COALTECH

Project 8.3

Rehabilitation of Mined Land
Irrigation of Pastures with Gypsiferous Mine water

By

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%N	Percentage Nitrogen
°C	Degree Celcius
µm	Micro meter
ADF	Acid detergent fiber
ADG	Average daily gain
$AU.ha^{-1}$	Animal unit per hectare
B	Boron
BS	Blooming stage
BW	Body Weight
C	Carbon
C_{32}	Isotope 32 of Carbon
C_{33}	Isotope 33 of Carbon
C_{36}	Isotope 36 of Carbon
Ca^{2+}	Calcium
$CaSO_4$	Calcium Sulfate
Cl^{-1}	Chloride

cm	Centimeter
cm^{-2}	square centimeter
CNS	Central Nervous System
CO_3^{2-}	Carbon trioxide
CP	Crude Protein
CRD	Controlled-release device
Cu	Copper
cv	Cultivar
DM	Dry matter
DMD	Dry matter digestibility
e.g	Example
EC	Electrical conductivity
Fe	Iron
FGP	Final germination percentage
g	gram
$g.cm^{-3}$	Gram per cubic centimeter
$g.day^{-1}$	Gram per day
$g.kg^{-1}$	Gram per kilogram
$g.kg^{-1}$ DM	Gram per kilogram Dry matter
$g.kg^{-1}$ OM	Gram per kilogram Organic matter
GC	Gas chromatography
GLM	General linear model
H	Hydrogen
h	Hours
H_3PO_4	Phosphoric acid
ha	Hectare
ha^{-1}	Per hectare
HCO_3^-	Bicarbonate
IVDMD	In vitro Dry matter disappearance
IVOMD	In vitro Organic matter digestibility
K	Potassium
kg	Kilogram
kg $DM.ha^{-1}$	Kilogram Dry matter per hectare
kg $DM.week^{-1}$	Kilogram Dry matter per week
kg $N.ha^{-1}$	Kilogram Nitrogen per hectare

kg P.ha^{-1}	Kilogram Phosphorus per hectare
kg.animal^{-1}	Kilogram per animal
kg.ha^{-1}	Kilogram per hectare
kg.m^{-3}	Kilogram per cubic meter
LSD	Least significant difference
LW$^{0.75}$/W$^{0.75}$	Metabolic live weight
m	Meter
m.s^{-1}	Meter per second
m^2	Square meter
mg	Milligram
mg.kg^{-1}	Milligram per kilogram
mg.l^{-1}	Milligram per litre
Mg^{+2}	Magnesium
ml	Millileter
mM	Milli Molar
mm	Millimeter
mm annum^{-1}	Millimeter per annum
Mn	Manganese
mS.m^{-1}	Milli Semens per meter
N	Nitrogen
Na$^+$	Sodium
NaCl	Sodium Chloride
NDF	Neutral detergent fibre
NH_3	Ammonia
NH_4^+	Ammonium
NH_4NO_3	Ammonium Nitrate
NO_3^-	Nitrate
OM	Organic matter
P	Phosphorus
Production.ha^{-1}	Production per hectare
S	Sulphur
S	Speed of germination
S.E.	Standard Error
SO^{4-}	Sulfate
t	Ton

$t.ha^{-1}$	Tons per hectare
$t.ha^{-1}year^{-1}$	Ton per hectare per year
T_{50}	Time when 50% of the tested seed are germinated
T_f	Threshold temperature
VFA	Volatile Fatty acids
Zn	Zinc

1.1 Introduction

Agricultural land is an extremely valuable resource. It is either directly or indirectly involved in the production of majority of our food (including crops, meat and other animal products, such as milk and eggs).

Remarkable growth in global agricultural production was seen over the last 50 years. Although food production increased in Asia, Latin America and China, Africa did not show the same favourable trend. The projected future population growth as well as increased per capita consumption will result in an increased food demand. The key is sustainable increase in food production in order to supply future needs. The adverse effect of climate change, increasing water scarcity and pressures on land available for food production (including growing cities, use for bio-fuel production, protected areas and soil erosion) limit the potential to meet increased food demands causing food insecurity (The Royal Society, 2009).

Land availability for agricultural use is also affected by the mining industry. Open cast coal mining results in removal of original vegetation and soil (Bradshaw, 1997). As described by Cairns (1983) management options for surface mined land used to include "(a) *restoration* to original condition, (b) *rehabilitation* of some desirable characteristics; (c) development of *alternative ecosystems* that may be quite unlike the original but may be desirable for a variety of reasons; (d) *neglect* of *natural reclamation* when evidence suggests that unaided natural processes will produce better results than human intervention." However he indicated that although neglect could, in rare cases, produce valuable conservation sites, scientists may not be able to determine if this will be the result.

Neglect is no longer an option due to South African legislative closure requirements (Act 28 of 2002). The mitigation of bio-physical as well as socio-economic impacts is required. The return of mine land to a viable post-mining land use is essential. Post mining land use determines the success of methods to rehabilitate the surface and ameliorate pollution (Limpitlaw *et al.,* 2005).

Mine waste water from coal mines in Mpumalanga tends to be gypsiferous, being high in calcium and sulphate ions (Annandale *et al.,* 2006). Problems associated with the disposal of mine waste water and the shortage of irrigation water created an opportunity. Various studies using mine water for irrigation have been conducted (Annandale *et al.,* 2001, 2006; Jovanovic *et al*., 1998, 2002; Mercuri *et al*. 2005). Soil appears to act as an effective salt sink, through precipitation of salts (Annandale *et al*., 2001, 2006). Long term studies showed an increase in soil salinity with time (Jovanovic *et al*., 1998, 2002) although unacceptable levels of salinity in soil are not expected (Annandale *et al.*, 2001). Various agronomic crops have been researched under these conditions, but very few pasture crops. Tall Fescue (*Festuca arundinacea*) is a cool season grass tolerant of these saline conditions (Alshammary *et al*., 2004; Kobayashi *et al*., 2004) and was the selected pasture specie to be researched under these conditions.

Pasture based systems provide beef with a more desirable fatty acid composition for human health and are less dependent on antibiotics than concentrate based systems (Steen *et al*., 2003). Compared to grain crops, pasture production can be seen as more environmentally friendly or sustainable as it require less fertilizer and pesticides (resulting in less water pollution) and forage corps protect soil against erosion (Jung & Allen, 1995). Economic returns from pastures, usually a cheap food source, are primarily a function of the production of the animals grazing these pastures and the costs associated with irrigation and fertilization.

The upper limit of production any animal can achieve is determined by its genetic potential. When all the nutrients required by the animal are available, feed is optimally utilized and only the genetic potential of the animal limits its production. The first limiting nutrient determines the extent to which the animal will reach its genetic potential. This assumption that that animal performance is related closely to intake of available nutrients is the basis of most feeding standards and models (Coleman & Moore, 2003).

It is clear that the production of animals on pasture is a function of the nutrients present in the pasture and the level of intake achieved by the animal. The crude protein content of pasture is influenced by the level of nitrogen fertilization (Eck *et al.,* 1981; Hedtcke *et al.,* 2002; Wolf & Opitz von Boverfeld, 2003; Peyraud & Astigarraga, 1998). Pasture intake is influenced by the stocking rate applied (Jung & Shalu, 1989; Dalley *et al.,* 1999; Stakelum and Dillon, 2004). Thus, stocking rate and level of nitrogen fertilization can influence the level of production achieved by animals on pasture.

1.1.1 Site introduction

In this study Tall Fescue (*Festuca arundinaceae)*, established on rehabilitated mine land and irrigated with gypsiferous mine water, and was grazed by weaned calves.

Figure 1: Arial view of the Tweefontein Pivot at Kleinkopje Colliery.

Figure 2: Irrigating the Tall Fescue pasture and cattle grazing the pasture.

The experimental site, previously used for open cast coal mining, was rehabilitated prior to the study. Coal mine spoil material was covered with a sandy clay soil of 40-80 cm in depth. The bulk density of the cover soil varied form 1.80 $g.cm^{-3}$ at 0-20 cm to 1.90 $g.cm^{-3}$ at 20-40 cm depths. The nutrient concentrations in the soil were as follows: Ca (2462 $mg.kg^{-1}$), P (17 $mg.kg^{-1}$), K (159 $mg.kg^{-1}$), Mg (448 $mg.kg^{-1}$) and Na (94 $mg.kg^{-1}$).

In June 2007 Tall Fescue (*Festuca arundinacea* cv. Dovey) was established on rehabilitated mine land. The pasture was divided into six paddocks, paddock A-F and a

centre paddock (Figure 8). The pasture was fertilized in June 2007 with 110 kg $P.ha^{-1}$ and 150 kg $N.ha^{-1}$ (paddock **A** received double the amount of N). In November 2007 the whole pasture was cut down to an average of 5 cm and the plant material was not removed. A second application of nitrogen was done in March 2008 at a rate of 150 $kg.ha^{-1}$.

Data were collected during two respective periods: 6 June to 16 July 2008 (Season 1) and 27 August to 5 November 2008 (Season 2). The pasture was irrigated with mine waste water with a pH of 7.6; an electrical conductivity of 435.25 $mS.m^{-1}$ and the chemical analysis is shown in **Table 1**.

Table 1: Chemical analysis of mine waste water used.

Mineral	concentration ($mg.L^{-1}$)
S	1176.8
Ca	563
Mg	498.8
Na	96.78
NO_3^-	53.3
Cl	38.9
K	37.1
NH_4^+	18.3
P	0.1
B	0.1
Fe	0
Cu	0
Mn	0
Zn	0
CO_3^{2-}	0
HCO_3^-	0

1.1.2 Location of experimental site

The study was conducted at the Tweefontein Pivot at Kleinkopje Colliery (26˚00'S, 29˚21'E; altitude 1570 m), near Witbank, Mpumalanga Province, South Africa. This high lying site is a summer rainfall region with very cold winters and warm summers. The average

precipitation is about 700 mm annum^{-1}, and an additional 500mm on average per year was applied through irrigation (When irrigation system was operational).

