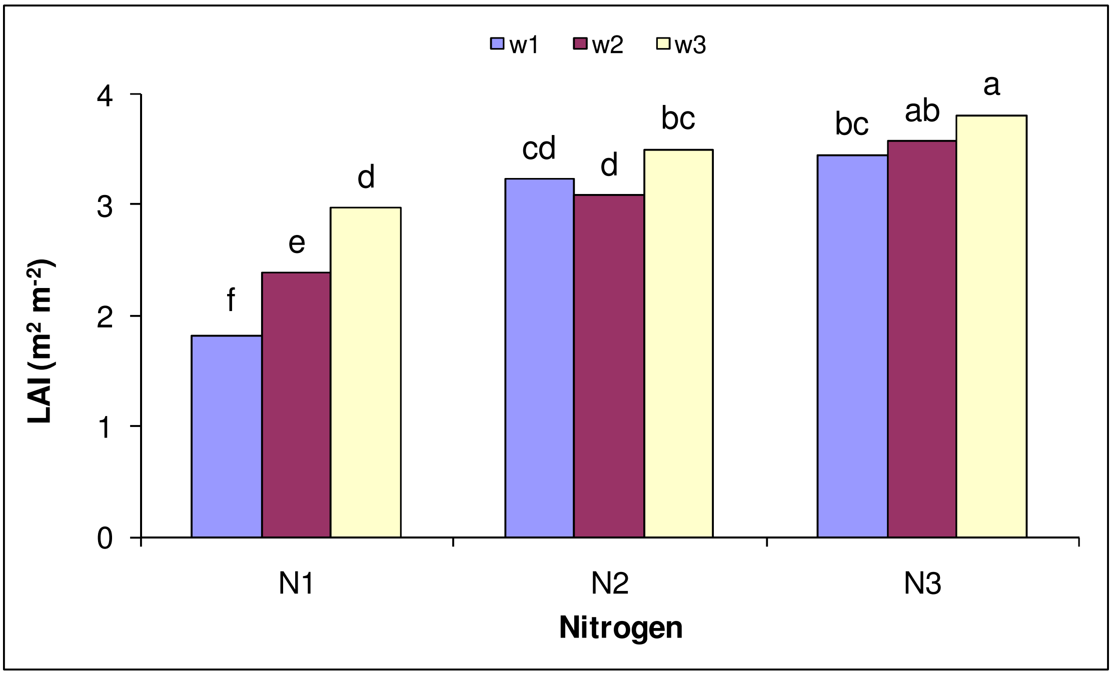

Figure 2.6: D14 Leaf area index (LAI) of annual ryegrass (*Lolium multiflorum* cv. Agriton) the second season (2008)

The LAI of D28 in the second season was significantly influenced by water and nitrogen applications. However, the effect of the treatment's interaction (WxN) on LAI was not significant (P>0.05) (Table 2.4). Highest LAI of 4.93 m^2 m^{-2} was recorded from W3 treatment averaged over the nitrogen application, while the lowest LAI of 4.33 m^2 m^{-2} was recorded from the W1 treatments. However, there was no significant difference between W1 and W2 treatments. With respect to the N application, the highest LAI of 5.19 m^2 m^{-2} was obtained in the N3 treatment, followed by 4.76 m^2 m^{-2} in the N2 and 3.80 m^2 m^{-2} in the N1 treatment. Larger LAIs were associated with greater yield. Canopy leaf area index increased with crop growth as the plots that received higher nitrogen and irrigated twice weekly, produced higher DM productions. Higher LAI under sufficient water and nitrogen supply is usual due to turgid cells and rapid cell production of plant leaves. Insufficient water with no fertiliser application has a negative impact on grass leaves and was the main consequence of LAI reduction in the treatments that received water every two weeks with no N fertiliser application.

2.3.3. Fractional radiation interception

Fractional interception of photosynthetically active radiation (PAR) is an important indicator of the overall above ground biomass production of plants. Generally the fractional interception of PAR increased with an increase in the leaf area and hence an increase in the dry matter production for all the treatments. The weekly change in radiation interception by the grass for growth cycles 2 and 3 is shown in Tables 2.5 (for the first growing season) and 2.6 (for the second growing season). Table 2.5 illustrates that in the first growing season there was no treatment interactions ($P>0.05$) for D7, D21 and D28 in the second growth cycle, however the sampling dates in the third growth cycle had significant treatment interactions at $P<0.05$. Interception of PAR to the tiller base, which was low immediately after the cut, increased rapidly every week. For D7 of the second growth cycle (Table 2.5), there was no significant difference between the frequencies of irrigation, however the effect of nitrogen application was significant. This could be as a result of applying the nitrogen fertiliser immediately after cutting. Radiation interception increased with the increase in nitrogen fertiliser application. This also corresponds well with the LAI, as the plots that received higher nitrogen had higher LAI and as a result increased DM production. In the third growth cycle (Table 2.5) the treatments had significant differences at $P<0.05$. As the frequency of irrigation and nitrogen application increased, the radiation interception also increased as these plots had higher LAI which could have been stimulated by favourable growing conditions.

Table 2.5: Fractional interception of photosynthetically active radiation (PAR) of annual ryegrass (*Lolium multiflorum* cv. Agriton) for growth cycles 2 and 3 in the first season (2007)

Main Effect	Growth cycle 2				Growth cycle 3			
	D7	D14	D21	D28	D7	D14	D21	D28
Water								
W1	0.42a[‡]	0.66b	0.71b	0.83c	0.43b	0.67b	0.74b	0.85c
W2	0.43a	0.72a	0.78a	0.86b	0.44a	0.73a	0.82a	0.89b
W3	0.43a	0.73a	0.79a	0.89a	0.45a	0.69b	0.82a	0.92a
LSD	***0.014***	***0.038***	***0.038***	***0.021***	***0.011***	***0.026***	***0.011***	***0.013***
Nitrogen								
N1	0.40c	0.66c	0.71c	0.81c	0.41c	0.63c	0.73c	0.85c
N2	0.43b	0.71b	0.75b	0.85b	0.43b	0.68b	0.78b	0.88b
N3	0.45a	0.75a	0.83a	0.93a	0.47a	0.78a	0.86a	0.93a
LSD	***0.014***	***0.038***	***0.038***	***0.021***	***0.011***	***0.026***	***0.011***	***0.013***
Significance								
Water	Ns	**	**	**	**	**	**	**
Nitrogen	**	**	**	**	**	**	**	**
WxN	Ns	**	Ns	Ns	**	*	*	**

[‡]Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; Ns= not significant W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction; D7,D14,D21 and D28= sampling dates

Table 2.6 shows that after one week of regrowth from cutting, 41% – 47% of the incoming PAR was intercepted and by the fourth week 83% - 94% of the PAR was intercepted by the canopy. There was no treatment interactions ($P>0.05$) for D7, D21 and D28 in growth cycle 2 and D7 in growth cycle 3 of the second season (table 2.6), but all the other sampling dates had significant interactions at $P<0.05$. As in the first season, interception of PAR to the tiller base was low immediately after the cut but increased rapidly for the first two weeks of regrowth and then slightly until the cutting date. The frequency of irrigation and nitrogen application had significant differences in all the sampling dates. The fact that top-dressing of the nitrogen fertiliser coupled with water application immediately after cutting may be the main cause for the rapid regrowth in the first two weeks. Interception of PAR increased with the increase in the frequency of irrigation and nitrogen fertiliser application, and vigorous growth was evident for the plots that received high water and high N. As expected these plots had higher LAI and DM yields.

Table 2.6: Fractional interception of photosynthetically active radiation (PAR) of annual ryegrass (*Lolium multiflorum* cv. Agriton) for growth cycles 2 and 3 in the second season (2008)

Main Effect	Growth cycle 2				Growth cycle 3			
	D7	D14	D21	D28	D7	D14	D21	D28
Water								
W1	0.42b‡	0.74b	0.79c	0.84c	0.43b	0.69b	0.75b	0.85c
W2	0.44a	0.75ab	0.82b	0.87b	0.45a	0.74a	0.83a	0.90b
W3	0.45a	0.77a	0.86a	0.92a	0.46a	0.71b	0.83a	0.93a
LSD	***0.011***	***0.025***	***0.028***	***0.024***	***0.015***	***0.027***	***0.022***	***0.018***
Nitrogen								
N1	0.41c	0.70c	0.78b	0.83c	0.42c	0.66c	0.75c	0.84c
N2	0.44b	0.76b	0.80b	0.86b	0.44b	0.70b	0.79b	0.89b
N3	0.47a	0.81a	0.89a	0.93a	0.47a	0.78a	0.87a	0.94a
LSD	***0.011***	***0.025***	***0.028***	***0.024***	***0.015***	***0.027***	***0.022***	***0.018***
Significance								
Water	**	*	**	**	**	**	**	**
Nitrogen	**	**	**	**	**	**	**	**
WxN	Ns	**	Ns	Ns	Ns	*	*	**

‡Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; Ns= not significant W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction; D7,D14,D21 and D28= sampling dates

2.4. Conclusions

In general, irrigation and nitrogen fertiliser application affected the dry matter yield and LAI significantly. Results from this experiment show that dry matter yield and LAI can be increased through the application of increased irrigation and nitrogen fertiliser. The application of 60 kg N ha^{-1} after every cut resulted in higher DM yield and LAI, provided that there is no water stress. The presence of sufficient plant available soil water with the highest nitrogen fertiliser, played an important role in maintaining higher LAI for a longer period, thereby intercepting more PAR which in turn led to increased DM yield from the treatment irrigated twice weekly with high nitrogen application. Lower rate of increase in the leaf area from the treatment that was irrigated once every two weeks with no N fertiliser application, resulted in a decrease in the rate of light interception and lower DM yield. It can therefore be concluded that the treatment with the high frequency of irrigation coupled with high N fertiliser application is responsible for the highest DM yield. This proves that the pasture production was positively associated with the soil moisture and fertiliser content.

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CHAPTER 3

FORAGE QUALITY OF RYEGRASS GROWN UNDER IRRIGATED CONDITIONS

Abstract

Annual ryegrass (*Lolium multiflorum*) is one of the most important high-quality, cool-season, irrigated pastures in South Africa. One of the main features that make it popular with livestock producers is its high forage quality and rapid regrowth. It performs well during the winter because it is a temperate crop. Water and nitrogen shortage can affect the forage quality of the grass but this can be improved by using a proper irrigation and nitrogen scheduling method. In this experiment, the effect of frequency of irrigation and nitrogen fertilisation on the quality of annual ryegrass was evaluated. The study was conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria over a period of two growing seasons, in a randomised complete block design with three replications. Treatments consisted of three water and three nitrogen levels. Water application to field capacity was scheduled twice a week, once a week or once every two weeks and nitrogen was top-dressed after each harvest at a rate of 0, 30 or 60 kg N per hectare. In each plot, an access tube was installed and the soil water content was measured with a Neutron Probe to a depth of 1.2 m. After calculating the deficit, plots were irrigated to field capacity. Ryegrass was harvested to 50 mm above the ground on a 28 day cycle. The dry matter content was significantly affected by the harvesting interval, the highest being recorded in the fourth harvest. It was also affected by the frequency of irrigation and nitrogen fertilisation. The leaf:stem ratio declined over the growing season with the lowest being recorded in the fourth growth cycle. *In vitro* organic matter digestibility (IVOMD) and crude protein (CP) were also affected by the frequency of irrigation, recording 83.1% and 28.5%, respectively from the treatments being irrigated once every two weeks. The highest CP content with respect to the nitrogen fertilisation was 28.2% from the N3 treatments, while the IVOMD was not affected by the N fertiliser. The neutral detergent fibre (NDF) was not significantly affected by the frequency of irrigation or the N fertiliser. Metabolisable energy (ME), however, was significantly affected by WxN interactions, the highest of 12.0 MJ kg^{-1} being recorded in the W1N1 treatment. Better CP values were found with the application of more nitrogen fertiliser. Decreasing the frequency of irrigation increased the IVOMD, dry matter content (DMC), ME and CP contents.

Key words: dry matter content, crude protein, *in vitro* organic matter digestibility, metabolisable energy

3.1. Introduction

In South Africa, Italian ryegrass (*Lolium multiflorum*), is an important pasture under irrigation and is mainly utilised for milk and fat lamb production (de Villiers and van Ryssen, 2001). High dry matter (DM) production and good quality forage are essential. Forage grasses, however, do not always fulfil livestock requirements completely. To obtain high levels of milk production, DM intake must be high. South African cultivars of *Lolium multiflorum* tend to have relatively high moisture contents (Meissner *et al*., 1992) which affect the DM intake adversely. In order not to affect the DM intake of grazing ruminants adversely, the DM content of forages should be at least 18–20% (Meissner *et al*., 1992). Furthermore, high levels of neutral detergent fibre (NDF) may limit the DM intake and lower overall digestibility because of a slow rate of degradation in the rumen (Reeves *et al*., 1996).

Forage quality is usually determined by animal performance when forages are fed to livestock, but differs for each animal class. The plant's environment, often exerts its greatest influence on forage quality by altering the leaf:stem ratio, but it also causes modifications in plant development and changes in chemical composition of plant parts (Buxton, 1996).

The nutritive value of forages depends upon a number of factors including plant species, growing conditions (soil, climate, grazing etc), plant fractions or parts and the stage of maturity at sampling. Maturity influences nutritive value more than any other single factor although environmental and agronomic factors may also modify the impact of maturity and cause variation between years, seasons and geographical locations, even when harvested at the same stage of development (Buxton, 1996). Temperature also plays an important role, as a rise in temperature increases cell wall constituents increasing lignification and decreases soluble carbohydrate concentrations and digestibility. It also increases the rate of plant development and eventually reduces the leaf:stem ratio of the forage, which directly affects the digestibility of the forage dry matter because of the lower digestibility of the stem relative to the leaf. The reduced leaf:stem ratio with maturity, is a major cause of the decline in forage quality (Buxton, 1996). Leaves have a higher quality than stems, and the proportion of leaves in forage declines as the plant matures and advances to the reproductive growth eventually lowering the leaf:stem ratio, and thus the forage quality (Smart *et al*., 2001).

Severe water stress usually inhibits tillering and branching of forages and hastens death of established tillers. Leaf mass is reduced because of the accelerated senescence of older leaves. Both protein nitrogen and soluble carbohydrates are moved out of leaves as they age and die. However, moderate water stress typically slows maturation of forages (Halim *et al*., 1989). Hence, if the leaf loss associated with drought is not severe, water deficit may actually improve the forage digestibility of herbage at any given time (Buxton, 1996).