Environmental factors used within this study, were quantified using an automatic weather station (measuring rainfall, minimum and maximum temperatures, wind speed and direction, relative humidity and solar radiation) as well as manual rain gauges measuring the amount of irrigation.

Figure 3: One of the two weather stations used to capture climatic data.

1.1.3 Tall Fescue

Figure 4: The Tall Fescue pasture used in the irrigation trial.

Tall Fescue (*Festuca arundinacea*) is a cool season, perennial grass native to Europe, North Africa, west and central Asia and Siberia (Gibson & Newman, 2001). It's adapted to a wide variety of soil, environmental and management conditions (Wilkinson & Mays, 1979)

Depending on variety used and defoliation frequency, expected annual dry matter (DM) yields of irrigated Tall Fescue in KwaZulu Natal range from 12.9 to 9.4 tons ha^{-1} (Klug *et al.,* 2000). The majority of production occurs during spring (about a third of its total production), but after an initial reduction in growth it is followed by an increase in autumn (Lacefield *et. al.,* 2003). Optimum growth for most temperate (cool-season) grasses occur at temperatures between 20 and 25 °C, with growth nearly ceasing when temperatures rise above 30 to 35 °C (Cooper & Tainton, 1968). In the study by Robson (1972) the optimum temperature for most aspects of leaf growth of Tall Fescue was close to 25 °C. Leasure (1952) found that Tall Fescue grew at mean weakly temperatures above 4.4 °C and was not completely dormant until mean weekly temperatures dropped to 1.1 °C.

This grass is tolerant to saline conditions (Alshammary *et al*., 2004) as a result of calcium chloride, magnesium chloride or sodium chloride (Kobayashi *et al*., 2004). The soil pH optimal for growth range from 6.5 to 8.0, although a wider range (pH 4.7 to 9.5) could be tolerated (Wilkinson & Mays, 1979).

Though Tall Fescue can tolerate adverse soil conditions, it will not persist in deep sandy soils (Burns & Chamblee, 1979). Good moist soils, heavy to medium in texture with considerable humus are needed for optimum growth (Buckner & Cowan, 1973). Tall Fescue in general, is a good temperate grass used extensively for grazing, and has a good feeding value. Ulyatt (1973) defined herbage feeding value as "a biological assessment of worth of a herbage in terms of animal production", that is, "the animal production potential of the herbage under a given set of environmental circumstances".

The production of calves can be measured either as their growth rate or average daily gain (ADG). The grazing pressure to be applied is determined by the stocking rate and is decided on by the manager. The ADG of animals on pasture is highly correlated with the stocking rate applied and the amount of herbage present (Bransby *et al.,* 1988). Increasing stocking rates generally results in reduced ADG but an increase in beef production per unit land area (Derner *et al*., 2007; Vavra *et al.,* 1973).This is due to the effect of grazing management on quality, yield, botanical composition and longevity of herbage (Bryant *et al*., 1970). Increasing stocking rates generally results in less available forage, lower quality and lower intake (Jung & Sahlu, 1989)

Various factors influence the quality of Tall Fescue when managed as a pasture. In young plants at a high level of fertilization (504 kg $N.ha^{-1}$) crude protein (CP) content can be as high as 306 $g.kg^{-1}$. The CP content generally decreases in summer and values as low as 51 g kg^{-1} has been recorded. In literature ranges for other chemical components was as follows: 444-652 g NDF.kg^{-1}, 75-383 g ADF.kg^{-1}, 57-329 g soluble carbohydrates.kg^{-1} (Burns, 2009).

Fulkerson *et al.* (2000) stated that although poor quality has been a problem with Tall Fescue in the past, newer varieties such as Vulcan and Dovey are higher in quality.

1.2 General aims and objectives

Due to the variability of factors influencing the quality parameters needed for environmental sustainability the identification of land end use and managing rehabilitated mine land poses a great challenge for the mining sector. Various studies have been conducted on rehabilitated mine land with such large variation in success, that the sustainability of agronomic crops cannot be closely compared to that of normal agricultural practices.

The main aim of this study was to try and identify alternative approaches to utilising rehabilitated mine land with less intensive inputs and perhaps to hand over a sustainable system to local communities out of which they will be able to gain access to and reap the necessary benefits. This study was to identify a sustainable system where one can graze livestock on rehabilitated mine land which was planted to Tall Fescue pastures and irrigated with gypsiferous water at an optimal stocking rate. The secondary aims of this study were to quantify animal performance (defined as average daily gain), pasture production and quality (nutritive value) of Tall Fescue at different levels of nitrogen fertilization during pasture establishment, the voluntary feed intake of animals when different stocking rates are applied.

Other smaller studies were conducted in conjunction with the main study to identify different quality parameters, different management strategies, different inorganic fertilizer applications as well as identifying other grass species that would be able to survive on these rehabilitated mine lands under the saline conditions prevalent from irrigation practices.

2 EXPERIMENTAL STUDIES

2.1 Experimental study 1 - *Evaluating the different stocking rates of a steer production system, on irrigated Tall Fescue (Festuca arundinacea) pastures, as a management tool for rehabilitated mine land.*

2.1.1 Introduction

Rehabilitation and utilization of surface coalmines is a tremendous challenge with respect to their post mining land use. Various methods of post mining land use have been adopted with different degrees of success. These agronomic methods include the establishment of different types of pastures as well as economical important crops such as maize and potatoes. The objective of this study was to determine if the establishment of a Tall Fescue pasture on rehabilitated mine land, while being irrigated with poor quality, gypsiferous water, is a viable option. These pastures where utilized as grazing for weaned cattle, at different stocking rates.

Figure 5: Cattle grazing Tall Fescue pastures on the Tweefontein pivot.

The rate, at which a planted pasture is stocked, is perhaps the single most important management factor affecting animal performance and profitability of a livestock system. The stocking rate influences, not only animal performance and animal production, but also the

availability of grazing material over a period of time, the effect of grazing animals on compaction as well as the recycling of nutrients. By determining the production.ha^{-1} as well as the production.animal^{-1}, we can determine the optimal stocking rates required to achieve this. This is the number of animals one can graze on such land, which ensures optimal animal performance to ensure maximum economic output for such a system.

2.1.2 Methodology

During this trial, three different stocking rates, over three different seasons namely early summer, late summer and winter, were monitored on a regular basis. The different factors that were influenced by the different stocking rates are monitored. These include: Average production per animal as well as production per hectare which was measured in bi - weekly intervals, 2) Pasture availability which was measured, by means of an Ellinbank Rising Plate Meter, 3) Pasture re - growth potential was measured and 4) Soil compaction rate (Compaction Alleviation Research Task 8.2.4). All of these aspects must not be seen as separate components, but rather as an integrated system. By determining optimal stocking rates, the pastures can be managed in an optimal way to ensure sustainable production of both pastures and animals.

Animal performance was measured by weighing the animals on a bi - weekly basis using a LS2000 scale by LMI (**Figure 7**), which was calibrated before every weighing, to calculate an average production per animal as well as production per hectare measured as an average daily gain (kg.animal^{-1} and production.ha^{-1}).

Figure 6: The scale used during the trial to weigh the cattle that were grazing the Tall Fescue pastures.

All animals were measured during the same time of day (early morning) to eliminate any possible variation that could be caused by rumen fill (animals weight vary depending on how much dry matter is consumed). This made the comparison between animals from different paddocks possible for different seasons.

Figure 7: The LS2000 electronic scale which was linked to the scale showed in Figure 6, to accurately obtain the animal weights.

Pasture availability was measured by means of an Ellinbank Rising Plate Meter and reflects the amount of forage available to the animals. The measurements were made using a grid measurement procedure (**Figure 12**).

Figure 8: An aerial view of the centre pivot which was divided into 6 different paddocks (A (*A1 & A2*), B (*B1 & B2*), C (*C1 & C2*), D, E and F).

The Ellinbank Rising Plate Meter (Figure 9) was calibrated (Figure 10 & Figure 11) prior to every series of measurements, by means of clipping plant material at a height of 50mm above ground level, in a 0.3m x 0.5m quadrant, drying the cut samples for 72 hours at 70°C after which the dried samples were weighed. By means of regression analyses and substituting the very representative readings taken for the paddocks, the available dry matter per hectare (kg DM.ha^{-1}) was then calculated.

Figure 9: The Ellinbank rising plate meter used in the trial to measure the available dry matter.

Figure 10: Calibrating the Ellinbank rising plate meter by measuring the pasture height in the quadrant and then clipping the utilizable dry material in the quadrant (Figure 11) and weighing it.

Figure 11: Calibrating the Ellinbank rising plate meter, using the following equipment by measuring the pasture height in the quadrant and then clipping the utilizable dry material in the quadrant and weighing it.

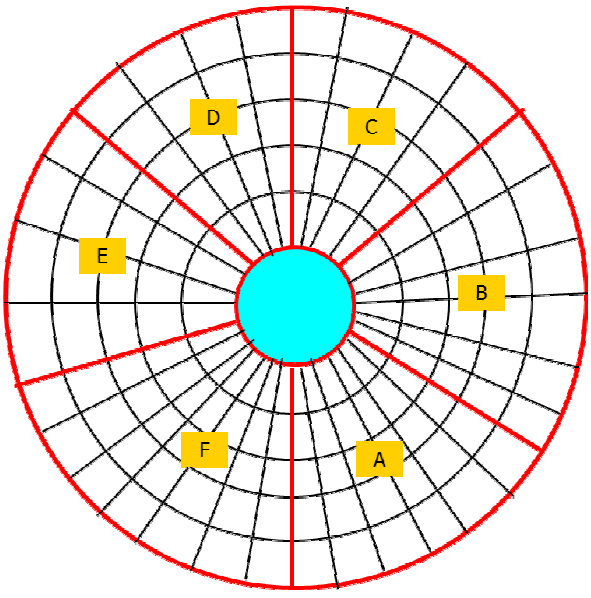

Figure 12: The grid used to take all the measurements on the pastures. Red lines indicate the paddock borders and the black lines indicate where consecutive readings were taken with the Ellinbank rising plate meter.