The main objective of this experiment was to analyse the effects of different irrigation frequencies in combination with different nitrogen fertiliser applications on the quality of ryegrass and to test the hypothesis that water stress could improve the quality of the grass.

3.2. Materials and methods

3.2.1. Experimental site

The experiment was conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria. The area has an elevation of 1327m above sea level, co-ordinates of 25º45'S and 28º16'E with an average annual rainfall of 670 mm (Annandale *et al.*, 1999). The soil of the experimental site is classified as a silt clay loam of the Hutton form that belongs to the Suurbekom family with a clay content of 26 – 37% (Soil Classification Working Group, 1991). To create suitable conditions for good soil and seed contact, the field was ploughed with a disc plough and rotavated. Prior to the commencement of the study, 12 soil samples were taken randomly from the top 0.15 m from the experimental site and were analysed in the Soil Science Laboratory of the University of Pretoria for pH (H_2O) and electrical conductivity (EC). A composite of the 12 samples was then analysed for C, NH_4, NO_3, SO_4, P and exchangeable cations (Ca, K, Mg and Na) using the ammonium acetate extractable technique. The results indicated that the site was slightly saline, so to rectify this condition, the salt was leached before planting. The chemical analyses of the soil at the experimental site are displayed in Appendix B.

3.2.2. Experimental layout

A 149.5 m^2 (6.5 m x 23.0 m) block under a rain shelter was divided into 27 plots of 3.0 m^2 (1.5 m x 2.0 m) each, with an interspacing of 0.5 m between each plot. In both seasons, superphosphate and potassium chloride were applied at planting. Nine treatment combinations of three water levels and three nitrogen levels were replicated three times. In the first week of June 2007, annual ryegrass (*Lolium multiflorum* cv. Agriton) was planted at a seeding rate of 30 kg ha^{-1}. Sprinkler irrigation was used for seven weeks until the grass was well established, and thereafter to control the water use more efficiently drip irrigation commenced. In the 2008 season, the grass was planted in April and sprinkler irrigation was used for eight weeks before the commencement of drip irrigation. The lateral spacing between the dripper lines and the distance between drippers in the line was 0.3 m. Irrigation was applied to individual plots depending on the soil water deficit to field capacity. Weeding was conducted manually during the course of the study. Weather data was collected from an automatic weather station located near the experimental site.

3.2.3. Treatments

In each plot, a neutron probe access tube was installed to a depth of 1.2 m and the soil water content was calculated using a neutron water meter. Three levels of irrigation were applied, namely W1: irrigation of once every two weeks to field capacity, W2: irrigation of once a week to field capacity and W3: irrigation of twice a week to field capacity. At the beginning of each season, the soil profiles of all the plots were brought to field capacity. Soil water deficit measurements were made using a neutron water meter model 503 DR CPN Hydroprobe (Campbell Pacific Nuclear, California, USA). The cumulative water deficit of the profile was calculated over a soil depth of 1.2 m, but irrigation was based on the upper 0.8 m of the soil profile as the roots of the grass were concentrated in the top 0.7 m. Three nitrogen levels, namely N1: 0 kg N ha^{-1}, N2: 30 kg N ha^{-1} and N3: 60 kg N ha^{-1} were applied after each cut. The nitrogen was applied as a top dressing in the form of limestone ammonium nitrate (LAN) – 28% N.

3.2.4. Leaf:stem ratio

To determine the leaf:stem ratio, fresh mass was determined immediately after cutting and then the samples were hand-separated into leaf blade and stem components and oven dried for 72 hours at 67 ℃ to a constant mass. The components were then weighed and the leaf blade dry weight was divided by the stem dry weight to calculate the leaf:stem ratio.

3.2.5. Chemical composition

For the quality analyses, samples were dried and milled to pass through a 1mm sieve and representative samples were stored in airtight containers. Analyses for quality was done in the University of Pretoria Nutrilab for dry matter content (DMC), *in vitro* organic matter digestibility (IVOMD), crude protein (CP), ash and metabolisable energy (ME). The DMC (AOAC 2000, procedure 934.01), IVOMD (Tilley and Terry, 1963 as modified by Engels and van der Merwe, 1967, using rumen fluid from cannulated sheep), CP (calculating N content using a Leco N analyser, Leco Corporation, St. Joseph, MI, USA, and multiplying by 6.25), ash (AOAC 2000, procedure 942.05), NDF (Robertson and Van Soest, 1981) and gross energy (GE; MC – 1000 Modular Calorimeter, Operators Manual) were analyzed by their respective procedures. Using equation 3.1, metabolisable energy (ME) was calculated as follows:

ME = 0.82 x GE x IVOMD (Robinson *et al*., 2004)   eq. 3.1

3.2.6. Statistical analyses

The plots were in a complete ramdomised block design and data was analysed using Statistical Analysis System (SAS) program for Windows v9.2 (Statistical Analysis System Institute Inc., 2002). Least significant difference (LSD) was calculated at the 5% significance level to compare the treatment means using the Student's t-test.

3.3. Results and discussion

3.3.1. Dry matter content

Table 3.1 illustrates that in the first season (2007), the dry matter content (DMC) was significantly influenced ($P<0.01$) by the time of harvest (H), water (W) and nitrogen (N) fertiliser as well as the interactions between HxW and HxN. It was, however, not significantly influenced ($P>0.05$) by WxN and also by HxWxN treatment interactions. Dry matter content of 10.5% to 15.5% was measured in the current study (Table 3.1) and similar results were obtained by McCormick *et al*., (2001) and Meeske *et al*., (2006). With respect to the time of harvest, the fourth harvest (H4) which was on November 15th, recorded the highest DMC of 15.3%. This was significantly higher ($P<0.01$) than the third (H3), second (H2) and first (H1) harvests. As the season progressed, the DMC increased and this could be due to the initiation of flowering stems and a decrease in the leaf:stem ratio. The highest ($P<0.05$) DMC of 15.5% with respect to the frequency of irrigation was recorded in the treatment that was irrigated once every two weeks while the lowest, a DMC of 11.5%, was recorded in the treatment that was irrigated twice a week. The probable reason for the lower DMC in the W3 could be due to the higher water availability that leads to the dilution of organic matter, as high yields were produced from these treatments. Nitrogen application also had a significant effect on the DMC. The highest ($P<0.05$) DMC of 14.1% with respect to the nitrogen treatment was recorded in the N1 treatment while the lowest DMC of 13.2% was recorded in the N3 treatment.

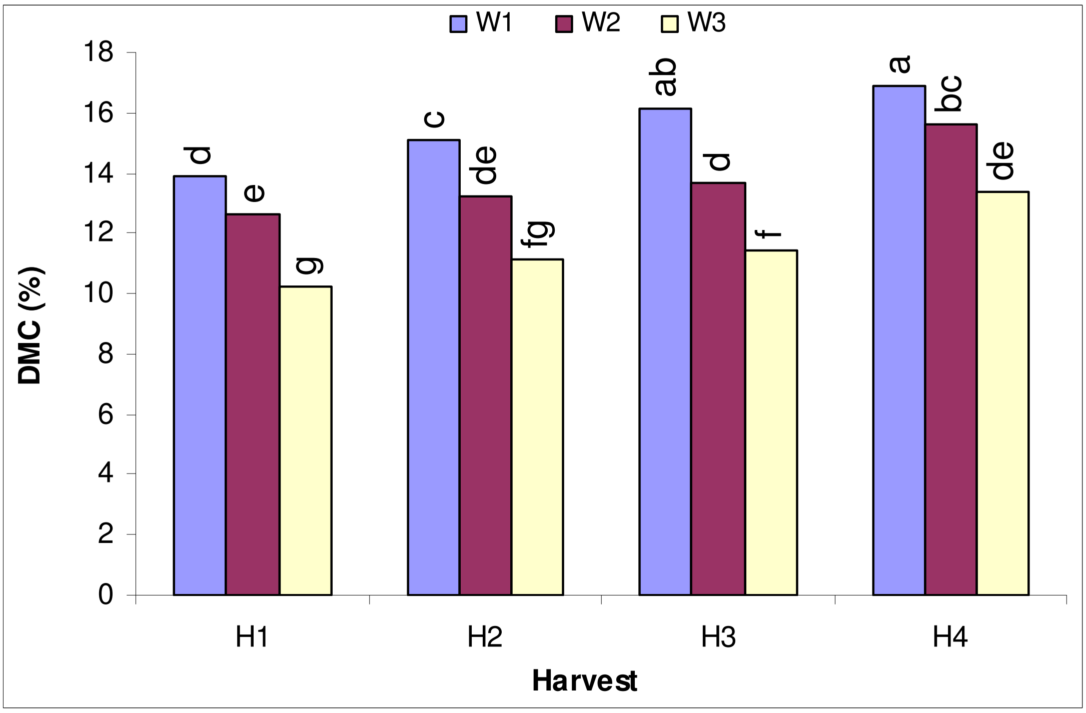
Table 3.1: DM content (% DM) of annual ryegrass (*Lolium multiflorum* cv. Agriton) for the first (2007) and second (2008) growing seasons

2007		2008	
Main Effect	DMC	Main Effect	DMC
Harvest (H)			
H1 (Aug 23)	12.2d‡	H1 (Jul 15)	11.1d
H2 (Sep 20)	13.1c	H2 (Aug 12)	12.1c
H3 (Oct 18)	13.7b	H3 (Sep 09)	13.2b
H4 (Nov 15)	15.3 a	H4 (Oct 07)	14.7a
LSD	***0.361***	***LSD***	***0.367***
Water (W)			
W1	15.5a	W1	15.4a
W2	13.7b	W2	12.4b
W3	11.5c	W3	10.5c
LSD	***0.290***	***LSD***	***0.289***
Nitrogen (N)			
N1	14.1a	N1	13.2a
N2	13.5b	N2	12.8b
N3	13.2c	N3	12.4c
LSD	***0.290***	***LSD***	***0.289***
Significance			
H	**	H	**
W	**	W	**
HxW	*	HxW	*
N	**	N	**
HxN	**	HxN	Ns
WxN	Ns	WxN	Ns
HxWxN	Ns	HxWxN	Ns

‡Values in each column followed by the same letters were not significantly different; ** significant at $P<0.01$; * significant at $P<0.05$; Ns= not significant, H= time of harvest, W= water treatment, N= nitrogen treatment, HxW= time of harvest and water interaction, HxN= time of harvest and nitrogen interaction, WxN= water and nitrogen interaction, HxWxN= interaction between time of harvest, water and nitrogen

Water availability had a significant effect on the DMC in each harvest (Figure 3.1a). The treatment that was irrigated once every two weeks recorded the highest DMC in the fourth harvest H4. This was not significantly different from the same treatment in the third harvest. Increasing the frequency of irrigation tended to lower the DMC in all the harvests but with the increase in the number of harvests, the DMC was increased. Increased nitrogen applications within harvests tended to lower the DMC and this agrees with the results obtained by Labuschagne (2005). This was, however, not true in the fourth harvest (H4), where there was no significant difference between N1 and N3 (Figure 3.1b). The reason for this could then be dependent on the time of harvest rather than nitrogen fertiliser, as in the time in which grass starts to flower.

(a)



(b)

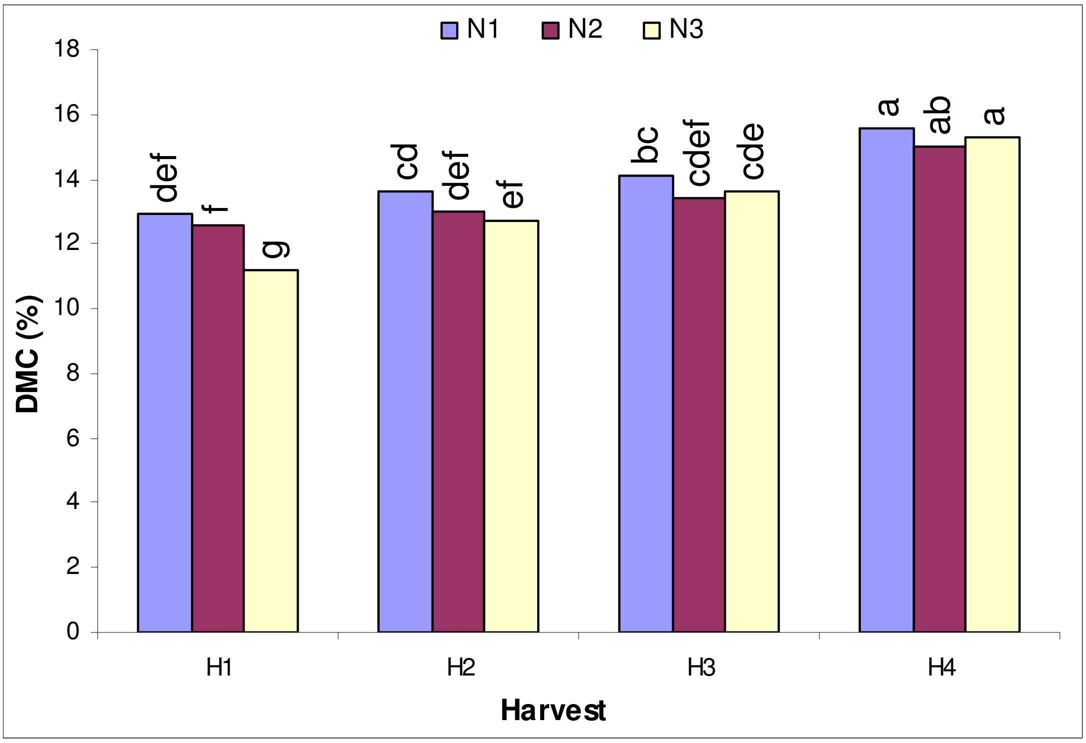


Figure 3.1: Interaction between (a) time of harvest and water and (b) time of harvest and nitrogen fertiliser on the dry matter content (DMC %) of annual ryegrass (*Lolium multiflorum* cv. Agriton) grown in the first growing season (2007)

In the second season the dry matter content was significantly influenced ($P<0.01$) by the time of harvest, water and nitrogen fertiliser as well as the interaction between HxW (Table 3.1). The fourth harvest (H4) which was on October 7th, recorded the highest ($P<0.05$) DMC of 14.7% while the lowest DMC was in the first harvest (H1) which was on July 15th and had a DMC of 11.1%. The DMC of H4 was significantly higher ($P<0.01$) than that of the other harvests. The increase in the DMC with season could be due to the initiation of flowering stems and a decrease in the leaf:stem ratio. The highest ($P<0.05$) DMC of 15.4% with respect to the frequency of irrigation was recorded in the treatment that was irrigated once every two weeks while the lowest, a DMC of 10.5%, was recorded in the treatment that was irrigated twice a week. Nitrogen application also had a significant effect on the DMC, where the highest ($P<0.05$) DMC of 13.2% was recorded in the N1 treatment while the lowest DMC of 12.4% was recorded in the N3 treatment (Table 3.1).