The pasture re - growth potential is the time the pasture needs to recover after a continuous grazing period. The quicker it recovers, the quicker that specific pasture can be grazed again. It was measured by placing three 1m x 1m exclosures on each paddock that was being grazed. Clippings were done on a bi - weekly basis simulating a grazing pattern and then monitoring the re - growth potential. (Kg DM.week^{-1}). The available data could also be an indication of the optimal utilisation level of these pastures for these challenging conditions.

Figure 13: The exclosures used to measure production data on the paddocks being grazed.

Figure 14: Production measurements were done by taking clippings using a small quadrant inside the exclosures.

Compaction (kg m^{-3}) will be another indication whether the pastures are over or under stocked and were monitored throughout the grazing seasons (Reported in Task 8.2.4 Compaction Alleviation Research Report). Measurements were made using a hydraulic and mobile handheld penetrometer (Figure 16) and samples were taken randomly over the whole of the centre pivot.

Figure 15: The hydraulic penetrometer used during the trial to measure the compaction on the pivot.

Figure 16: The handheld penetrometer used during the trial to measure the compaction on the pivot.

Considering that live animals were used in the research trial, an approval from the ethical committee of the University of Pretoria was granted, and a qualified veterinarian was appointed throughout the research period to monitor animal health.

All of these aspects must not be seen as separate components, but rather as an integrated system. By determining optimal stocking rates, the pastures can be managed in an optimal way to ensure sustainable production of both pastures and animals. Similar systems have been researched, but this unique scenario of reclaimed mine land being utilized as part of a steer production system, makes it one of its kind thus far. Previously mined soils could now be reclaimed and put to good agricultural use and furthermore, being irrigated with gypsiferous water, which there is ample amounts of and cannot be discarded in any way due to its high salt content. Previously re-claimed mined land and poor quality gypsiferous water, can now be incorporated into a steer production system and can be utilized as a valuable resource to enhance the growth of pastures for animal production.

2.1.2.1 Method how animals were allocated onto paddocks

One week before every grazing season commenced, representative samples were taken throughout the paddocks planned to be grazed in each specific season. Firstly the Ellinbank rising plate meter was calibrated to the specific physiological stage of the pasture as discussed in section 2.1.2, to obtain a linear regression curve that was used to calculate

the available dry matter. Secondly, the average pasture height was measured using the same Ellinbank rising plate meter to which the pastures were calibrated to. The measurements were done using a grid measurement method (Figure 12). It is important to take at least 200 measurements ha^{-1}, to ensure that the average pasture height is obtained, and would be representative of the pasture that was going to be grazed.

The average pasture height was then used in the linear equation to calculate the available dry material.$hectare^{-1}$ and then the available dry material was extrapolated to the size of the paddock to determine how many kilograms of utilizable dry matter was available in the specific paddocks to be grazed.

The animals to be used to graze were weighed the morning before they were allocated to the. An average weight was the determined and then these animals were randomly allocated into the amount of groups to be used in the specific grazing season.

The stocking rates on each paddock were then determined by calculating how much dry material a certain animal of a particular live weight would ingest throughout the grazing season which varied from 50 to 70 days depending on the different readings that were taken during the specific grazing season. Thus, the pasture allowance determined how much cattle were to graze the specific paddock. For example: For the first grazing season, there was 4036.8 kg of dry material.$hectare^{-1}$ available on paddock A. Paddock A was 3.2ha in size, thus in total there was 12917.89 kg dry material available to be utilized over a period of 60 days. Pasture allowance was an allowance of 3% of live animal body weight, which for trial purposes varied from 2%, 2,5% and 3% to obtain a different stocking rate, of the live body weight to be taken in per day. The parameter then measured was the average weight of the livestock, which was 151kg, pasture allowance of 3% and the available dry mater which was 12917.89kg. The available dry matter per day was then calculated by taking the total available dry material and dividing it into the amount of days required for the grazing season, which then equaled to 215.3kg of dry material available per day. Three percent of pasture allowance of 151kg live weight is 4.53kg of dry material to be taken in per day^{-1}. Thus, there was 215.3kg of dry material available to be grazed per day and the amount of dry material to be taken in by the livestock was an average of 4.53kg per day. Thus the amount of livestock to be allocated for this specific scenario was calculated by taking the amount of dry material available per day (215.3kg) and dividing it into the average amount of dry material to be taken in per day (4.53kg). This amounted to be 48 cross bred cattle to be grazed on paddock A.

The aforementioned method was used for the first, second and third grazing season.

To obtain the stocking rate, the total amount of live weight was calculated by taking the amount of cattle (48) and multiplying it with their average weight (151kg). This amounted to 7248kg total live weight that was grazed on the paddock. The paddock was 3.2ha in size, thus there was 2265kg of live weight grazing the paddock per hectare. Taking the definition of an animal unit into account (One Animal Unit is equivalent to a 450kg steer with a specific daily dry matter requirement) one can then take the amount of live weight grazing the paddock per hectare and dividing it into 450kg which is equivalent to one animal unit. This amounts to 5.03 animal units per hectare.

For the second season a different approach was followed. The three paddocks were stocked in relation to the estimated pasture availability and predicted growth in order to achieve a pasture allowance of 2, 2.5 and 3% body weight. Pasture availability was determined every second week and adaptations to the number of animals (stocking rate) were made in order to keep a constant grazing pressure (Wheeler et al., 1973). Weights of these "put-and-take" animals were not used in calculations of average daily gain.

This different approach was followed after the first season which delivered the best average daily gain of 350 grams. This second grazing season also fell within a warmer period, with the expectation that the growth rate of Tall Fescue would decline quickly as well as the quality of the pasture. The approach was adapted to achieve better animal production, but since the expected results were not obtained, the approach was then changed back to the original approach for the second and third grazing seasons where the stocking rate was fixed at the start of the season and the animals that was left on the paddock for the whole grazing season.

2.1.3 Results and discussion

2.1.3.1 First grazing season: 03 June 2008 – 01 August 2008

During the first grazing season the lowest stocking rate of 4.43 AU.ha^{-1} delivered the lowest ADG. This could have been due to less competition among animals, thus grazing more selectively. A high performance grazing system, rather than a high utility grazing system was thus established in which the animals grazed much more selectively and thus not utilizing the pasture to its fullest extent. Looking at Figure 18, all three stocking rates provided a similar animal performance pattern, but after day 38, the very palatable material was exhausted and the animals had to start utilizing the less palatable material. Only after the 38th day into the grazing period, did the different stocking rates show their full effect.

Correlating this to Figure 17, one can see that there was still sufficient available dry matter left on the paddock to be grazed. The highest ADG of 350 g.day^{-1} was obtained from the intermediate stocking rate of 5.03 AU.ha^{-1}. Correlating this finding to Figure 17, one can see that an increase in available dry matter was evident for this paddock. This can be ascribed to the effect of a fully operational irrigation system and thus optimal growth of the pasture overall.

Table 2: Stocking rates of paddocks during the first grazing season starting 03 June 2008 and ending 01 August 2008 (60 Days).

Paddock	**A**	**B**	**C**
Animal Units (AU).ha^{-1} *	5.03	4.43	6.62
Average Daily Gain (ADG) (kg.day^{-1})	0.350	0.060	0.234

* One Animal Unit is equivalent to a 450kg steer with a specific daily dry matter requirement.

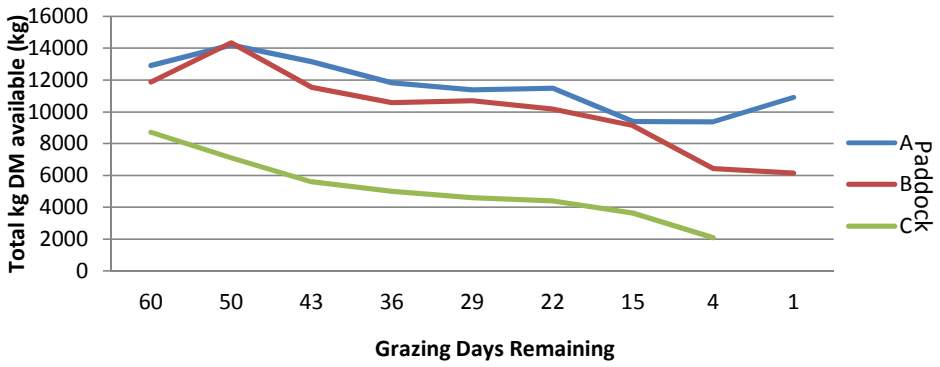

Figure 17: Total amount of dry matter available in each paddock vs. the amount of grazing days remaining for the first grazing period.

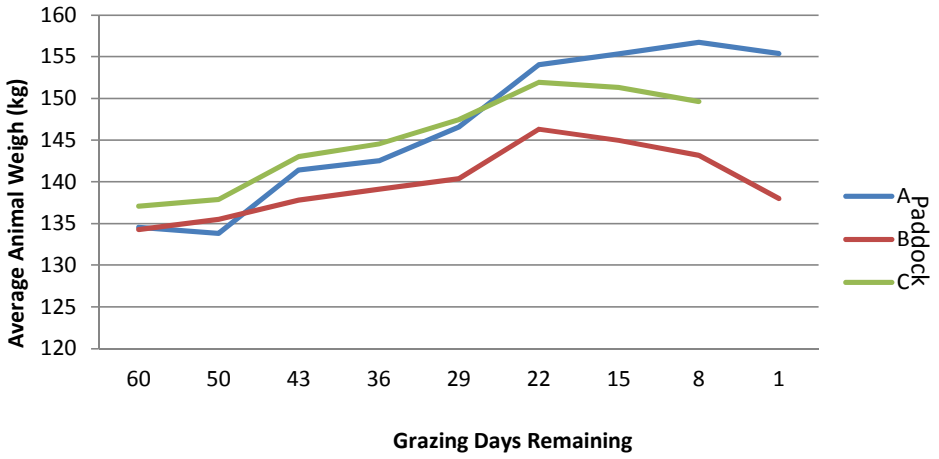

Figure 18: Total amount of dry matter available in each paddock vs. the amount of grazing days remaining for the first grazing period.