Low frequency of irrigation coupled with harvesting towards the end of the season, yielded a higher DMC (Figure 3.2). As the season progressed, the increase in the DMC could be explained by the fact that the stem of the grass was mature and the grass entered into a stage of flowering. Low DMC may reduce animal productivity as a result of low DM intake, because the DM intake is reduced if the moisture content of forages is excessively high. South African *Lolium multiflorum* cultivars have a relatively low dry matter content, which according to Meissner *et al*., (1992) has definite negative connotations.

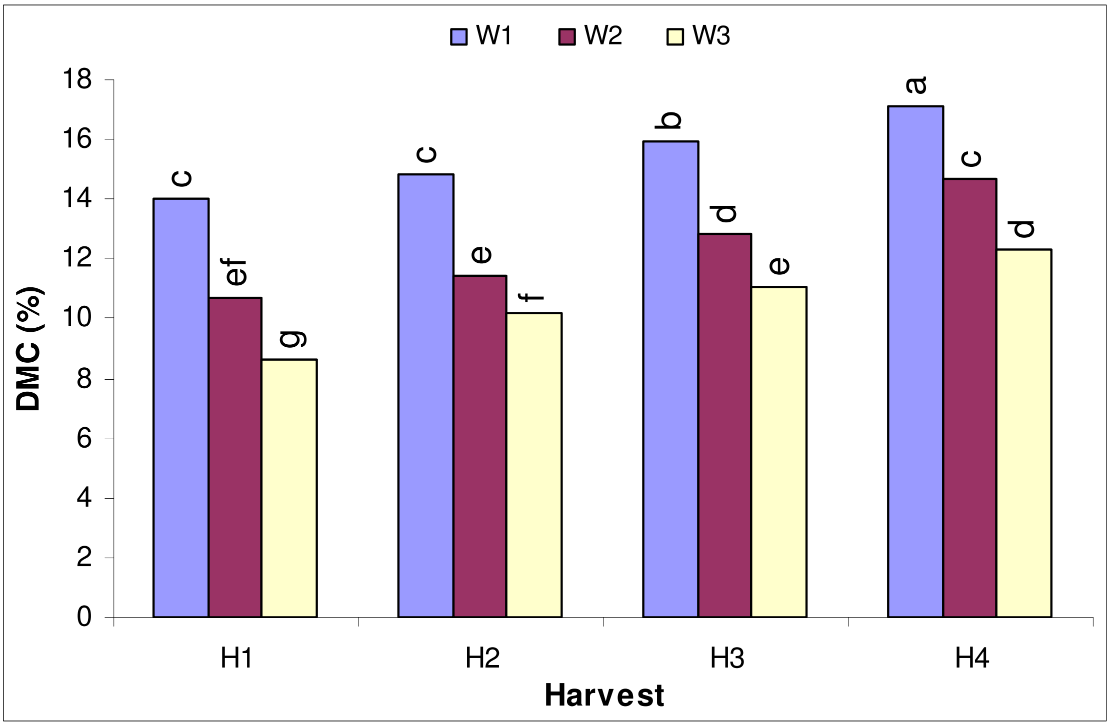


Figure 3.2: Interaction between time of harvest and water on the dry matter content (DMC %) of annual ryegrass (*Lolium multiflorum* cv. Agriton) grown in the second growing season (2008)

3.3.2. Leaf:stem ratio

The leaf:stem ratio of grasses is an important factor affecting diet selection, quality, and intake of forages. A higher proportion of forage leafiness is often associated with a higher nutritive value because leaves contain more protein and less fibre than stems (Lin *et. al*., 2001). An estimate of leaf:stem ratio is commonly based on a labour-intensive process of hand separating leaf and stem of a grass sample. Table 3.2 illustrates the leaf:stem ratios for the first growing season (2007). Leaf:stem ratios declined over the growing season with the lowest being recorded in the third and fourth growth cycles. The highest leaf:stem ratio was recorded for treatments with high frequency of irrigation (W3) and highest nitrogen (N3) application while the lowest was recorded for treatments with low frequency of irrigation and no nitrogen. Generally, the leaf:stem ratio decreased as the season progressed. This is because the grass becomes reproductive and the amount of stem increases relative to the leaf material. Any decrease in the leaf:stem ratio has a negative effect on the quality of the grass (Arzani *et al*., 2004). Crude protein is more concentrated in the leaves while the stem is high in fibre content, so as the grass becomes older the amount of leaf decreases while the amount of non-leaf material (including stem, leaf sheath and inflorescence) increases (Table 3.2) thereby decreasing the quality of the grass.

Table 3.2: Leaf:stem ratios of annual ryegrass (*Lolium multiflorum* cv. Agriton) for the first season (2007)

Main effect	GC 1	GC 2	GC 3	GC 4
Water (W)				
W1	0.485b‡	0.473b	0.450b	0.433b
W2	0.492b	0.474b	0.454b	0.432b
W3	0.550a	0.526a	0.498a	0.481a
LSD	***0.0277***	***0.0329***	***0.0394***	***0.0282***
Nitrogen (N)				
N1	0.441c	0.430c	0.413b	0.392c
N2	0.500b	0.478b	0.451b	0.438b
N3	0.586a	0.565a	0.538a	0.515a
LSD	***0.0277***	***0.0329***	***0.0394***	***0.0282***
W	**	*	*	*
N	**	**	**	**
WxN	Ns	Ns	Ns	Ns

‡Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; Ns= not significant W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction; GC1-4= growth cycles

3.3.3. Neutral detergent fibre

Table 3.3 shows that the neutral detergent fibre (NDF) content was not significantly influenced (P>0.05) by water and nitrogen treatment interactions or by the main effects of these factors. The NDF values remained relatively constant across all treatments. The fact that the NDF value being constant between the treatments was totally unexpected. The highest NDF contents were registered on treatments that had been irrigated once every two weeks. The NDF values ranged from 38.2% DM to 40.9% DM. The same ranges of results were also reported by McCormick *et al.*, (2001), Granzin (2004), Fulkerson *et al.*, (2005), Gehman *et al.*, (2006) and Meeske *et al.*, (2006). Generally, NDF is an estimate of the cell wall concentration. Typically, lower NDF concentration equates with greater nutritive value, but excessively low forage NDF concentrations can result in digestive problems (NRC, 2001). Because leaves have low NDF concentrations, they are consumed more readily than stems. The NDF content of forages grown under higher temperatures is usually less digestible than forages grown under lower temperatures because of increased lignification (Fulkerson *et al.*, 2005).

3.3.4. Ash

The ash content was not significantly influenced (P>0.05) by water and nitrogen treatment interactions but was significantly affected (P<0.05) by an increase in the nitrogen application (Table 3.3). There was no significant effect (P>0.05) by the frequency of irrigation on the ash content but, it decreased with the increase in nitrogen fertiliser. The highest ash contents were recorded on those treatments receiving no nitrogen. The ash content ranged from 10.9% DM to 12.1% DM. These values are higher than the values reported by McCormick *et al.*, (2001) and Meeske *et al.*, (2006) for annual ryegrass. The slight increase in the ash content indicates a higher mineral content in the grass.

3.3.5. Metabolisable energy

Metabolisable energy (ME) is one of the first limiting nutrients for dairy cows grazing high quality pasture (Kolver, 2003) making it necessary to feed an energy rich supplementation if higher production is to be achieved. Table 3.3 shows ME concentrations between 10.7 MJ kg^{-1} DM and 11.8 MJ kg^{-1} DM. This was within the expected range for annual ryegrass. Granzin (2004), Fulkerson *et al*., (2005) and Meeske *et al*., (2006) reported ME vales for annual ryegrass in the range of 10.3 MJ kg^{-1} DM to 12.2 MJ kg^{-1} DM. Differences in ME values could be due to different growing conditions and different equations used to estimate ME. Fulkerson *et al*., (2005) used organic matter digestibility (OMD) x 0.16 – 1.8 to calculate ME. The ME value was significantly influenced ($P<0.05$) by WxN treatment interactions. Irrigating once every two weeks (W1) was significantly higher than W2 and W3. Generally, as the frequency of irrigation was decreased the ME values increased (Figure 3.3). Nitrogen (N) applications also had a significant effect on the ME value. As the N levels were increased the ME values decreased. The possible reason for this could be when the frequency of irrigation increases, the grass growth becomes more vigorous, and this decreases the leaf:stem ratio, thereby decreasing the digestibility. This in turn decreased the ME values as there is a positive relationship between digestibility and ME concentration.

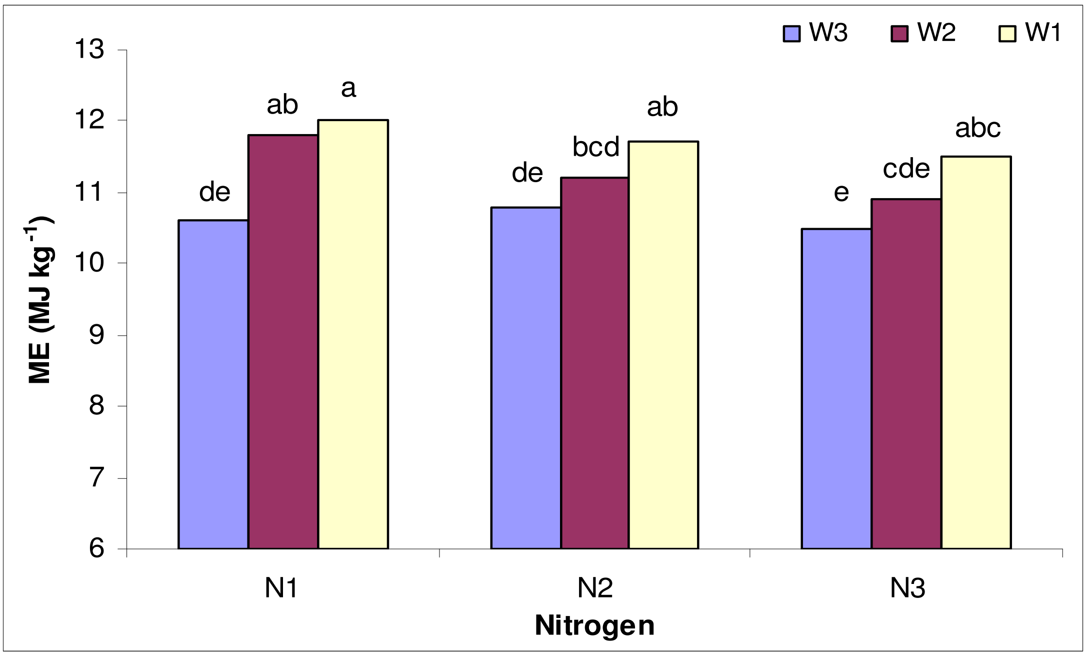


Figure 3.3: Metabolisable energy (MJ kg^{-1} DM) of annual ryegrass (*Lolium multiflorum* cv. Agriton) grown in 2008

3.3.6. Crude protein

As expected for annual ryegrass, the crude protein (CP) content ranged from 23.6% DM to 28.6% DM (Table 3.3). Similar results were also obtained by McCormick *et al*., (2001), Granzin (2004) and Meeske *et al*., (2006). The National Research Council (NRC, 2001) recommended that forage with CP content of 15% and more will maintain high producing dairy cows on grazed pastures. The results show that all treatments have greater than 15% CP content, so practically these can satisfy the CP requirement of high producing dairy cows. Meissner *et al*., (2000), however, reported that if the CP is in the form of non-protein nitrogen (NPN), then additional protein may be required to fulfil the protein requirement. The highest CP was recorded for the treatments irrigated once every two weeks with the highest nitrogen application, while the lowest was recorded for the treatment with the highest frequency of irrigation and no nitrogen. Interactions between water and nitrogen were not significant (P>0.05). Results are thus presented only for the main effects. The CP content of N3 was significantly higher (P<0.05) than of N2 and N1, nevertheless, the CP content of N2 was significantly higher (P<0.05) than of N1. Increase in N fertilisation rates resulted in an increase in the CP content. Also, the CP content of W3 was significantly higher (P<0.05) than both W2 and W1, while W2 was significantly higher than W1. Generally, as the frequency of irrigation increased the CP content decreased significantly (P<0.05). This may be due to the dilution of nutrients with the increase in production. These results correspond well with the results of Sumanasena *et al.*, (2004) who reported that the lower CP contents with frequent applications of water were associated with nitrogen leaching and the inability of ryegrass to absorb nitrogen in soils with moisture content near saturation point. Van Niekerk (1997) also reported that grasses high in CP content often produced lower DM yields.

3.3.7. *In vitro* organic matter digestibility

The range in *in vitro* organic matter digestibility (IVOMD) was between 75.7% DM to 83.2% DM (Table 3.3). This is similar to that reported by Fulkerson *et al.*, (2005) for the same type of pasture, while Theron and Snyman (2004) reported slightly lower (72% to 81%) IVOMD values. Differences could be related to different amounts of fertiliser, growing conditions, stage of maturity at the time of harvest and defoliation intervals. Labuschagne (2005) reported IVOMD values in the range of 75% DM to 83% DM for perennial ryegrass. The DM digestibility of annual ryegrass is generally high in the early season of growth, but may decrease as the season advances. The IVOMD was not significantly influenced (P>0.05) by WxN treatment interactions or by the level of N fertilisation, but the frequency of irrigation had a significant effect (P<0.05). Plots irrigated once every two weeks (W1) had a significantly higher (P<0.05) IVOMD value than W3 but similar (P>0.05) to that of W2. Increases in the frequency of water application resulted in lower IVOMD values. The reason for the higher IVOMD values with the decrease in the frequency of irrigation could be due to the fact that the grass increasing in the leaf:stem ratio, which in turn increases the digestibility. These are in line with the results obtained by Thompson *et al*., (1989) who reported that better digestibility was recorded under water stressed than under non-stressed conditions. However, Marais (2005) found that the whole plant digestibility tended to increase with higher amounts of water applied. In the current study, N fertiliser rate did not significantly influence IVOMD as there was no significant difference in the IVOMD from the different N fertiliser applications, although Valente *et al*., (2000) reported that nitrogen fertiliser may cause a slight decrease in the digestibility of Italian ryegrass. The age of plants at harvest has a more profound effect on the digestibility than does fertilisation. Due to research limitations, forage analysis was limited to only one harvest and therefore, it was not possible to compare the quality over the season. *In vitro* digestibility from hand harvesting is, however, only an indication of the potential digestibility and could be different from what the animal actually consumes due to selective grazing (van Niekerk, 1997). Pistorius (1993) stated that it is important to base conclusions on more than one experiment and where possible, *in vivo* organic matter digestibility should be used to estimate digestibility more accurately because *in vitro* organic matter digestibility used by the Tilley and Terry method, may underestimate the digestibility and may cause a substantial error in the estimation of dry matter intake.

Table 3.3: Chemical composition of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the 2008 season

Main Effect	IVOMD %	NDF %	ME %	ASH %	CP %
Water (W)					
W1	83.18a‡	40.93a	11.76a	11.13a	28.58a
W2	80.49a	39.71a	11.33b	11.91a	26.01b
W3	75.66b	38.21a	10.67c	11.27a	23.55c
LSD	***3.446***	***2.986***	***0.271***	***1.140***	***1.589***
Nitrogen (N)					
N1	80.78a	39.94a	11.49a	12.10a	24.12c
N2	79.37a	38.49a	11.28a	11.26ab	25.77b
N3	79.17a	40.42a	11.01b	10.94b	28.24a
LSD	***3.446***	***2.986***	***0.271***	***1.140***	***1.589***
W	**	Ns	**	Ns	**
N	Ns	Ns	*	*	**
WxN	Ns	Ns	*	Ns	Ns

‡Values in each column followed by the same letters were not significantly different; ** significant at P<0.01; * significant at P<0.05; W= water treatment; Ns= non significant; N= nitrogen treatment; WxN= water and nitrogen interaction; IVOMD - *in vitro* organic matter digestibility; NDF=neutral detergent fibre; ME=metabolisable energy; CP=crude protein

3.4. Conclusions

Forage quality depends upon a number of factors that include plant species and the growing conditions. Sometimes we do not have a choice to change the species but we can have, to some extent, a control over the growing conditions. In this study, the growth cycle had a significant effect on the dry matter content, the highest being on the fourth harvest in the first season. The frequency of irrigation had a significant effect on some of the quality parameters (DMC, digestibility, ME and CP). The decrease in the frequency of water application resulted in an increase in the ME, DMC, digestibility and CP value. The level of nitrogen had a significant effect on the DMC, ME and CP. An increase in the nitrogen application increased the CP but decreased the DMC and ME. The leaf:stem ratio decreased as the season progressed, but due to chemical analyses being limited to only one harvest, it was not possible to compare the change in the forage quality with the change in the leaf:stem ratio over time. It can therefore be concluded that water stress did improve the quality of the pasture by increasing the DMC, ME, IVOMD and CP contents.

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CHAPTER 4

WATER USE AND WATER USE EFFICIENCY OF RYEGRASS AT THREE WATER AND NITROGEN LEVELS

Abstract

At present, and more so in the future, irrigated agriculture will take place under water scarcity. Owing to the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimize water use efficiency (WUE). Irrigation management will shift from emphasizing production per unit area to maximizing the production per unit of water consumed. In South Africa, annual ryegrass (*Lolium multiflorum*) is an important pasture species under irrigation and is mainly utilised for milk, and to some extent, meat production. Shortages of water and nitrogen can, however, be limiting factors for the production of this pasture. By using appropriate irrigation and nitrogen management tools, water and nitrogen productivity of the pasture can be improved. The objective of this study was, therefore, to determine the effects of different water levels in combination with different N fertiliser applications on the water use (WU) and WUE of annual ryegrass. For two seasons, the trial was conducted under a rain shelter on the Hatfield Experimental Farm of the University of Pretoria. The plots were arranged in a complete randomised block design with three replications. Treatments consisted of three water and three nitrogen levels. The three water applications to field capacity were; a schedule of 1) once every two weeks, 2) once a week and 3) twice a week. Nitrogen was top-dressed after each harvest at a rate of 0, 30 or 60 kg N per hectare. In each plot, an access tube was installed and the soil water content was measured with a Neutron Probe to a depth of 1.2 m. After calculating the deficit, plots were irrigated to field capacity. Ryegrass was harvested to 50 mm above the ground on a 28 day cycle. Irrigation treatments ranged from 282 to 464 mm. The WUE ranged from 26.4 kg $ha^{-1}mm^{-1}$ to 28.6 kg $ha^{-1}mm^{-1}$ for the treatment that was irrigated once every two weeks and top-dressed with the highest nitrogen. A decrease in the water use in the second season was observed because of a lower atmospheric evaporative demand (ETo). This increased the water use efficiency. From this study, it was concluded that water use was affected by the ETo, and the WUE was improved with higher N fertiliser applications as higher yields were produced.

Key words: irrigation, nitrogen, evapotranspiration, vapour pressure deficit

4.1. Introduction

In semi-arid regions, water is the primary and nitrogen the secondary contributor to grassland production (Whitney, 1974). The development of a well-established pasture requires good growing conditions with no water stress. This leads to higher yields and good nutritive value pasture. Grasses are often grown under dryland conditions, however, there is a trend towards greater use of irrigation by farmers to improve the reliability of yield of pasture. In some situations, irrigation may give little or no advantage, especially in humid areas. On the other hand, water deficits, even for short periods, may limit metabolic processes in plants, which can reduce growth rates (Dovrat, 1993). The purpose of irrigation management in pasture production is thus to ensure that an adequate amount of water is available for the crop at all times. The onset of water stress, at any time during the growing season, will reduce the potential yield of an irrigated pasture. A common irrigation scheduling strategy is to deplete available soil water and then re-fill the profile to field capacity when a certain amount of plant available water in the active root zone has been depleted (Panda *et al.*, 2004). Therefore, it is important to know what the water holding capacity of the soil is, as well as the amount of water applied by irrigation, so water and nitrogen fertilizer will not pass through the root zone. The use of a given irrigation system, calls for a specific approach to irrigation water management, since water influences most production factors – from tillage and planting, to seed germination, root extension, nutrient management and uptake, leaching of hazardous salts to maintain a favourable salt balance and, most important, plant growth and yield formation (Dovrat, 1993). Key factors in the supply of water to the crop are management decisions regarding irrigation and uniformity of application. The design of field irrigation systems consists primarily of four factors: the total amount of required irrigation water, irrigation intervals, irrigation method and layout of the irrigation system (Dovrat, 1993).

Water use (WU) is defined as the total amount of water needed for plant growth which includes water lost by evaporation and transpiration from the soil and plant surfaces (Van Vuuren, 1997). Transpiration increases as the leaf surface area increases. Nitrogen fertilisation increases shoot growth and we would expect increases in water use under higher nitrogen regimes. Deficient N levels will also lead to lower evapotranspiration due to a lower growth rate. When soil water content is high, water use is primarily a function of evaporative demand and estimates based upon that demand are estimates of maximum water use. As soil water content declines below a threshold value, which is usually quite a bit drier than the field capacity, water use becomes more and more a function of water availability (Van Vuuren, 1997).

Water use efficiency (WUE), defined as the total above ground dry matter produced per unit of water consumed. It can be influenced by atmospheric demand, soil water availability and other cultural practices such as fertilization, different cultivation practices and defoliation methods (Van Vuuren, 1997). Improved WUE could reduce negative environmental impacts by reducing runoff, erosion, drainage and leaching of nutrients (Shi-Wei *et al.*, 2006). Water use efficiency is an important physiological characteristic which is directly related to the ability of the plant to cope with water deficit stress. Some species may use more water per unit of dry matter accumulated than others, and most species may have the same relative sensitivity to available water, but the species which uses less water per unit dry matter increment will have the highest water use efficiency (Pearson and Ison, 1997).

Thus crop species in combinations with different soil types and soil water monitoring techniques need to be investigated for the development of best irrigation management strategies and extrapolate the results to other sites. The objective of this study was therefore to determine the effects of different water levels in combination with different N fertiliser applications on the WU and WUE of annual ryegrass and to test the hypotheses that higher production but lower WUE will be obtained with increased irrigation frequency and the well fertilised pasture to use water more efficiently than the N deficient crops.

4.2. Materials and methods

4.2.1. Experimental site

To exclude rainfall effects on the proposed irrigation treatments, the experiment was conducted under a rain shelter at the Hatfield Experimental Farm of the University of Pretoria. The area has an elevation of 1327m above sea level, and co-ordinates of 25º45'S and 28º16'E with an average annual rainfall of 670 mm (Annandale *et al.*, 1999). The soil of the experimental site is classified as a silt clay loam of the Hutton form that belongs to the Suurbekom family with a clay content of 26 – 37% (Soil Classification Working Group, 1991). To create suitable conditions for good soil and seed contact, the field was ploughed with a disc plough and rotavated. Prior to the commencement of the study, 12 soil samples were taken randomly from the top 0.15 m from the experimental site and were analysed in the Soil Science Laboratory of the

University of Pretoria for pH (H_2O) and electrical conductivity (EC). A composite of the 12 samples was then analysed for C, NH_4, NO_3, SO_4, P and exchangeable cations (Ca, K, Mg and Na) using the ammonium acetate extractable technique. The analysis indicated that the site was slightly saline, so salt was leached before planting. The chemical analyses of the soil at the experimental site are displayed in Appendix B.

4.2.2. Weather

Weather data was collected from an automatic weather station located near the experimental site. The automatic weather station consisted of an LI 200X pyranometer (LiCor, Lincoln, Nebraska, USA) for measuring solar radiation, an electronic relative humidity and temperature sensor installed in a Gill screen, an electronic cup anemometer (MET ONE, Inc. USA) to measure wind speed, an electronic rain gauge (RIMCO, R/TBR tipping bucket rain gauge, Rauchfuss Instruments Division, Australia) and a CR 10X data-logger (Campbell Scientific Inc., USA). All of the above data were monitored and recorded every 10 seconds with the data-logger. The logged data was downloaded once a month.

4.2.3. Experimental layout

A 149.5 m^2 (6.5 m x 23.0 m) block was divided into 27 plots of 3.0 m^2 (1.5 m x 2.0 m) each, with an interspacing of 0.5 m between each plot. In both seasons, superphosphate and potassium chloride were applied at planting. In the first week of June 2007, annual ryegrass (*Lolium multiflorum* cv. Agriton) was planted at a seeding rate of 30 kg ha^{-1} under the rain shelter. Sprinkler irrigation was used for seven weeks until the grass was well established, and thereafter to control the water use more efficiently, drip irrigation commenced. In the 2008 season, the grass was planted in April and sprinkler irrigation was used for eight weeks before the commencement of drip irrigation. The lateral spacing between the dripper lines and the distance between the drippers in the line was 0.3 m. Irrigation was applied to individual plots depending on the soil water deficit to field capacity. Weeding was conducted manually during the course of the trial.

4.2.4. Treatments

Three levels of irrigation were applied, namely W1: irrigation of once every two weeks to field capacity, W2: irrigation of once weekly to field capacity and W3: irrigation of twice weekly to field capacity. At the beginning of each season, the soil profiles of all the plots were brought to field capacity. Three nitrogen treatments, namely N1: 0 kg N ha^{-1}, N2: 30 kg N ha^{-1} and N3: 60 kg N ha^{-1} were applied after each cut. This gave nine treatment combinations that were replicated three times in a complete ramdomised block design. In each plot, a neutron probe access tube was installed and soil water content measured using a neutron water meter (NWM) model 503 DR CPN Hydroprobe (Campbell Pacific Nuclear, California, USA). The cumulative water deficit of the profile was calculated over a soil depth of 1.2 m, but irrigation was based on the upper 0.8 m of the soil profile as the roots of the grass were concentrated in the top 0.7 m. Nitrogen was applied as a top dressing in the form of limestone ammonium nitrate (LAN) – 28% N.

4.2.5. Water use

Water use (*ET*) in mm was calculated using equation 4.1.

$$ET = I + P - Dr - \Delta S - R \qquad \text{eq. 4.1}$$

where *I* stands for the applied irrigation in mm, *P* is precipitation in mm (the value of *P* is zero because the experiment was under a rainshelter), *Dr* is drainage in mm (assumed to be negligible), *ΔS* is change in soil water storage in mm and *R* is runoff in mm (assumed to be negligible).

4.2.6. Crop coefficient

The crop coefficient (K_C) was calculated using equation 4.2

$$Kc = \left(\frac{ET}{ETo} \right) \qquad \text{eq. 4.2}$$

where *ET* was calculated using equation 4.1 and the daily reference evapotranspiration (ET_O) was calculated using the Penman-Monteith equation from data collected by an automatic weather station at the site using the FAO 56 method (Allen *et al.,* 1998).

4.2.7. Water use efficiency

Water use efficiency (*WUE*) in kg ha^{-1} mm^{-1} was calculated using equation 4.3.

$$WUE = \left(\frac{Y}{ET} \right) \qquad \text{eq. 4.3}$$

where *Y* is yield in kg ha^{-1} and *ET* is water use in mm.

4.2.8. Statistical analyses

The data was analysed using the Statistical Analysis System (SAS) program for Windows v9.2 (Statistical Analysis System Institute Inc., 2002). Least significant differences (LSD) were calculated at the 5% significance level to compare the treatment means using the Student's t-test.

4.3. Results and discussion

4.3.1. Weather data

Figure 4.1 shows a summary of the monthly reference evapotranspiration, and maximum and minimum temperatures for 2007 and 2008 downloaded from the automatic weather station near the experimental site.