2.1.3.2 Second grazing season: 27 August 2008 – 05 November 2008

During the second grazing period a so called "put and take system" was used and managed on the three paddocks. This was decided upon, since there had been an abundant amount of plant material grown throughout the winter period, however, the commencement of grazing took place in the spring/summer growing season and the growth rate of Tall Fescue declines rapidly during this time, running the risk of insufficient dry matter for animals. This kept the stocking rate fixed by keeping the ratio of live animal weight grazing to available dry matter constant by adding and removing animals on a bi-weekly basis as the available dry matter increased or decreased. During this period the highest ADG was achieved with the lower stocking rate of 5.89 AU.ha^{-1}. This was as a result of steers grazing quality pasture rather than quantity. The intermediate ADG was achieved by the highest stocking rate of 10.25 AU.ha^{-1}. This was due to the fact that there was tremendous competition amongst animals for dry matter, forcing the steers to utilize as much dry matter as possible. Towards the end of this grazing period, the pastures were under severe drought and grazing stress as a result of limited irrigation, which contributed to cattle being more prone to disease. There was an outbreak of *Trichophyton sp.* virus, better known as ringworm, which influenced the animal's condition, causing weight loss explaining the lower ADG compared to the first grazing season.

Figure 19: A typical example of a steer infected with the *Trichophyton sp.* Virus.

The stocking rates for the grazing cycle were calculated taking into account the amount of grazing available before the grazing cycle commenced, in addition to the dry matter intake of the animals based on the three selected body weight percentages.

Table 3: Stocking rates of paddocks and average daily gain during the second grazing season starting 27 August 2008 and ending 05 November 2008 (70 Days).

Paddock	D	E	F
Animal Units (AU).ha^{-1} *	10.25	6.93	5.89
Average Daily Gain (ADG) (kg.day^{-1})	0.120	0.090	0.190

* One Animal Unit is equivalent to a 450kg steer with a specific daily dry matter requirement.

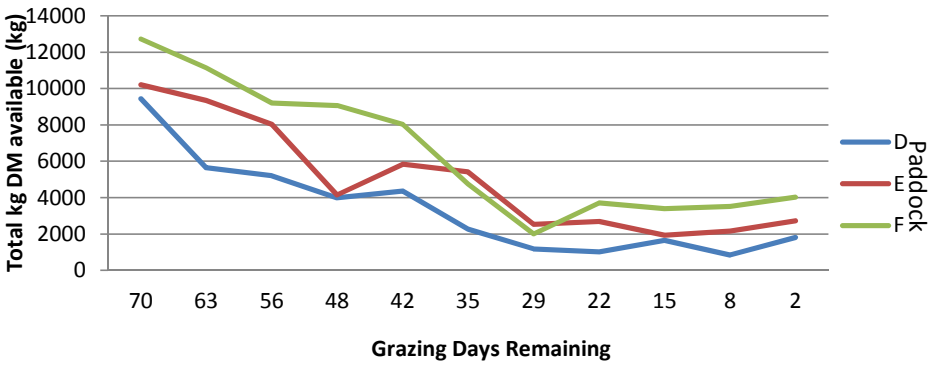

Figure 20: Total amount of dry matter available in each paddock vs. the amount of grazing days remaining for the second grazing period.

To determine the quality of a pasture, it is of importance that the proportion of leaf to stem material of the plant is measured. It is interesting to note from Figure 21 that the amount of leaf material is 60-80% more than stem, highlighting the high quality of pasture grown, since the leaf component is the most nutritious part of the plant. As expected the stem component does increase towards the end of the growth cycle, but not lowering the quality of the pasture significantly.

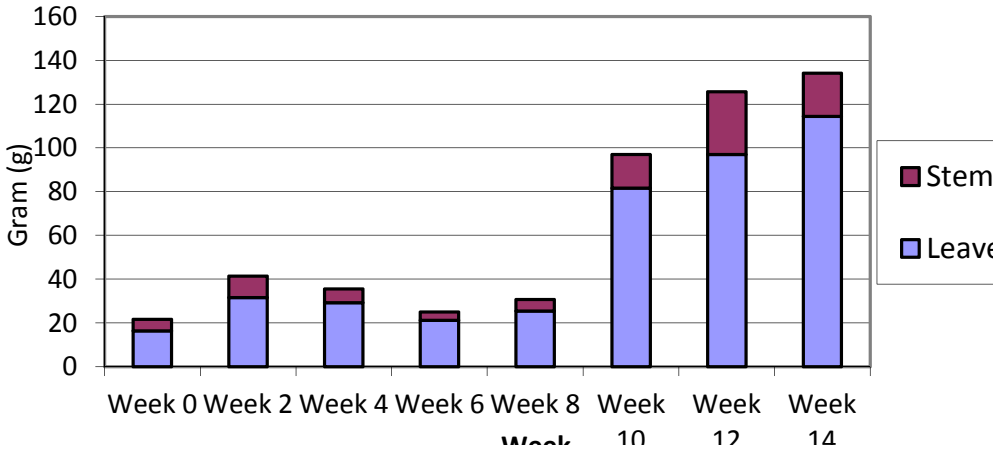

Figure 21: The Leave and Stem material obtained during the second grazing season using the exclosures.

The Leaf: Stem ratios as presented in Table 4 also substantiate the aforementioned results, offering ratios of 3:1 up to 5.77:1, which is higher than a target value of 2:1, which is an acceptable ratio for pastures.

Table 4: The Leave: Stem ratios obtained during the second grazing season.

Week	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**
Leave: Stem Ratio	3.15	3.19	4.60	5.78	4.80	5.28	3.35	5.77

2.1.3.3 2009 Grazing seasons

The research trial was planned to initiate another early winter grazing cycle in addition to a late winter grazing cycle as well, since two successful grazing periods had been completed during 2008. Unfortunately, an out of control veld fire found its way onto the pivot and ended up burning most of the available Tall Fescue pasture that was planned for evaluation in the 2009 grazing periods.

Figure 22, Figure 23 and Figure 24 illustrate the effects of the fire, resulting in the postponement of the grazing trial for the proposed grazing periods. Another contributory factor to the slow recovery of the pasture was the out of order irrigation system, since the fire had destroyed the electrical cables of the pivot system.

Figure 22: A photo taken from the centre paddock up into paddock A.

Figure 23: A view over the lowland area of the Tweefontein pivot.

Figure 24: Note the pasture that was available in the foreground and the burnt area in the background.

2.1.3.4 Third grazing season: 23 March 2010 – 26 June 2010

During the planning of the third grazing season, it was realized that due to financial constraints and beef prices sky rocketing due the FIFA World Cup, only half of the livestock, which was intended for the season, could be purchased. To overcome this challenge, the amount of livestock needed had to be halved. This was possible by dividing each paddock on the lowland area, **A, B** and **C**, into two parts, which then created six paddocks, **A1, A2, B1, B2, C1** and **C2** (Figure 8). This in turn had the advantage of only grazing half of the lowland during one season, thus allowing another grazing season on the lowland for more data collection.

Paddocks **A2**, **B1** and **C1** were selected randomly to be grazed during the third grazing seasons and these paddocks were stocked according to the best performance data that has been obtained during the 2008 grazing periods during the same time of year which is summarised in Table 5. The stocking rates for the grazing cycle, were calculated taking into account the amount of grazing available before the grazing cycle commenced, in addition to the dry matter intake of the animals based on the three selected body weight percentages.

Table 5: Stocking rates of paddocks and average daily gain during the third grazing season starting 23 March 2010 and ending 26 June 2010 (60 Days).

Paddock	**A2**	**B1**	**C1**
Large Stock Unit.ha^{-1*}	6.39	5.58	5.32
Average Daily Gain(kg.day^{-1})	0.017	0.130	0.067

* One Animal Unit is equivalent to a 450kg steer with a specific daily dry matter requirement.

Looking at the graph during the first 10 days, paddocks **B1** and **C1** experienced an increase in available dry matter. This is largely because the centre pivot was working and these paddocks received ample irrigation just before a power failure interrupted the irrigation. The power failure lasted for about 4 days, after which it was rectified and the centre pivot was functional again. The rest of the pastures located on the upland portion of the Tweefontein pivot were irrigated, only to be interrupted by another electricity outage just after irrigating paddock **A2** which explains the increase in dry matter for paddock **A2** when 34 days of the grazing period was left. Unfortunately the power to the pivot was never restored after this; the pastures therefore could not produce the amount of dry material needed for the whole grazing season.

The total dry matter available for each paddock during the third grazing period is illustrated in **Figure 25**.

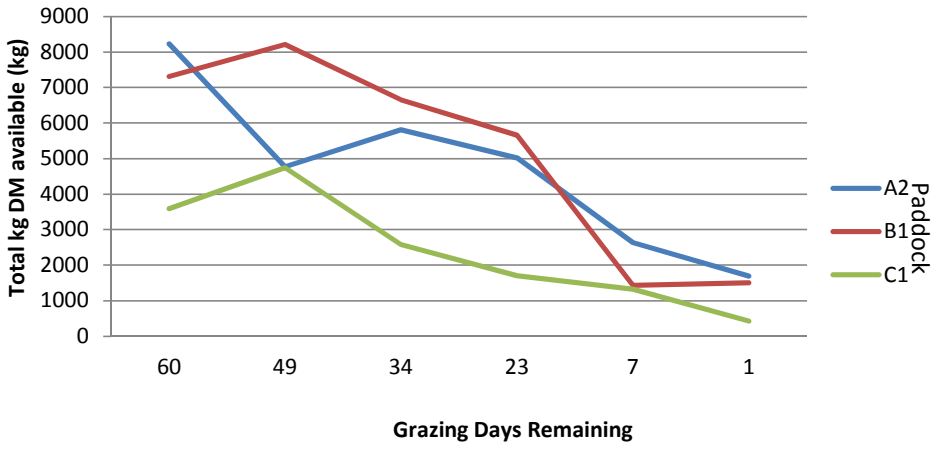

Figure 25: Total amount of dry matter available in each paddock vs. the amount of grazing days remaining for the third grazing period.

In Figure 26, the average animal weight during the third grazing period, clearly correlates directly to the aforementioned graph. When optimal amounts of dry matter were available, the animals tended to gain weight rather than losing weight, which would be the

expectation.

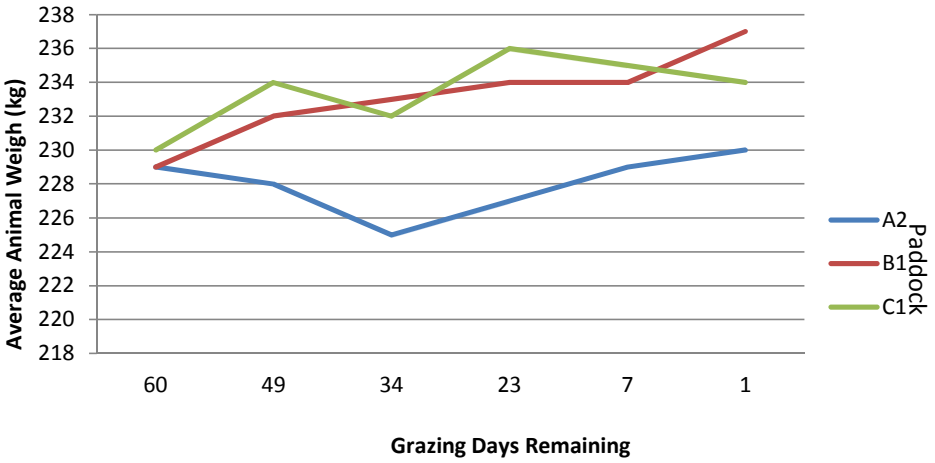

Figure 26: Average animal weight plotted against the grazing days remaining for the third grazing period.

The animals grazing paddock **A2** decreased in weight for the first period of the grazing cycle. This is ascribed to the fact that the specific herd of cattle, hadn't adapted to the pastures as well as the other two groups, and were clearly competing for the higher quality available

It is evident from this grazing cycle that paddock **B1** and **C1** had the best pasture production under the circumstances prevailing. It is also true that the stocking rates applied to these two paddocks allowed the paddocks sufficient opportunity to regrow and sustain the requirements of the allocated animals, resulting in a suitable stocking rate for these conditions.

2.1.3.5 Fourth grazing season: 26 June 2010 – 16 August 2010

The paddocks for the fourth grazing season on the lowland area of the pivot were stocked according to the best performance data that had been obtained during the 2008 grazing periods during the same time of year and is summarised in **Table 6**. The stocking rates for the grazing cycle, were calculated taking into account the amount of grazing available before the grazing cycle commenced, in addition to the dry matter intake of the animals based on the three selected body weight percentages.

Table 6: Stocking rates of paddocks and average daily gain during the fourth grazing season starting 26 June 2010 and ending 16 August June 2010 (50 Days).

Paddock	**A1**	**B2**	**C2**
Large Stock Unit.ha^{-1}*	7.73	5.3	7.84
Average Daily Gain(kg.day^{-1})	0.200	0.300	0.060

* One Animal Unit is equivalent to a 450kg steer with a specific daily dry matter requirement.

The total available dry matter for the fourth grazing season on the lowland area was to be grazed, paddocks **A1**, **B2** and **C2**. The total available dry matter is illustrated in **Figure 27**. The same trend was noted, that when the centre pivot was working correctly and could irrigate the pastures, the pastures were able to grow and sustain production, but as soon as the soil dried out, the growth of the Tall Fescue, slowed and production of dry material also halted, and is clear from the results obtained in this cycle, and can be reflected in the animal weight gains initially, which then eventually stabilized. Not only will the production potential of the pastures cease or decline but the quality of the material as well resulting in lower animal performance.

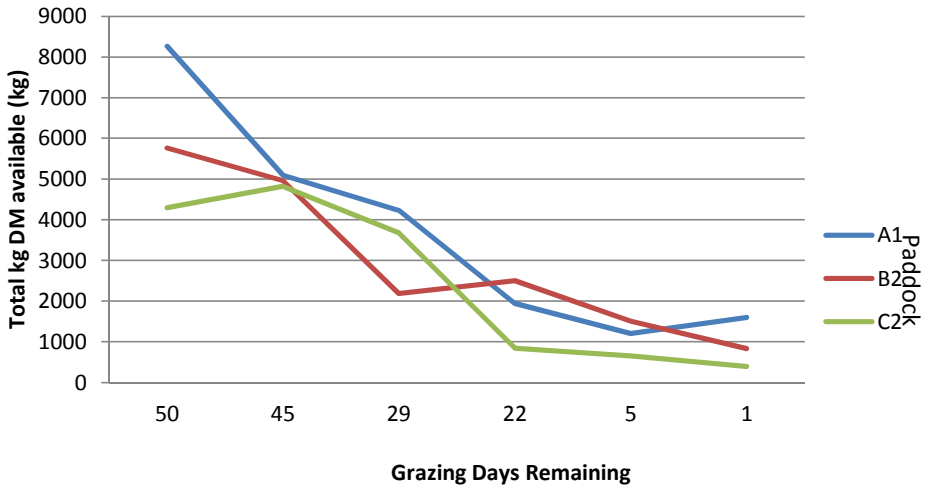

Figure 27: Total amount of dry matter available in each paddock vs. the amount of grazing days remaining for the fourth grazing period.

Figure 28 illustrates the average animal weight during the fourth grazing season which was much better than the third grazing season. The animals initially maintained their weight for the first 15 days of the grazing period, were after they started to gain weight rather well. This was expected since Tall Fescue was in its active growing season (Apr-September and animals were gaining weight in the winter as it would be required since this is the time water is in excess on the mines to irrigate pastures.

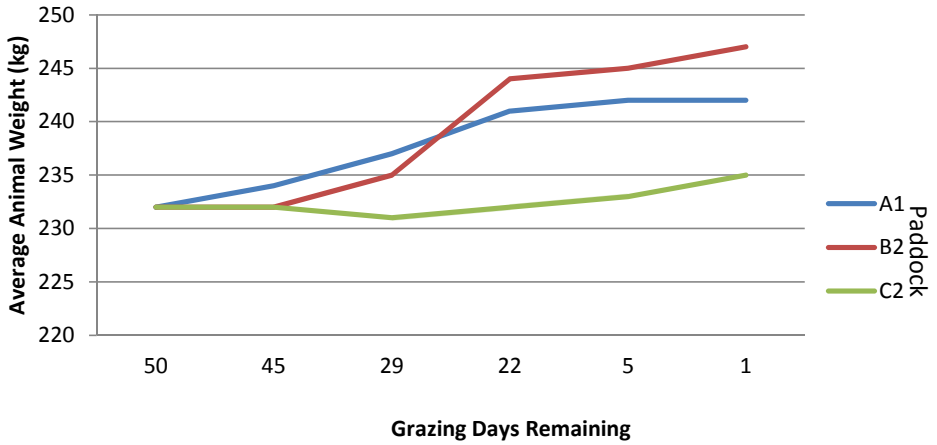

Figure 28: Average animal weight plotted against the grazing days remaining for the fourth grazing period.

The same tendency was found that when the centre pivot was able to irrigate the pastures, the pastures were able to grow and the cattle gained weight better than on stressed non-irrigated pastures.

2.1.4 Conclusion

It can be noted from the data, that grazing cycles commenced at different times of the year, and this was decided upon once the pasture availability was sufficient. During the first grazing cycle the highest ADG of 350g was achieved with the stocking rate of 5.03 AU.ha^{-1}. The second grazing cycle, however, recorded the highest ADG of 190g for a stocking rate of 5.89 AU.ha^{-1}. During the third grazing period the highest ADG of 130g was produced with the intermediate stocking rate of 5.58 AU.ha^{-1} and during the fourth grazing period the highest ADG of 300g was produced with the lowest stocking rate of 5.3 AU.ha^{-1}.

From the four grazing periods an ADG of 242g on average can be achieved with a stocking rate of 5.45 AU.ha^{-1} for Tall Fescue pastures on rehabilitated mine land irrigated with gypsiferous water throughout the year. However, one can be more specific and identify the best season to graze Tall Fescue pastures, which is during late winter and stock these pastures accordingly. The first and fourth season both commenced in mid-winter and ended towards the end of winter. Although the stocking rates for these two seasons were a bit lower than the average they both produced the best average daily gains from all the stocking rates tested. The outputs, in terms of average daily gain, are worth much more than the

price one has to pay to stock the planted pasture at a lower stocking rate than the average, thus creating a much more effective grazing system.

From the data obtained from the four grazing seasons, it is evident that the season in which the grazing season took place, played a significant role in the performance of the cattle in terms of production. Tall Fescue, being a temperate species, has two peak production periods, spring and autumn. The best ADG obtained was from the first grazing period during early autumn and the second best ADG in the fourth grazing period that took place during late spring. During these two grazing periods, the cattle were able to utilise the optimal amount of good quality forage that was available to sustain optimal performance.

Many data has been collected and was correlated to the aforementioned data, to get a better interpretation. Nevertheless, it is evident from the data that if conditions for production, not only plant production, but animal production too, are optimal one can achieve sustainable production figures on rehabilitated mine land irrigated with gypsiferous mine water.

Pasture production could potentially be much higher if the irrigation is managed more intensely and is functional more often. This will prevent pastures wilting and possibly developing anti-quality factors for livestock which will in turn allow the pasture to grow and sustain and optimise production of dry material, ensuring good livestock production.

We have seen a large improvement in the soil bulk density during the trial on the paddocks that have been grazed due to the effect of natural recycling of organic material and associated nutrients through cattle manure. Since organic matter deficient on these rehabilitated mine lands, resulting in quicker compaction, this type of system is certain to help alleviate compaction on these soils by natural incorporation of organic material. More information is available in the Compaction Alleviation Report Task 8.2.4.