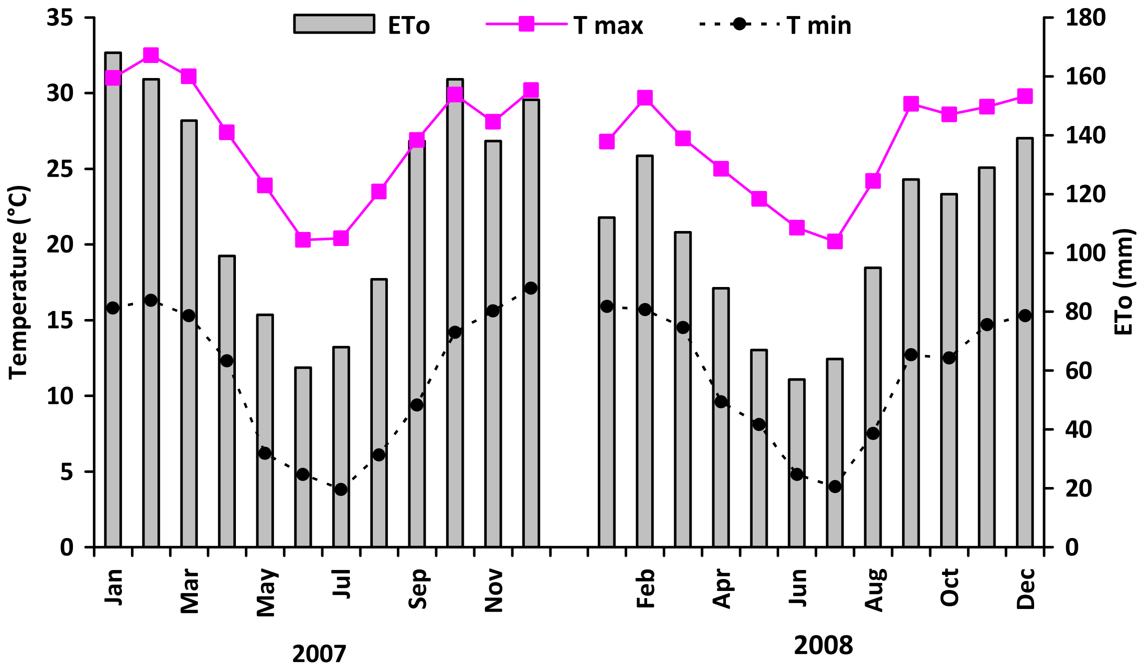

Figure 4.1: Monthly reference evapotranspiration (ET_o), and maximum and minimum temperatures (T_{max} and T_{min}) for Hatfield Experimental Farm, Pretoria (2007 – 2008)

4.3.2. Water use

Water use (WU) was calculated as the sum of water applied during the growing season and the soil water deficit at the end of the season. In the first season the highest cumulative water use averaged over the nitrogen treatment was 429 mm for the W3 treatment while the lowest cumulative water use was 333 mm for the W1 treatment (Table 4.1). The highest cumulative water use for the nitrogen treatment averaged over the frequency of irrigation was 416 mm for the N3 treatment and the lowest was 346 mm for the N1 treatment. In the second season the highest cumulative water used with respect to the water treatment was 384 mm for the W3 treatment and the lowest was 297 mm for the W1 treatment. With respect to the nitrogen application treatments the highest cumulative water used was 371 mm for the N3 treatment and the lowest was 316 mm for the N1 treatment (Table 4.1). These values are for a total of four harvests per season. In both seasons, the cumulative WU was significantly influenced ($P<0.05$) by WxN treatment interactions (Table 4.1). Irrigating twice a week (W3) was significantly higher ($P<0.05$) than W2 and W1 while for the nitrogen treatment, N3 was significantly higher ($P<0.05$) than N2 and N1. The main reason for the differences in the water use could be due to the increased dry matter (DM) production with increased frequency of water and higher nitrogen application. Higher dry matter was produced in the treatments that received more water and were top-dressed with the highest nitrogen level. These treatments had higher leaf area index (LAI) and the transpiration rate was greater, thereby increasing the total water use.

Table 4.1: Water use (mm) of annual ryegrass (*Lolium multiflorum* cv. Agriton) at the Hatfield Experimental Farm, Pretoria (2007 – 2008)

Main Effect	Season 1 (2007)					Season 2 (2008)				
	GC1	GC 2	GC 3	GC 4	Total	GC1	GC 2	GC 3	GC 4	Total
Water (W)										
W1	69c‡	85c	86c	93c	333c	48c	71c	87c	91c	297c
W2	74b	101b	100b	109b	384b	52a	76b	99b	120b	347b
W3	81a	110a	114a	124a	429a	53a	81a	106a	144a	384a
LSD	***1.61***	***1.36***	***1.29***	***1.29***	***1.88***	***1.98***	***2.39***	***2.14***	***2.16***	***5.33***
Nitrogen (N)										
N1	68c	90c	90c	98c	346c	47c	71c	90c	108c	316c
N2	75b	100b	99b	109b	383b	50b	76b	96b	120b	342b
N3	81a	106a	110a	119a	416a	55a	81a	107a	128a	371a
LSD	***1.61***	***1.36***	***1.29***	***1.29***	***1.88***	***1.98***	***2.39***	***2.14***	***2.16***	***5.33***
Significance										
Water	**	**	**	**	**	**	**	**	**	**
Nitrogen	**	**	**	**	**	**	**	**	**	**
WxN	*	*	**	**	**	*	Ns	**	*	**

‡Values in each column followed by the same letters were not significantly different;

** significant at P<0.01; * significant at P<0.05; Ns= not significant, GC= growth cycle, W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction

Generally, WU increased as the frequency of irrigation increased. Within the same irrigation frequency, WU increased with increasing nitrogen application. In the first season, the highest WU of 464 mm was recorded for the W3N3 treatment, while, the lowest water use of 306 mm was recorded for the treatment that received water once every two weeks with no nitrogen (W1N1) application (Figure 4.2). The W3N1 treatment was not significantly different (P>0.05) from the W2N2 treatment. As the irrigation interval increased from twice a week (W3) to once every two weeks (W1), the amount per application increased accordingly, but the total amount of water applied throughout the whole season decreased because of the lower irrigation frequency. In the second season, the treatment that was irrigated twice weekly with the highest nitrogen application, used the most water, a total of 423 mm while the lowest, a total of 282 mm was recorded for the treatment that was irrigated once every two weeks with no nitrogen application (Figure 4.3). The higher water use in the frequently irrigated treatments could be attributed to the high evapotranspiration rate associated with a large canopy and high water availability. Wallace (2000) indicated that more frequent irrigation encourages water loss through evapotranspiration. There was no significant difference between W3N2 and W2N3 and also between W3N1 and W2N2 in 2008 (Figure 4.3). Even though the frequency of irrigation of these treatments varies, the reason for the non significant difference in water use could be due to the higher application of nitrogen fertiliser that led to the production of higher yield which in turn leads to higher transpiration. For each treatment, the amount of water applied was lower in the second season than the first season (Figures 4.2 and 4.3). This may be due to the higher reference crop evapotranspiration (ET_O) values recorded in the first season (Figure 4.1). In 2007, the cumulative ET_O value over the period of the growing season was 414 mm while in the second season the cumulative ET_O value was only 370 mm. The ET_O and WU were highly correlated, as can be seen when ET_O increases. As would be expected, the crop coefficient (K_C) values followed the same order as the WU, with W3N3 having the highest K_C value of 1.12 in the first season and a K_C value of 1.14 in the second season. The higher K_C values indicate a higher DM production from these plots as the K_C value is affected by the canopy cover and surface wetness. These values show that the grass was not over-irrigated as values of K_C over 1.2 indicate over-irrigation (Allen *et al*., 1998).

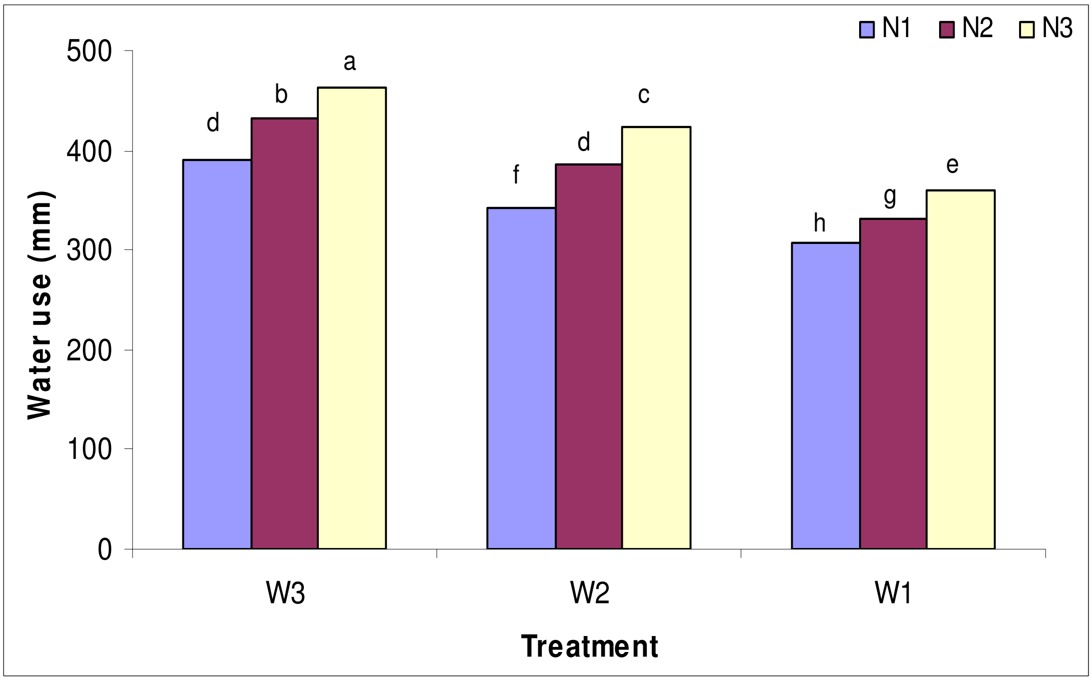

Figure 4.2: Cumulative water use (mm) of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the first growing season (2007)

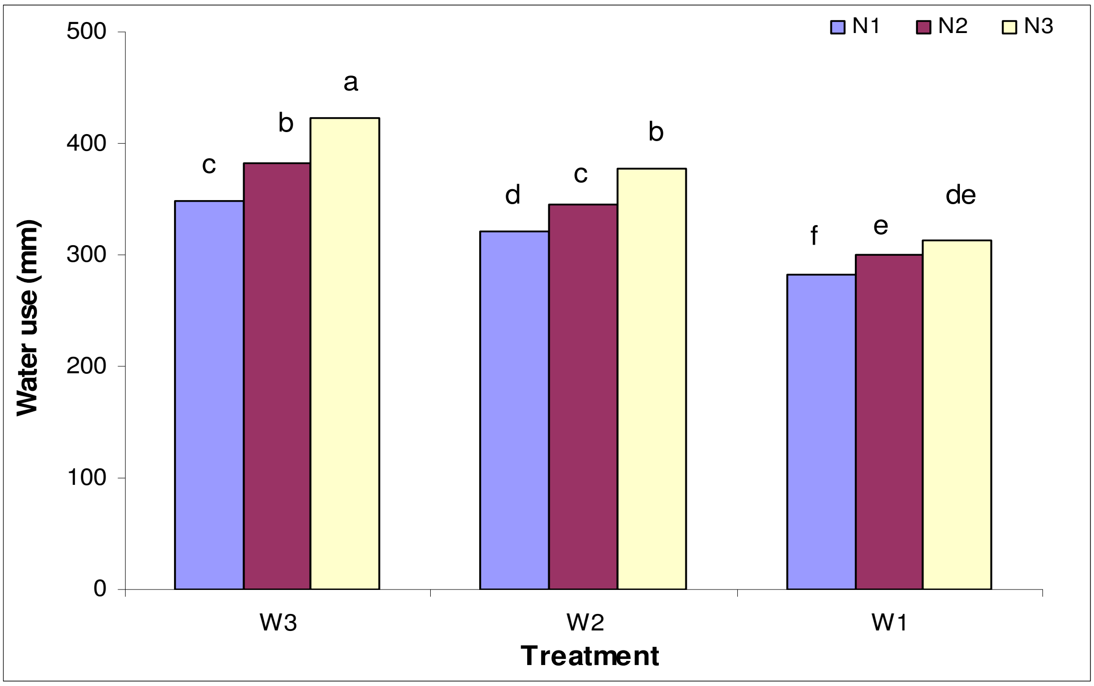

Figure 4.3: Cumulative water use (mm) of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the second growing season (2008)

4.3.3. Soil water depletion

The effect of different irrigation treatments on plant available water (PAW) content is shown in Figures 4.4 and 4.5. The period shown is from the start of the treatment to the date of last harvest. After calculating the deficit, plots were irrigated to field capacity. Within one growth cycle, W3 was irrigated 8 times, while W1 was irrigated only twice. As expected, the soil profile of the W3 treatment maintained higher water content and tended to be wet consistently throughout the season. More water was depleted from the soil as irrigation interval increased. This was especially noticeable for the W1 treatment, as irrigation depth ranged from 40 – 50 mm per application, whilst for W3, the range was from 10 -15 mm per application (Figures 4.4 and 4.5). From the figures, it is clear that W1 had the highest soil water deficits throughout the season. This treatment had the lowest seasonal water consumption and recorded the lowest dry matter yields proving that this treatment was water stressed. Towards the end of the season, more water was depleted from the soil. This could be related to the higher evapotranspiration due to the increase in temperature. At the early stages (the first growth cycle), more water was depleted in the first season (Figure 4.4) than in the second season (Figure 4.5). This could be related to the difference in the growth months, where in the first season the first growth cycle was in July/August and in the second season the first growth cycle was in June/July. Due to these time differences, there was a difference in temperature, as ET_O was higher in the first season. Within the same irrigation frequency, more water was depleted in the N3 treatments than from the N1 treatments. This could be due to the higher transpiration rates from the higher LAI evident for the N3 treatments.

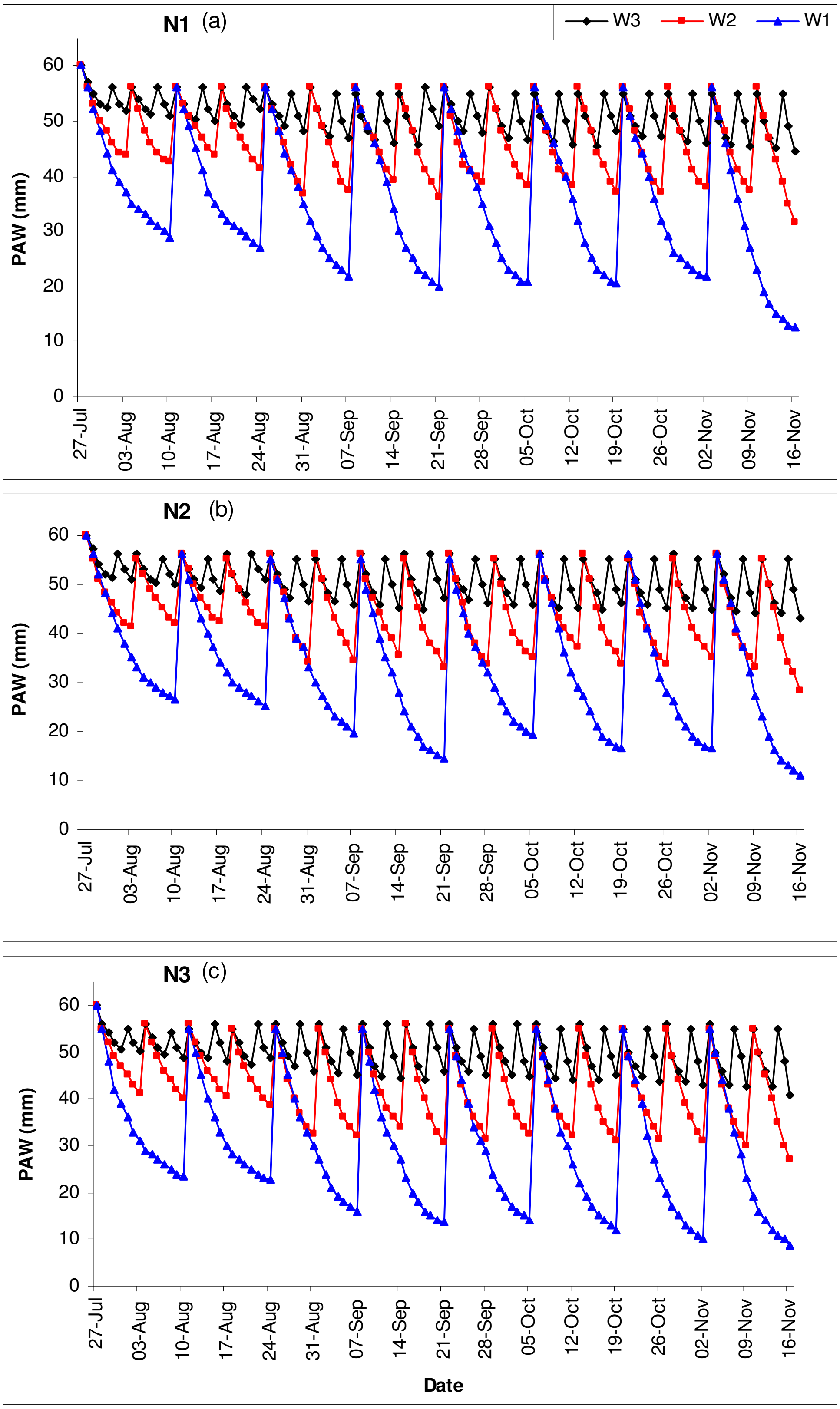

Figure 4.4: Soil water depletion patterns in the root zone of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the first growing season (2007) for (a) N1; (b) N2 and (c) N3 with three irrigation frequencies W1, W2 and W3 each. PAW= plant available water

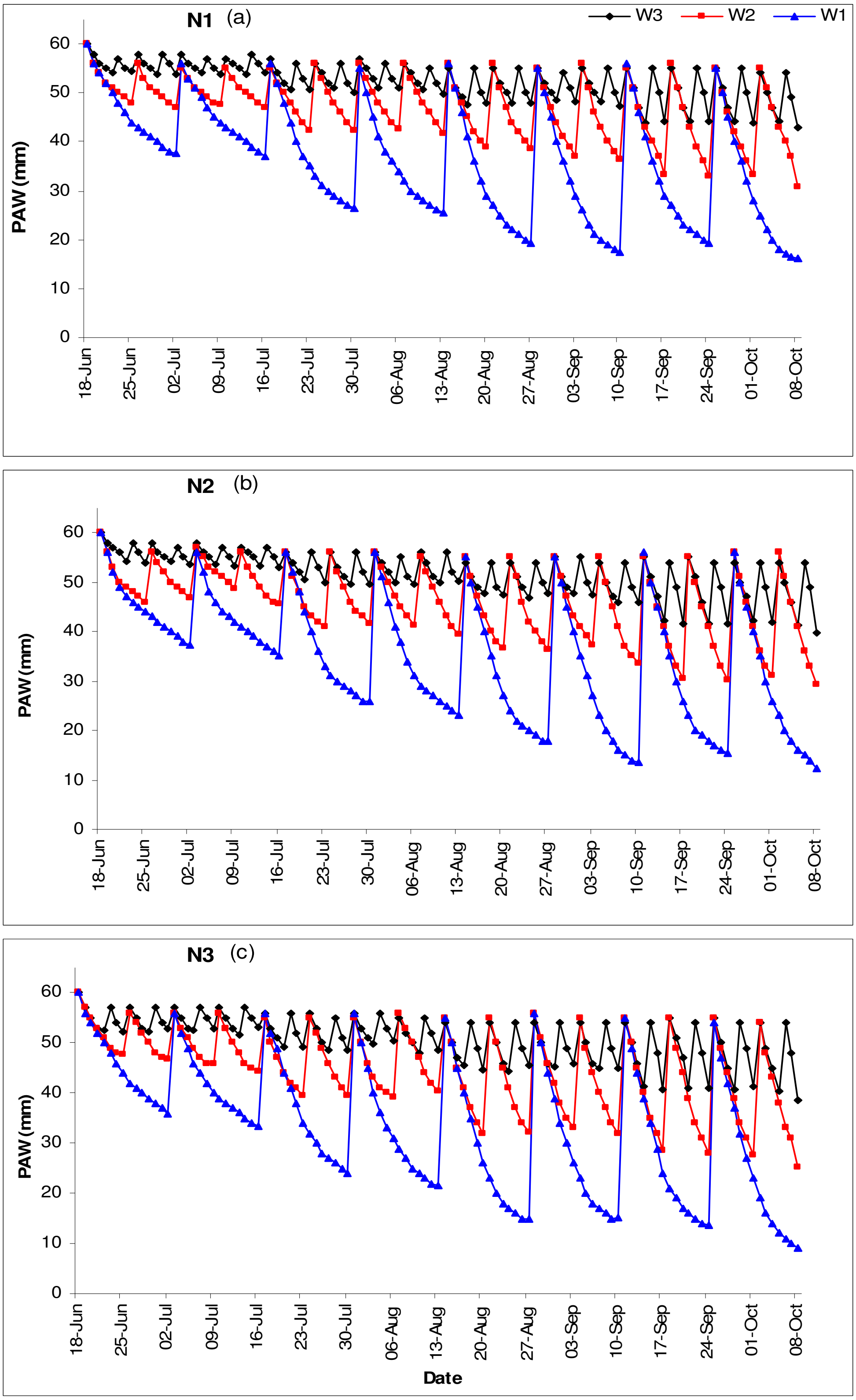

Figure 4.5: Soil water depletion patterns in the root zone of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the second growing season (2008) for (a) N1; (b) N2 and (c) N3 with three irrigation frequencies W1, W2 and W3 each. PAW= plant available water

4.3.4. Water use efficiency in terms of dry matter yield

Water use efficiency is shown over two seasons for 2007 (Figure 4.6) and 2008 (Figure 4.7). In both seasons there were significant differences ($P<0.05$) in the WUE of the treatments with respect to total yield. Water was used more efficiently in the W1 treatment followed by W2 and W3. The increase in WUE for the W1 treatment could be ascribed in part due to reduced evaporation from the soil, resulting from a lower wetting frequency as these treatments were being irrigated once every two weeks. Even though maximum yield was obtained from the W3 treatments, they recorded the lowest WUE. The low WUE may be due to the fact that frequently watered treatments had higher evaporation. In both seasons, the treatments that were irrigated once every two weeks recorded the highest WUE for N2 and N3, but for N1, these treatments recorded the lowest WUE, where in these cases N fertiliser was the limiting factor. The reason for this could be because of the very low dry matter production due to water and nitrogen stress. Nitrogen fertilisation significantly increased ($P<0.05$) WUE averaged over the irrigation treatment (Figures 4.6 and 4.7). Within the same irrigation frequency treatments, plots that were top-dressed with more nitrogen had higher WUE. This could be attributed to the fact that more DM was produced with increasing N application. In the first season (2007), for the high N treatments, highest WUE of 26.4 kg $ha^{-1}mm^{-1}$ was recorded for W1, followed by 23.7 kg $ha^{-1}mm^{-1}$ for W2 and 22.5 kg $ha^{-1}mm^{-1}$ for W3 (Figure 4.6). The increase in WUE was mainly due to the large reduction in the amount of water as W1 used 77% of the water used by W3 while the yield was reduced by only 8%. Some reports (Zhang *et al.*, 2006) indicated that a certain degree of water stress improved

WUE while Eiasu *et al*., (2009) report that slight water stress throughout the season did not improve WUE consistently, but water stress in different physiological stages had an effect on the WUE. In this study, water stress did improve WUE, as the highest WUE was recorded in the treatment that was irrigated once every two weeks. Because less water was used, the WUE was higher in the second season (Figure 4.7). This could be due to the lower evaporative demand (Figure 4.1). In the second season, for the high N, highest WUE of 28.6 kg $ha^{-1}mm^{-1}$ was recorded in the W1 treatment, followed by 26.9 kg $ha^{-1}mm^{-1}$ for W2 and 24.6 kg $ha^{-1}mm^{-1}$ for W3. In both seasons the treatment with no nitrogen application recorded the lowest WUE throughout the season (Figures 4.6 and 4.7). The main reason for this could be because the dry matter production from these treatments was very low.

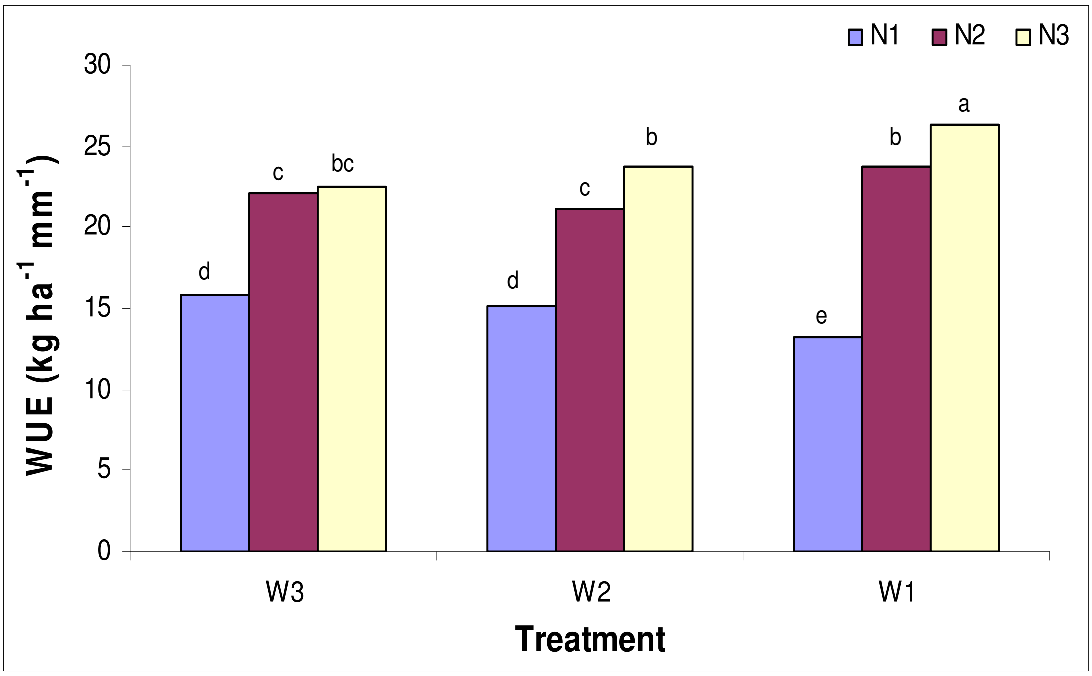

Figure 4.6: Water use efficiency (WUE) of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the first growing season (2007)

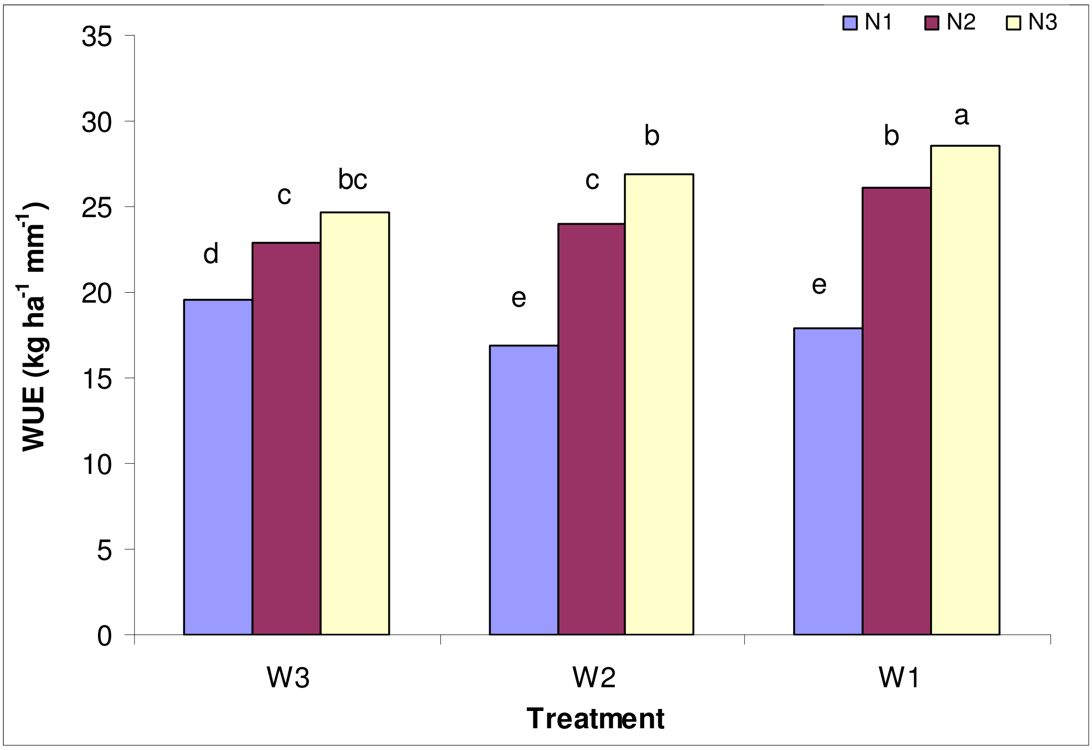

Figure 4.7: Water use efficiency (WUE) of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the second growing season (2008)

Figure 4.8 illustrates the trend of WU, ET_O and WUE between the four harvests of the non-stressed treatment (W3N3) in the second season. From the figure, it is clearly seen that as the season progressed ET_O increased thereby increasing WU. The reason for the increase in WU could be due to the increase in atmospheric demand as a result of higher temperatures. When we look at the vapour pressure deficit (VPD) for the growing season, there was an increase with time over the four harvests. The average VPD for the first harvest (15 Jul) was 0.99 kPa. This increased to 1.16 kPa in the second harvest (12 Aug) and then to 1.48 kPa in the third harvest (09 Sep) and in the final harvest (07 Oct) to 1.86 kPa. The increase in VPD had a major impact on the increase of WU. Even though the WU increased as the season progressed, the WUE decreased because there was a decrease in dry matter production. This was especially noticeable for the fourth harvest (07 Oct), as air temperature exceeded the cut-off temperature ($T_{cut\text{-}off}$) of the grass, which is around 25 ^{O}C (Hunt and Thomas, 1985). Above this temperature, annual ryegrass will decrease DM production, even if water and fertiliser are non-limiting. During the fourth growth cycle, about 48% of days recorded temperatures higher than the cut-off temperature ($T_{cut\text{-}off}$). There were three occasions in which the maximum temperature was higher than the cut-off temperature for three consecutive days. This decrease in DM production due to the cut-off temperature being exceeded and an increase in WU due to a higher ET_O led to a decrease in the WUE not only in this treatment but also in all the others.