2.2 Experimental study 2 - *Dry matter (DM) intake of cattle on pasture irrigated with gypsiferous mine water and its influence on animal production on rehabilitated mine land.*

2.2.1 Introduction

The aim of this study was to quantify pasture quality and animal production through DM intake of cattle as effected by different levels of nitrogen fertilization (comparing paddock A and B) or when different stocking rates are applied (comparing paddock B and C).

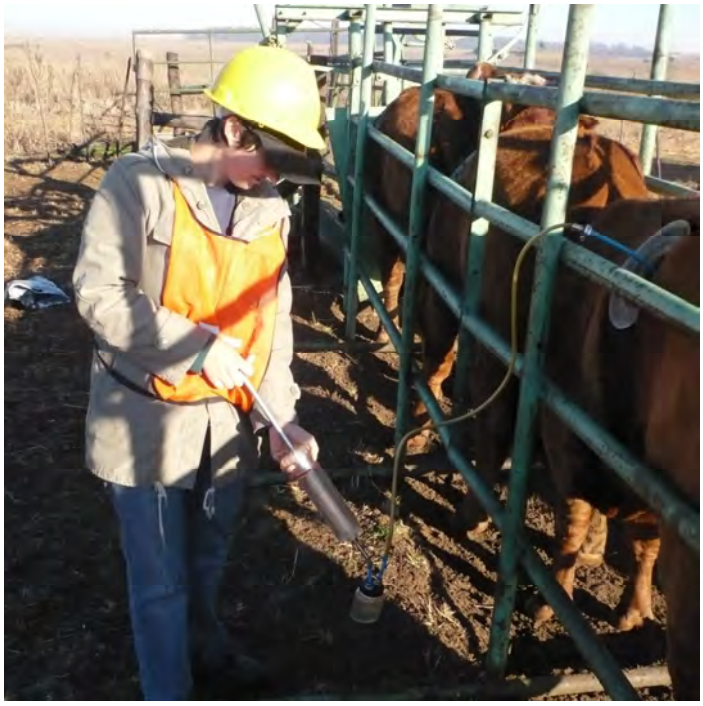

Figure 29: Rumen samples being taken from one of the canulated Beefmaster steers to determine various digestibility parameters of the pastures.

Pasture quality and intake are influenced by animal characteristics, pasture characteristics and the environment. Management of stocking and N fertilization influence animal production through its effect on pasture quality and intake. The hypothesis is that a higher rate of N fertilization or lower stocking rate will result in a higher level of animal production through its effect on pasture quality and availability respectively.

2.2.1.1 Factors influencing pasture quality

2.2.1.1.1 Species and temperature

Tropical (warm-season) grasses exhibit the C_4 photosynthetic pathway and are found growing in warm climates compared to temperate (cool-season) grasses exhibiting the C_3 photosynthetic pathway (Buxton & Fales, 1994). Nutritional differences between tropical and temperate grasses are a result of the temperature in which they normally grow and of the differences in anatomical structure associated with the different photosynthetic pathways.

Plants grow and mature less rapidly in temperate areas with a reasonably uniform distribution of rainfall compared to those in warmer climates. Protein and phosphorous

content decline and fibre content rise at a slower rate in temperate climates. These plants can thus be utilized at an earlier age of growth when nutritive value is high. Herbage available in the tropics (commonly fibrous and high in moisture content in the wet areas with desiccated herbage as standing hay in drier areas) typically have a digestibility value of 0.1-0.15 units lower than temperate herbage (McDonald *et al.,* 2002). Temperate and tropical forages also respond differently to high temperatures. When compared at the same high temperatures warm-season grasses have a higher level of structural components and thus a lower digestibility (Buxton & Fales, 1994).

Characteristics of the C_4 plant metabolism results in lower protein content (associated with survival at low soil fertility) and storage of carbohydrates as starch, rather than fructans. Leaf anatomy of sub-tropical grasses differ in that vascular bundles and thick-walled bundle sheaths are more (hence more lignin) and that mesophyll cells are more densely packed in the central tissue. The smaller amount of intercellular air spaces in sub-tropical grasses might partly explain the higher tensile strength (resistance to particle breakdown) and consequently lower digestibility (McDonald *et al*., 2002).

Compared to legumes, grasses normally have a higher cell wall concentration and more rapidly accumulate lignin, resulting in a more rapid decline in digestibility with maturity (Buxton & Fales, 1994). Pasture legumes also contain higher concentrations of protein and minerals than grasses (McDonald *et al.,* 2002). Further literature will focus on temperate grass pastures.

2.2.1.1.2 Cultivar

A study by Asay *et al.* (2002) comparing forage quality of 10 Tall Fescue cultivars over an irrigation gradient showed significant differences for CP, NDF and true in vitro true digestibility between cultivars. These differences tended to be consistent across water levels.

2.2.1.1.3 Stage of growth (maturity) and plant parts

At an immature stage DMD (dry matter digestibility) is similarly high, but large differences occur between the different fractions at maturity. Grazing animals tend to select the upper more digestible plant parts. Leaves have a higher calcium (Ca) and CP concentration than stems, however phosphorous (P) concentration do not differ consistently between these two plant parts (Minson, 1990).

Young leafy plants are high in moisture content, as the plant matures the moisture content decreases (McDonald *et al.,* 2002). When considering DMD, plant growth can be separated into three phases: the digestibility plateau, the phase of rapid decrease in digestibility and the phase where digestibility of the mature forage is relatively constant (Minson, 1990). A reduction in digestibility as the plant matures is associated with an increase in fibre content of the whole plant (Kilcher, 1981; Cherney *et al.,* 1993; Burns *et al*., 2006). This is a result of a reduction in leaf: stem ratio and an increase in indigestible fibre in the stem (Nordheim-Viken *et al.,* 2009). Crude protein content and most minerals including Ca and P decline as the plant ages (Murray, 1984; McDonald *et al.,* 2002).

In the study by Callow *et al*. (2003) plant development had a considerable influence on forage quality of pure Tall Fescue strands (nitrogen fertilized and under irrigation). The IVDMD declined either linearly or exponentially as the plant tissue matured. A significant ($P<0.05$) negative linear relationship between CP content and weeks post-defoliation was found for spring growth. During the other three seasons CP content and weeks post-defoliation showed a quadratic relationship, with little change for the first four weeks before a rapid decline in week 6 and 8.

2.2.1.1.4 Nitrogen fertilization

Poor nitrogen (N) fertilization results in lower CP concentration in pastures (Eck *et al.,* 1981; Peyraud & Astigarraga, 1998; Hedtcke *et al.,* 2002; Wolf & Opitz von Boverfeld, 2003; Burns, 2009. Digestibility and NDF can either be unaffected or (Peyraud & Astigarraga, 1998; Hedtcke *et al.,* 2002) N fertilization can increase DMD and decreased NDF respectively (Burns, 2009).

2.2.1.1.5 Frost

Sakai and Larcher (1987) defined frost as “a condition in which temperatures fall below 0°C”. Freezing of water inside the plant occurs at temperatures lower than 0°C. The level to which the temperature sinks during frost, the duration and time of onset, whether it is confined to the area surrounding the shoot or if it also penetrates the ground is of great significance to the plant (Sakai & Larcher, 1987).

The threshold temperature (T_f), i.e. “the highest temperature at which freezing of living plant tissues occurs”, depends on plant and tissue properties. The freezing point is usually lower for cells lower in water content and higher in water-soluble carbohydrates (Sakai & Larcher, 1987).

Naturally frozen tissues rarely show ice formation within living cells. Ice crystals form in extracellular spaces, water diffuses out of the cells and as a result the cells shrink. When ice crystals melt in frost hardy plants the water diffuses back into the cells and they resume their metabolism. Damage to membranes and other cellular components during thawing may occur in non-acclimated plants. As a result water cannot re-enter the cells completely and metabolism cannot be resumed (Salisbury & Ross, 1992).

With partial frost injury, the plant is weakened and production and reproduction is reduced (at least temporarily); however repair is possible. In freezing tolerant cells, death occurs at temperatures corresponding to a specific threshold for dehydration tolerance. The most frequent and clearest indication of freezing injury is the discoloration of any plant part. This is the result of coloured reaction products (when the cell contents come in contact with each other and with oxygen) which adhere to the cell proteins and cell walls. During winter frost resistance increase as temperatures drops to sub-zero and decrease as it rises above zero. (Sakai & Larcher, 1987).

Sakai & Larcher (1987) arranged plants in the order of their potential frost resistance forming a series from freezing-sensitive to freezing tolerant plants, with Tall Fescue falling between these two groups.

When leaf or stem death occur, from senescence or frost, soluble material is translocated or metabolised and primarily structural material remain resulting in lower digestibility (Beaty & Engel, 1980).

2.2.1.1.6 Water application

Quality trends over an irrigation gradient of 10 Tall Fescue cultivars were studied by Asay *et al.* 2002. They found a near linear increase in CP content with decreasing levels of irrigation applied; however, total protein yield decreased with a trend closely following that of forage yield. . No consistent trends were detected for NDF and *in vitro* true digestibility across water levels. At the late-season harvest at the drier water levels NDF values tended to be lower and *in vitro* true digestibility higher.

Similar results were seen in the study by Eck *et al.* (1981) where the total nitrogen was higher and calcium lower in forage receiving the lower level of irrigation, while the IVDMD and phosphorous level was unaffected. Generally a higher level of irrigation depresses the CP content.

2.2.1.1.7 Soil compaction

Soil compaction usually reduce plant uptake of nutrients including N, P and Ca. Lower accessibility of plants to nitrogen and greater denitrification in compacted soils results in greater losses of nitrogen compared to non-compacted soils (Lipiec & Stępniewski, 1995).

2.2.1.1.8 Stocking rate (Grazing intensity)

The high stocking rate in the study of Jung and Sahlu (1989) was too low to suppress physiological maturation and was associated with lower forage quality at later periods compared to low stocking. The lower forage quality (lower CP and in vitro DM digestibility, higher NDF) was attributed to a higher rate of removal of high-quality forage during periods of slow forage regrowth.