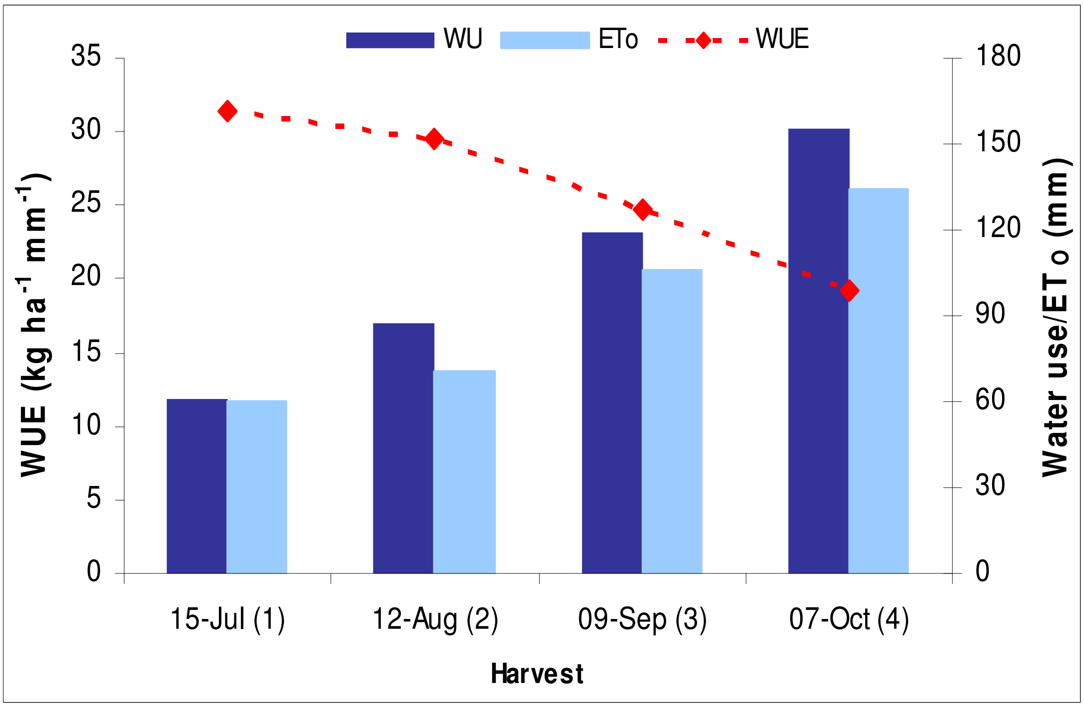

Figure 4.8: WU, ET_O and WUE of the W3N3 treatment of annual ryegrass (*Lolium multiflorum* cv. Agriton) in the second growing season (2008)

4.3.5. Water use efficiency in terms of digestible dry matter

Water use efficiency in terms of digestible dry matter (WUE_{DDM}) was not significantly ($P>0.05$) influenced by WxN interactions, but there was a significant ($P<0.05$) difference between main effects. In the present study, WUE_{DDM} had a positive relationship with nitrogen fertiliser application and an inverse relationship with the frequency of irrigation. This is because the WUE_{DDM} was improved due to an increase in N application, and decreased with an increase in the frequency of irrigation. The highest WUE_{DDM} with respect to irrigation frequency was 22.8 kg ha^{-1} mm^{-1} (Table 4.2) for the W1 treatment. This treatment did not differ significantly ($P>0.05$) in WUE_{DDM} from W2 which had a WUE_{DDM} of 21.8 kg ha^{-1} mm^{-1} but both differed significantly ($P<0.05$) from W3 which recorded the lowest WUE_{DDM} of 20.2 kg ha^{-1} mm^{-1}. The higher WUE_{DDM} of W1 is in accordance with the IVOMD of the same treatment. The probable reason for the low WUE_{DDM} in the frequently irrigated plots could be related to the vigorous growth of the grass as a result of continuous supply of irrigation leading to a higher yield and lower leaf:stem ratio. These results correspond well with those of Marais (2005) where higher WUE_{DDM} were obtained from the treatments that were water stressed. With respect to the N treatment, N3 had the highest WUE_{DDM} of 24.2 kg ha^{-1} mm^{-1}. This differed significantly ($P<0.05$) in the WUE_{DDM} from N2 and N1 which recorded the lowest WUE_{DDM} of 17.9 kg ha^{-1} mm^{-1}. The fact that nitrogen fertiliser increased the WUE_{DDM} was totally unexpected. It was surprising as it was expected that with vigorous growth an increase in fibre would depress digestibility but instead it favoured digestibility.

4.3.6. Water use efficiency in terms of crude protein yield

Water use efficiency in terms of crude protein yield (WUE_{CP}) was not significantly (P>0.05) influenced by WxN treatment interactions but there was a significant (P<0.05) difference within the main effects. Increasing the irrigation frequency decreased WUE_{CP} while increasing N fertilisation increased WUE_{CP}. This corresponds well with the CP values obtained in this study, as higher CP was recorded in the treatments that were irrigated once every two weeks and top-dressed with the highest N fertiliser rate. The WUE_{CP} of W1 was significantly higher than that of W2 and W3. The highest WUE_{CP} with respect to irrigation frequency was 7.9 kg CP ha^{-1} mm^{-1} from the treatment that was irrigated every two weeks, followed by 7.1 kg CP ha^{-1} mm^{-1} for W2 and 6.3 kg CP ha^{-1} mm^{-1} for W3 (Table 4.2). The reason for the lower WUE_{CP} for W3 could be due to the higher water use and lower CP produced that resulted in dilution of nutrients as higher dry matter yields were produced from these treatments. These results correspond well with those of Marais (2005), who reported that higher WUE_{CP} values were found from water stressed treatments. With respect to N fertilisation, the WUE_{CP} of N3 was significantly higher than that of N2 and N1. The highest WUE_{CP} of 8.6 kg CP ha^{-1} mm^{-1} was recorded for N3 followed by 7.4 kg CP ha^{-1} mm^{-1} for N2 and 5.3 kg CP ha^{-1} mm^{-1} for N1 (Table 4.2). The reason for the increase in WUE_{CP} could be due to the increase in the N fertilisation that resulted in the production of higher CP values in these treatments.

4.3.7. Water use efficiency in terms of metabolisable energy

Water use efficiency in terms of metabolisable energy yield (WUE_{ME}) was not significantly (P>0.05) influenced by WxN treatment interactions. Results are thus presented for the main effects. Increasing the irrigation frequency and N fertilisation had a positive effect on the WUE_{ME}. The WUE_{ME} of W3 was significantly (P<0.05) higher than that of W1 but did not differ significantly (P>0.05) for W2. The highest WUE_{ME} of 314.8 kJ ha^{-1} mm^{-1} was recorded for W3 with respect to the irrigation frequency, followed by 305.4 kJ ha^{-1} mm^{-1} for W2 and 293.7 kJ ha^{-1} mm^{-1} for W1 (Table 4.2). Irrespective of the irrigation frequency, the highest WUE_{ME} of 335 kJ ha^{-1} mm^{-1} was recorded for N3. This did not differ significantly (P>0.05) from the WUE_{ME} of N2 but both had a significant (P<0.05) difference from N1 which had a WUE_{ME} of 254.7 kJ ha^{-1} mm^{-1}.

Table 4.2: Water use efficiency of annual ryegrass (*Lolium multiflorum* cv. Agriton) in terms of digestible dry matter, crude protein and metabolisable energy

Main Effect	WUE_{DDM}	WUE_{CP}	WUE_{ME}
Water (W)			
W1	22.8a[‡]	7.9a	293.7b
W2	21.8a	7.1b	305.4ab
W3	20.2b	6.3c	314.8a
LSD	***1.37***	***0.54***	***13.41***
Nitrogen (N)			
N1	17.9c	5.3c	254.7b
N2	22.8b	7.4b	324.3a
N3	24.2a	8.6a	335.0a
LSD	***1.37***	***0.54***	***13.41***
Significance			
W	**	**	*
N	**	**	**
WxN	Ns	Ns	Ns

[‡]Values in each column followed by the same letters were not significantly different; ** significant at $P<0.01$; * significant at $P<0.05$; Ns= not significant, WUE_{DDM}= water use efficiency in terms of digestible dry matter, WUE_{CP}= water use efficiency in terms of crude protein, WUE_{ME}= water use efficiency in terms of metabolisable energy, W= water treatment, N= nitrogen treatment, WxN= water and nitrogen interaction

4.4. Conclusions

Results from this study indicate that in both seasons WU was highest in the treatment that was irrigated twice a week and top-dressed with 60 kg N ha^{-1} after each cut. Nitrogen application had an effect on the WU, as less water was used in treatments that received no nitrogen. The highest cumulative water used over four harvests was 464 mm in the first season and 423 mm in the second season. The decrease in the WU could be due to the lower atmospheric demand as the ET_O was lower in the second season. The highest K_C value of 1.14 was recorded in the W3N3, the treatment with the highest water use and this indicates that the treatment was not over-irrigated. As the irrigation interval increased, more water was depleted from the soil profile. Depletion rates increased as the season progressed but generally it was minimal in the frequently irrigated treatments. Increase in WUE was achieved by reducing the frequency of irrigation from twice a week to once a week without causing significant yield loss. It can be concluded that at the expense of dry matter production, the highest WUE was achieved under water limiting conditions. Also, within the same irrigation frequency, N fertiliser applications increased the WUE through increases in the dry matter production.

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CHAPTER 5

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Annual ryegrass (*Lolium multiflorum*) is a fast-growing, cool-season bunchgrass grown nearly in any place where there is adequate available soil water. It could be seeded alone, or overseeded in warm-season pastures like kikuyu. Annual ryegrass is considered to be one of the highest quality winter pastures utilized in South Africa. It is a very useful interim crop during winter which is usually planted from March to early April, and where productivity can be expected from May to November. It responds well to high soil nutrient levels. However, best yield results, with greatest water use efficiency, could be achieved by improving fertility and available soil water throughout the season. The pasture can be grazed or cut when plants reach an approximate height of 15-20 cm. Animals can graze the forage as low as 4-8 cm, which allows sufficient leaf area remaining for regrowth.

From the experiments conducted during 2007 and 2008 irrigation and nitrogen fertiliser application affected the dry matter yield, LAI and FI significantly. Higher frequency of irrigation coupled with high nitrogen application significantly improved the dry matter yield. Canopy size influenced the LAI and FI which in turn affects the yield. In this study, the effect of irrigation and nitrogen application on DM yield, LAI and FI were investigated and the study showed that the treatments that were irrigated twice weekly and top-dressed with 60 kg N ha^{-1} after each cut consumed the most water, and this resulted in the production of higher yield, maintenance of the largest leaf area index and higher interception of the incoming solar radiation. The highest cumulative yield of 10.98 t ha^{-1} over four harvests was recorded in the second season, with a LAI of 5.19 m^2m^{-2} and fractional radiation interception of 94%. However, there was no significant difference in yield between the treatments that were irrigated twice weekly and once a week at the high N application. The non-significant difference in yield could be due to the grass's ability to use water stored in the soil profile, hence all the treatments were filled to field capacity at the beginning of each season. The increase in these parameters may be due to the sufficient water and nitrogen fertiliser that induces rapid cell elongation as a result of higher water potential, higher turgor pressure and higher photosynthetic processes. However, the treatments that were irrigated once every two weeks with no N application consumed the least water, resulting in low DM production and maintenance of the lowest leaf area index. Water and nitrogen deficits resulted in a statistically significant yield reduction, compared to the treatments with no stress. Results from this experiment show that dry matter yield and LAI can be increased through the application of increased irrigation and nitrogen fertiliser. This proves that the pasture production was positively associated with the soil water and fertiliser content.

Nutritive value is another aspect that needs to be evaluated with respect to pastures. In this study, the ryegrass recorded a high IVOMD, CP and ME values while the leaf:stem ratio and DMC was of acceptable levels. The nutritive values of the grass ranged between 10.6 MJ kg^{-1} - 11.7 MJ kg^{-1} for ME, 23.5% - 28.5% for CP, 75.6% - 83.1% for IVOMD and 10.2% - 15.3% DMC. These values recorded are still sufficiently high for dairy farming as digestibility values greater than 65%, ME values greater than 9% and CP values higher than 18% can safely support the maintenance plus production requirement of animals. It was also noted that the growth cycle had a significant effect on the dry matter content, the highest being on the fourth harvest while the leaf:stem ratio decreased as the season progressed. The decrease in the frequency of water application resulted in an increase in the DMC, digestibility, ME and CP values. The level of nitrogen had a significant effect on the DMC, ME and CP. An increase in the nitrogen application increased the CP but decreased the DMC and ME. It can therefore be concluded that water stress did improve the quality of the pasture by increasing the DMC, IVOMD, ME and CP contents. The results of this study highlight that under optimal conditions of growth, the nutritive quality of the ryegrass is able to meet the requirements of even high producing dairy cows, provided that animals consume sufficient DM to achieve this level of production.

The amount of available water is declining as a result of pressure from other competing factors (domestic, environmental, recreation and industrial), hence the need improve WUE. In agricultural production it is possible to make best use of the available water efficiently through irrigation scheduling. Two of the important variables used to quantify plant water usage are WU and WUE. Generally, WU of annual ryegrass varies depending on region, climate, cultivar and stage of growth. Results from this study indicate that in both seasons WU was highest in the treatment that was irrigated twice a week and top-dressed with the 60 kg N ha^{-1} after each cut. Nitrogen application had an effect on the WU, as less water was used in the treatments that received no nitrogen. The highest cumulative water used over four harvests was 464 mm in the first season and 423 mm in the second season. The decrease in the

WU could be due to the lower atmospheric demand as the ET_O was lower in the second season. Highest K_C value of 1.14 was recorded in W3N3, the treatment with the highest water use and this indicates that the treatment was not over-irrigated. As the irrigation interval increased, more water was depleted from the soil profile. Depletion rates increased as the season progressed but generally it was minimal in the frequently irrigated treatments. Increase in WUE was achieved by reducing the frequency of irrigation from twice a week to once a week without causing significant yield loss. A possible reason for the increase in the WUE by reducing the irrigation frequency could be ascribed in part to reduced evaporation from the soil resulting from the lower wetting frequency of the deficit irrigation treatments. Within the same irrigation frequency, higher WUE was achieved by alleviating a limiting factor, N fertiliser, in this case, through increases in dry matter production. The highest WUE was achieved by irrigating once every two weeks. However, in some treatments, the WUE was not improved with the reduction in the frequency of irrigation as the water saved was overshadowed by yield loss. Increasing the WUE is beneficial, however, high WUE on its own is not necessarily an indication of the best irrigation scheduling method as one may need to quantify the trade-off between yield loss because of low levels of irrigation and the economic advantage that would be achieved by saving water. It can be concluded that at the expense of dry matter production, the highest WUE was achieved under water limiting conditions. Also, within the same irrigation frequency, N fertiliser applications increased the WUE through increases in the dry matter production.

The input costs of ryegrass under irrigation and fertilisation are high and that is why production should not only be high but the feed must be of a high quality. Water and nitrogen deficiency can limit the production of pastures. By adopting appropriate irrigation and nitrogen management strategies, we can improve the yield and quality of these pastures. Proper and efficient irrigation management minimises water loss due to runoff, deep percolation, surface evaporation and reduction of leached of nutrients, while better nitrogen management increases production and forage quality. Based on the data from this experiment, it can be concluded that by irrigating once a week and fertilising with 60 kg N ha^{-1} after each harvest, optimum yield can be achieved with better quality pasture, and a better WUE. In areas where the scarcity of water is a crucial issue, high water use efficiency at the expense of some dry matter yield could be achieved. Fewer irrigation frequencies, depending on the type of soil and climate, are required during the initial stages of growth so as to save both water and fertilizer. On the other hand, where there is no shortage of water, the farmer's choice could be to irrigate more frequently and maximize transpiration so as to have a maximum dry matter production.

RECOMMENDATIONS

The experiment was done in a confined place under a rain shelter. A logical extension of this work would be to do the trial in an open field to analyze the effect of irrigation and nitrogen fertilization on the growth, yield and quality of the pasture and then extrapolate the results to other sites and soil types using models. Also the influence of water and nitrogen stress on the maturity of the crop needs to be assessed as this plays an important role in the quality of the pasture. Another recommendation would be to examine the voluntary intake of dairy cows grazing the pasture at the optimum stage of growth, in order to determine the practical return on the production.

APPENDIX

A. Summaries of ANOVA tables

Table A1: Summary of ANOVA table on the chemical composition of annual ryegrass (Tukey's studentized range test)

Source of variation	Degree of freedom	F-probability levels									
		IVOMD		NDF		ME		Ash		CP	
		F value	Pr > F	F value	Pr > F	F value	Pr > F	F value	Pr > F	F value	Pr > F
Block	2	0.08	0.9222	26.70	<.0001	0.27	0.7676	0.79	0.4725	0.75	0.4869
Water	2	16.33	<.0001	2.78	0.0923	55.73	<.0001	1.77	0.2021	22.46	<.0001
Nitrogen	2	0.85	0.4450	1.51	0.2499	10.91	0.0010	3.73	0.0467	15.33	<.0001
Water*nitrogen	4	0.96	0.4534	0.46	0.7617	3.32	0.0369	0.30	0.8730	1.25	0.3289

IVOMD - *in vitro* organic matter digestibility; NDF=neutral detergent fibre; ME=metabolisable energy; CP=crude protein

Table A2: Summary of ANOVA table on the dry matter yield, water use and water use efficiency of annual ryegrass in 2007 (Tukey's studentized range test)

Harvest	Source of variation	Degree of freedom	F-probability levels					
			Dry matter yield		Water use		Water use efficiency	
			F value	Pr > F	F value	Pr > F	F value	Pr > F
Cut 1 (Aug 23)	Block	2	0.00	0.9958	3.33	0.0619	0.57	0.5753
	Water	2	45.83	<.0001	191.30	<.0001	10.49	0.0012
	Nitrogen	2	490.20	<.0001	197.18	<.0001	482.74	<.0001
	Water*nitrogen	4	0.56	0.6944	5.82	0.0043	49.80	<.0001
Cut 2 (Sep 20)	Block	2	3.55	0.0529	0.27	0.7693	4.23	0.0335
	Water	2	63.71	<.0001	1193.60	<.0001	30.70	<.0001
	Nitrogen	2	812.52	<.0001	491.47	<.0001	605.42	<.0001
	Water*nitrogen	4	12.90	<.0001	8.27	0.0008	36.20	<.0001
Cut 3 (Oct 18)	Block	2	3.17	0.0695	0.23	0.7982	2.82	0.0890
	Water	2	90.76	<.0001	1580.80	<.0001	31.02	<.0001
	Nitrogen	2	1085.23	<.0001	741.98	<.0001	688.41	<.0001
	Water*nitrogen	4	4.76	0.0101	21.49	<.0001	16.79	<.0001
Cut 4 (Nov 15)	Block	2	1.61	0.2306	0.63	0.5463	1.56	0.2409
	Water	2	115.03	<.0001	1929.95	<.0001	9.02	0.0024
	Nitrogen	2	882.62	<.0001	895.87	<.0001	409.49	<.0001
	Water*nitrogen	4	6.99	0.0019	15.40	<.0001	15.74	<.0001
Total/ Average	Block	2	3.44	0.0571	3.74	0.0464	1.78	0.2001
	Water	2	180.11	<.0001	8795.71	<.0001	13.49	0.0004
	Nitrogen	2	1896.32	<.0001	4526.65	<.0001	1383.60	<.0001
	Water*nitrogen	4	10.08	0.0003	70.85	<.0001	61.59	<.0001

Table A3: Summary of ANOVA table on the dry matter yield, water use and water use efficiency of annual ryegrass in 2008 (Tukey's studentized range test)

Harvest	Source of variation	Degree of freedom	F-probability levels					
			Dry matter yield		Water use		Water use efficiency	
			F value	Pr > F	F value	Pr > F	F value	Pr > F
Cut 1 (Jul 15)	Block	2	4.06	0.0376	2.56	0.1082	0.18	0.8330
	Water	2	13.64	0.0003	17.77	<.0001	7.17	0.0060
	Nitrogen	2	434.12	<.0001	35.86	<.0001	92.02	<.0001
	Water*nitrogen	4	13.84	<.0001	5.08	0.0077	5.16	0.0073
Cut 2 (Aug 12)	Block	2	2.86	0.0868	1.67	0.2202	1.10	0.3571
	Water	2	111.36	<.0001	41.72	<.0001	1.79	0.1987
	Nitrogen	2	1930.45	<.0001	36.51	<.0001	210.69	<.0001
	Water*nitrogen	4	10.83	0.0002	1.12	0.3835	3.32	0.0369
Cut 3 (Sep 09)	Block	2	0.40	0.6778	1.61	0.2298	1.48	0.2582
	Water	2	299.97	<.0001	172.63	<.0001	1.40	0.2757
	Nitrogen	2	1926.28	<.0001	144.07	<.0001	394.09	<.0001
	Water*nitrogen	4	22.21	<.0001	14.82	<.0001	16.58	<.0001
Cut 4 (Oct 07)	Block	2	0.38	0.6897	0.03	0.9690	0.10	0.9055
	Water	2	568.40	<.0001	1333.92	<.0001	33.42	<.0001
	Nitrogen	2	1993.34	<.0001	192.48	<.0001	489.88	<.0001
	Water*nitrogen	4	77.21	<.0001	10.98	0.0002	44.64	<.0001
Total/ Average	Block	2	4.51	0.0279	2.11	0.1536	0.82	0.4586
	Water	2	987.81	<.0001	596.29	<.0001	8.80	0.0026
	Nitrogen	2	7113.00	<.0001	233.76	<.0001	536.41	<.0001
	Water*nitrogen	4	100.20	<.0001	13.27	<.0001	20.85	<.0001

Table A4: Summary of ANOVA table on the leaf area index of annual ryegrass in 2007 and 2008 (Tukey's studentized range test)

Harvest	Source of variation	Degree of freedom	F-probability levels							
			2007 D14		2007 D28		2008 D14		2008 D28	
			F value	Pr > F	F value	Pr > F	F value	Pr > F	F value	Pr > F
Cut 1	Block	2	0.57	0.5779	2.71	0.0968	0.07	0.9335	0.08	0.9209
	Water	2	89.87	<.0001	87.12	<.0001	25.51	<.0001	3.04	0.0759
	Nitrogen	2	210.26	<.0001	177.68	<.0001	34.48	<.0001	3.69	0.0480
	Water*nitrogen	4	3.51	0.0308	4.11	0.0176	4.36	0.0142	1.45	0.2635
Cut 2	Block	2	0.77	0.4784	11.31	0.0009	5.88	0.0121	15.81	0.0002
	Water	2	49.88	<.0001	179.01	<.0001	148.22	<.0001	142.09	<.0001
	Nitrogen	2	189.75	<.0001	754.85	<.0001	375.01	<.0001	611.01	<.0001
	Water*nitrogen	4	4.45	0.0131	5.29	0.0066	14.26	<.0001	6.93	0.0020
Cut 3	Block	2	5.36	0.0165	7.35	0.0054	0.40	0.6801	0.80	0.4678
	Water	2	15.05	0.0002	75.23	<.0001	17.34	<.0001	23.27	<.0001
	Nitrogen	2	115.81	<.0001	221.97	<.0001	79.58	<.0001	114.72	<.0001
	Water*nitrogen	4	5.18	0.0072	2.95	0.0528	5.13	0.0075	0.20	0.9351
Cut 4	Block	2	5.32	0.0169	2.45	0.1184	4.58	0.0267	1.04	0.3771
	Water	2	18.95	<.0001	85.33	<.0001	29.19	<.0001	48.39	<.0001
	Nitrogen	2	379.50	<.0001	458.99	<.0001	260.60	<.0001	299.55	<.0001
	Water*nitrogen	4	50.19	<.0001	7.84	0.0011	44.59	<.0001	11.45	0.0001
Mean	Block	2	12.51	0.0005	19.86	<.0001	3.20	0.0680	1.82	0.1934
	Water	2	159.07	<.0001	378.15	<.0001	79.31	<.0001	51.84	<.0001
	Nitrogen	2	973.29	<.0001	1307.77	<.0001	334.79	<.0001	267.49	<.0001
	Water*nitrogen	4	27.02	<.0001	4.21	0.0162	18.66	<.0001	0.70	0.6057

D14 and D28= sampling dates from date of harvest

Table A5: Summary of ANOVA table on the mean dry matter content of annual ryegrass in 2007 and 2008 (Tukey's studentized range test)

Source of variation	Degree of freedom	F-probability levels			
		2007		2008	
		F value	Pr > F	F value	Pr > F
Block	2	1.66	0.1973	1.61	0.2067
Harvest	3	166.05	<.0001	242.64	<.0001
Water	2	543.65	<.0001	849.51	<.0001
Harvest*water	6	3.03	0.0109	3.52	0.0042
Nitrogen	2	25.99	<.0001	20.82	<.0001
Harvest*nitrogen	6	5.81	<.0001	1.03	0.4114
Water*nitrogen	4	0.97	0.4313	0.53	0.7117
Harvest*water*nitrogen	12	0.97	0.4313	1.46	0.1621

DMC= dry matter content

Table A6: Summary of ANOVA table on the leaf:stem ratio of annual ryegrass in 2007 (Tukey's studentized range test)

Source of variation	Degree of freedom	F-probability levels							
		Growth cycle 1		Growth cycle 2		Growth cycle 3		Growth cycle 4	
		F value	Pr > F	F value	Pr > F	F value	Pr > F	F value	Pr > F
Block	2	0.05	0.9513	0.67	0.5232	1.85	0.1887	0.58	0.5711
Water	2	21.84	<.0001	11.45	0.0008	6.27	0.0097	13.08	0.0004
Nitrogen	2	93.22	<.0001	58.10	<.0001	35.61	<.0001	65.10	<.0001
Water*nitrogen	4	2.20	0.1156	2.37	0.0960	0.94	0.4645	2.73	0.0664

B. Summaries of soil analyses

Table B1: Soil analysis for the composite soil sample

Soil parameter	value
C (%)	0.99
NH_4 (mg kg^{-1})	1.51
NO_3 (mg kg^{-1})	61.60
SO_4 (mg kg^{-1})	0.07
P (mg kg^{-1})	118.9
Ca (cmol kg^{-1})	8.568
K (cmol kg^{-1})	0.265
Mg (cmol kg^{-1})	8.894
Na (cmol kg^{-1})	0.373

NH_4= ammonium, NO_3= nitrate, SO_4= sulphate

Table B2: Soil analysis for pH and EC

Field No.	pH water	EC (mS/m)
1	7.3	463.3
2	7.4	435.0
3	7.5	415.0
4	7.3	460.0
5	7.4	437.0
6	7.4	496.0
7	7.5	404.0
8	7.5	420.0
9	7.4	372.0
10	7.4	424.0
11	7.3	351.0
12	7.3	201.0

EC= electrical conductivity