Vavra *et al.* 1973 found no significant difference in CP content, DM digestibility and dietary energy value due to grazing intensity. They indicated that this might be due to sufficient regrowth in the heavily utilized pasture to keep forage quality at a similar level as the light utilized pasture.

Higher stocking rates tend to result in higher quality pasture by keeping the pasture at a younger stage of regrowth.

2.2.1.2 Intake control

Forage intake in ruminants is thought to be controlled through the complex integration of signals from various receptors to the central nervous system (CNS). Information is transmitted to the CNS via several routes from receptors in various parts of the digestive tract and associated organs, which are sensitive to several physical and chemical stimuli. It is integrated with information from special senses and memory into the food intake-controlling system. The evidence supporting this theory of additivity has been reviewed elsewhere (Allen, 1996; Forbes, 1996).

Physical distension in the gastrointestinal tract limits intake of diets with low digestibility (Allen, 1996). Conrad *et al.* (1964) suggested intake is limited by gut fill up to a breakpoint in digestibility beyond which the relationship between intake and digestibility become negative and controlled by energy requirements. Allen (1996) stated that this is “likely a convenient mathematical simplification” and that as digestibility increases the effect of fill and intake gradually diminishes.

Pasture quality and intake are highly correlated. Feed that is more digestible results in higher intakes and fibrous feed with a high intake have a lower digestibility of the fibrous fraction.

2.2.1.3 Factors affecting intake

Intake by ruminants is affected by animal and management controlled factors. The major animal-related factors affecting level of voluntary intake appear to be body size and physiological stage of ruminants. The major management-controlled variables affecting intake of these animals are kind and amount of supplementation, forage availability and grazing intensity (Allison, 1985).

Pasture intake is a function of time spent grazing and intake rate, which in turn is a function of bite mass and bite rate. (Allden & Whittaker, 1970).

2.2.1.3.1 Animal size and physiological stage

Romney and Gill (2000) stated that across animal species, size is the factor most closely correlated with intake.

The fasting metabolism (and thus energy requirements) of larger animals are higher than that of smaller animals, but per unit of live weight, it is greater for small animals. Fasting metabolism (and therefore intake) is more proportional to the metabolic live weight ($LW^{0.75}$) of animals than to their weight (McDonald *et al*., 2002).

Higher intakes per unit body weight have been observed for younger compared to older animals (Hunter & Siebert, 1986) and lactating or pregnant versus dry animals (Hunter & Siebert, 1986; Vanzant *et al.,* 1991)

2.2.1.3.2 Species and cultivar

Higher intakes usually associated with legumes compared to grasses are due to a lower resistance to breakdown. Temperate forages are generally consumed in greater quantities compared to tropical due to lower fibre levels and higher digestibility (Minson, 1990). Minson (1990) stated that in studies where intake differences occurred between temperate species harvested at the same date in spring, data was difficult to interpret due to differences in stage of maturity.

2.2.1.3.3 Stage of growth (maturity) and plant parts

With increasing maturity there is generally an increase in fibre content and a reduction in DMD, leaf: stem ratio, CP and most minerals. The changes in maturity are accompanied by a reduction in intake. Minson (1990) identified three causes for this reduction in intake: the higher proportion of stem, lower intakes of both leaf and stem, and nutritional deficiencies.

Higher intake of leaf compared to stem in legumes and grasses seems to be due to its shorter retention time in the rumen and not due to differences in digestibility as such. This shorter retention time might be due to higher rate of digestion of NDF, higher passage of NDF from the rumen and higher potential digestibility of the leaf. (Allison, 1985)

2.2.1.3.4 Nitrogen fertilization

Nitrogen fertilization does not seem to have a consistent effect on intake (Minson, 1990), although when forage of the same age were used DM intake is usually unaffected by nitrogen fertilization (Peyraud & Astigarraga, 1998).

2.2.1.3.5 Water content

Kenney *et al.* (1984) showed that with increasing internal water of fresh herbage intake increased and DM intake was reduced up to the DM content of 40% (60% water) after which it remained relatively constant.

External water (or surface water) was shown to result in a reduction in DM intake (Butris & Phillips, 1987; Phillips *et al.*, 1991) with no effect on intake (Butris & Phillips, 1987). Recent studies (Cabrera Estrada et al., 2003, 2004) found that external water did not affect intake. Cabrera Estrada *et al*. (2004) concluded that only internal and not external plant water limited DM intake.

2.2.1.3.6 Climate

Mammals (including cattle and sheep) need to maintain a thermal balance. The rate of heat loss is influenced by the animal's environment (temperature, relative humidity, air velocity and solar radiation) as well as its insulation. The thermal neutral zone refers to the temperature between the points where the animal needs to increase or reduce its heat production in order to maintain a thermal balance (McDonald *et al.,* 2002).

Temperatures above the thermal neutral zone are usually associated with lower intakes and temperatures below this zone normally result in higher intakes (Weston, 1982;

McDonald *et al.,* 2002), provided severe cold stress does not occur (Weston, 1982). Lower intakes are also associated with high solar radiation and relative humidity (Weston, 1982).

2.2.1.3.7 Animal health

Reduced intakes are usually associated with infectious, metabolic and parasitic diseases (Weston, 1982).

2.2.1.3.8 Sward structure

Allden and Whittaker (1970), found a sevenfold increase in herbage intake rate by sheep grazing pastures of 7.7 cm tiller length compared to 3.7 cm. At greater tiller lengths intake rate remained constant. This was associated with an almost linear increase in bite size, while the rate of biting decreased after a small initial increase.

In the study by Chacon and Stobbs (1976) showed that later stages of progressive defoliation was associated with reduced grazing time, bite mass and bite size in cattle. They concluded that intake was restricted by the low leaf density.

Barre *et al.* (2006) found significantly lower intakes at shorter leaf blade length, but failed to find significant differences in fresh matter intake with significant differences in tiller density. Shorter herbage height and lower density usually results in lower intakes.

2.2.1.3.9 Supplementation

When abundant forage is available overall DM intake tends to increase with supplementation, although intake of the basal herbage may be either increased or decreased (Minson, 1990; Romney & Gill, 2000).

When the supplement supplies a limiting nutrient (e.g. protein or phosphorous), intake of poor quality feed may be increased (Minson, 1990; Moore *et al*., 1999; Romney & Gill, 2000; Coleman & Moore, 2003).

2.2.1.3.10 Stocking rate (Grazing intensity)

Higher stocking rates (or lower herbage allowance) tend to result in lower intakes. Low pasture availability reduces the opportunity for selective grazing and decreasing the quality of ingested material (Bryant et al., 1970)

2.2.2 Methodology (*1st Season)*

This study focussed on estimating dry matter intake of cattle using alkanes. Primarily odd-chain alkanes are present in the wax layer of all higher plants. Alkane concentration in herbage can be influenced by sampling date and plant part samples (Zhang *et al*., 2004). Dove and Mayes (2006) summarised the methods for the administration of even-chain alkanes. This includes paper pellet, gelatine capsule, paper bung, paper filter, alkane-labelled feed, alkane suspension, alkane emulsuion and intra-ruminal alkane controlled-release device (CRD). Errors associated with daily dosing of alkanes, due to diurnal variation, and the need for daily dosing can be avoided with the use of controlled-release devices (CRD). These CRD is dosed to animals and release C_{32} and C_{36} at a predictable rate for 20 days after insertion (Dove & Mayes, 2006). The recommended sampling period is between days 8 and 16 when a constant release rate and steady state exists (Argenta). Voluntary intake of grazing animals can be estimated by the concurrent use of dosed and herbage alkanes. This method can be relatively accurate provided that the alkane pair used have similar faecal recovery rates (Berry *et al.,* 2000, Dove & Mayes 2006) and the release rate of the controlled release device used were determined for the trial situation (De Oliveira *et al*., 2008; Ferreira *et al*., 2004). The use of alkane pair C_{32} and C_{33} give relatively accurate estimates of intake due to their similar faecal recoveries (Dove & Mayes 2006). Decruyenaere *et al.* (2009) reviewed methods to quantify intake and concluded that currently the n-alkane technique appears to be one of the best ways to predict digestibility and intake at the same time.

The study was conducted on the Tweefontein Pivot on the Kleinkopje Colliery. In June 2007 Dovey Tall Fescue was established. The pasture was divided into 7 paddocks, paddock A-F and a centre paddock (Figure 8). The pasture was fertilized in June 2007 with 110kg $P.ha^{-1}$ and 150kg $N.ha^{-1}$ (paddock A received double the amount of N) and again in March 2008 with 150kg $N.ha^{-1}$. Data were collected during two respective periods (seasons): 6 June to 16 July 2008 (season 1) and 6 August to 28 November 2008 (season 2).

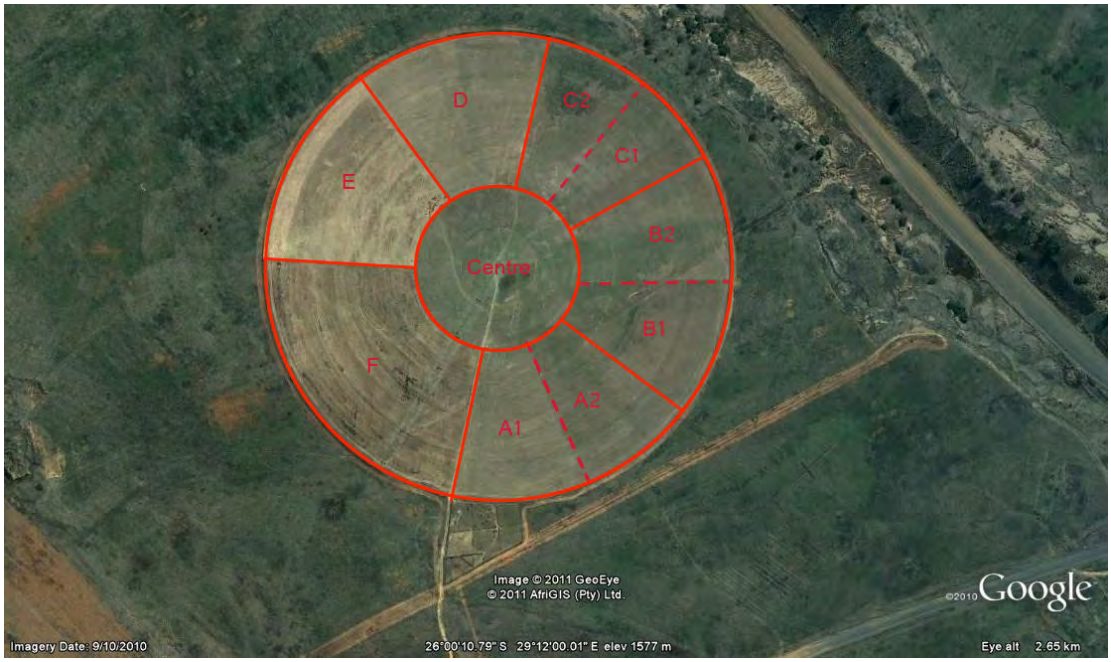

Figure 30: The Tweefontein pivot divided into different size paddocks.

During season 1 paddock A, B and C (3.2, 3.3 and 2.5 ha in size) was grazed from 6 June to 16 July 2008 (a period of six weeks), while paddock D, E and F had been rested. The pasture was irrigated with approximately 10mm per week and no rain occurred during this period. The minimum and maximum temperatures were -4.5°C and 23.2°C respectively. The first frost for the season occurred during the morning of the 26th of June.

Grass was cut at different cutting frequencies; every 2 , 4 , 6 weeks and when 10% of grass had developed an inflorescence (10% blooming stage). Sampling started in September 2008 and continued up to August 2009

2.2.2.1 Animals and experimental design

Pasture availability was estimated using an Ellinbank Rising Plate Meter. Fixed stocking rates were applied (Wheeler et al., 1973) for each paddock over the observation period, to achieve the sought after grazing pressure. The terms stocking rate and grazing pressure refers to the number of animals per unit of area and the number of animals per unit of available forage respectively (Wheeler et al., 1973). To achieve a sought after grazing pressure a certain stocking rate is to be applied. Following a week of adaptation in the centre paddock, four canulated Beefmaster steers, with an average weight of 610 kg, and 141 cross bred calves with an average weight of 146 kg were randomly divided between paddocks A-C to achieve the sought after grazing pressure.

Paddock A that received a higher level of N fertilization in June 2007, had a pasture availability of 4036.8 kg dry matter (DM).ha^{-1} at the start of season 1. It was stocked with two of the Beefmaster steers and 46 randomly selected crossbred calves to achieve a pasture allowance of 3% body weight (BW). A pasture availability of 3596.4 kg DM.ha^{-1} was measured in paddock B and was stocked with one Beefmaster steer and 45 randomly selected cross bred calves to achieve a similar pasture allowance as in paddock A (3% BW). The same level of fertilization was applied to paddock B and C. Paddock C had a pasture availability of 3490.0 DM.ha^{-1} at the start of season 1 and was stocked with one Beefmaster steer and 50 crossbred calves to achieve a pasture allowance of 2% BW. Stocking rate was calculated for a period of 60 days, although the trial was terminated two weeks early due to very low pasture availability and persistent animal weight loss.

Clipped samples of the pasture were taken on a weekly basis from 24 quadrants in each paddock in a random stratified manner. Quadrants were 50 x 100 cm in size and all the herbage in the quadrant were clipped 5 cm from the soil surface. Four representative pasture samples were obtained by mixing six random pasture samples. During the fourth collection period, paddocks were sampled over three consecutive days. Paddock A, B and C was sampled on 25, 27 and 26 June respectively.

2.2.2.2 Management and parameters measured

The cattle were kept on the pasture and clean drinking water as well as a salt phosphate lick (50 kg rumenvite 12P: 50 kg salt) was supplied *ad libitum* for the duration of the study. Animals were weighed every week after an overnight fasting period. Pasture samples were sub-sampled to determine leaf: stem ratio while the rest were dried at 60°C for 2 days and used for chemical analysis. Dried pasture samples were milled to pass through a 1mm screen for chemical analysis.

2.2.2.3 Leaf: stem ratio

Leaf and stem material separated and dried at 60 °C for 2 days. Each component was weighed and the dry matter was determined to calculate leaf: stem ratio. Leaf: stem ratio was calculated as follows:

$$\text{Leaf \%} = \frac{\text{Dry leaf weight}}{\text{Dry leaf weight + dry stem weight}} \times 100$$

Equation 1: Equation to calculate leaf %.

$$\text{Stem \%} = \frac{\text{Dry stem weight}}{\text{Dry leaf weight + dry stem weight}} \times 100$$

Equation 2: Equation to calculate stem %.

2.2.2.4 Chemical analysis of clipped samples

Pasture samples were analysed at Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria. Analysis was done to determine: dry matter (DM) (934.01 AOAC, 2000), neutral detergent fibre (NDF) (Robertson & Van Soest, 1981) on a Tecator Fibrotec System, in vitro organic matter digestibility (IVOMD) (Tilley & Terry, 1963) using a shaking water bath, calcium (Ca) (Giron, 1973) using a Perken-Elmer 5100 Atomic Absorption Spectrometer and phosphorous (P) (965.17 AOAC, 2000) content using a Specol 1300 Spectrophotometer.

In order to determine the crude protein (CP) concentration (968.06 AOAC, 2000) the nitrogen concentration was determined using a LECO System model (CHN-1000), a block digester was used for sample digestion and a Tecator Kjeltec System Model for distillation. The crude protein concentration was calculated as follows:

$$\%CP = \%N \times 6.25.$$

Equation 3: Equation to calculate % crude protein.

2.2.3 Results and discussion *(1st Season)*

2.2.3.1 Dry matter content

Dry matter (DM) content, of pasture samples collected weekly from 6 June to 16 July 2008, is shown in Table 7. At the start of the season the DM content in paddock B was significantly ($P < 0.05$) higher compared to Paddocks A and C, which did not differ significantly ($P < 0.05$) from each other. Paddock A consistently had a significantly ($P < 0.05$) lower DM content compared to paddock B.

Table 7: Pasture dry matter content ($g.kg^{-1}$)

	Paddock						Total	
	A		B		C		mean	SEM
06-Jun	$359.3^{b}{}_{4}$	(±13.5)	$438.0^{a}{}_{4}$	(±13.9)	$363.3^{b}{}_{3}$	(±10.9)	386.9_{5}	6.4
13-Jun	$374.3^{b}{}_{34}$	(±9.2)	$444.5^{a}{}_{4}$	(±5.3)	$359.9^{c}{}_{3}$	(±10.9)	392.9_{5}	4.4
19-Jun	$396.4^{b}{}_{23}$	(±19.4)	$447.4^{a}{}_{4}$	(±26.1)	$357.2^{c}{}_{3}$	(±14.4)	400.3_{5}	10.3
25 - 27 Jun	$392.6^{b}{}_{241}$	(±28.8)	$491.8^{a}{}_{33}$	(±32.7)	$430.4^{b}{}_{22}$	(±7.5)	438.3_{4}	12.8
02-Jul	$416.0^{b}{}_{2}$	(±47.0)	$511.0^{a}{}_{23}$	(±39.5)	$457.3^{b}{}_{2}$	(±37.0)	461.4_{3}	20.7
09-Jul	$463.3^{c}{}_{1}$	(±29.1)	$528.8^{b}{}_{2}$	(±34.9)	$581.1^{a}{}_{1}$	(±14.5)	524.4_{2}	13.8
16-Jul	$473.4^{c}{}_{1}$	(±8.9)	$567.5^{b}{}_{1}$	(±11.1)	$597.0^{a}{}_{1}$	(±19.6)	546.0_{1}	7.0

abcRow means that do not have a common superscript differ ($P < 0.05$)

123 Column means that do not have a common subscript differ ($P < 0.05$)

1 Paddock A samples collected 25 June

2 Paddock C samples collected 26 June

3 Paddock B samples collected 27 June

Within paddock A the DM content showed a slow increasing trend, with significant ($P < 0.05$) changes from one week to the next only detected between 2 and 16 July. No significant ($P < 0.05$) change in DM content was found within paddock B and C during the first three sampling dates. Within paddock B a significant ($P < 0.05$) weekly increase was only detected during two periods: 19 and 27 June as well as 9 and 16 July.

Paddock A (high initial N, low stocking) consistently had a significantly ($P < 0.05$) lower DM content compared to paddock B (low initial N, low stocking). Changes in DM content in paddocks A and B followed the same increasing pattern. Paddock C (low initial N, high stocking) showed more drastic increases in dry matter content. As a result DM content in paddock C was significantly ($P < 0.05$) lower at the first five sampling periods and significantly ($P < 0.05$) higher at the last two sampling periods, compared to paddock B.

The total mean DM content for the pasture as a whole did not differ significantly ($P < 0.05$) between the first three sampling periods. From the third sampling onwards a significant weekly increase in DM content occurred ($P < 0.05$). The mean DM content within paddock B (high initial N, low stocking) was significantly ($P < 0.05$) higher compared to either paddock A (low initial N, low stocking) or B (low initial N, high stocking).

Throughout the sampling season CP values in paddock B (low initial N, low stocking) were significantly ($P < 0.05$) lower compared to paddocks A (high initial N, low stocking) and

C (low initial N, high stocking). However the change in CP content was smaller in paddock B compared to either paddock A or C.

The total mean CP content showed a decreasing trend with significant ($P < 0.05$) differences between samples taken two weeks apart. The mean CP content within paddock B was significantly ($P < 0.05$) lower compared to paddock A and C, respectively.

Changes in DM content in paddocks A and B followed the same increasing pattern. Paddock C showed more drastic increases in dry matter content (Figure 31). As a result DM content in paddock C was significantly ($P < 0.05$) lower at the first five sampling periods and significantly ($P < 0.05$) higher at the last two sampling periods, compared to paddock C.

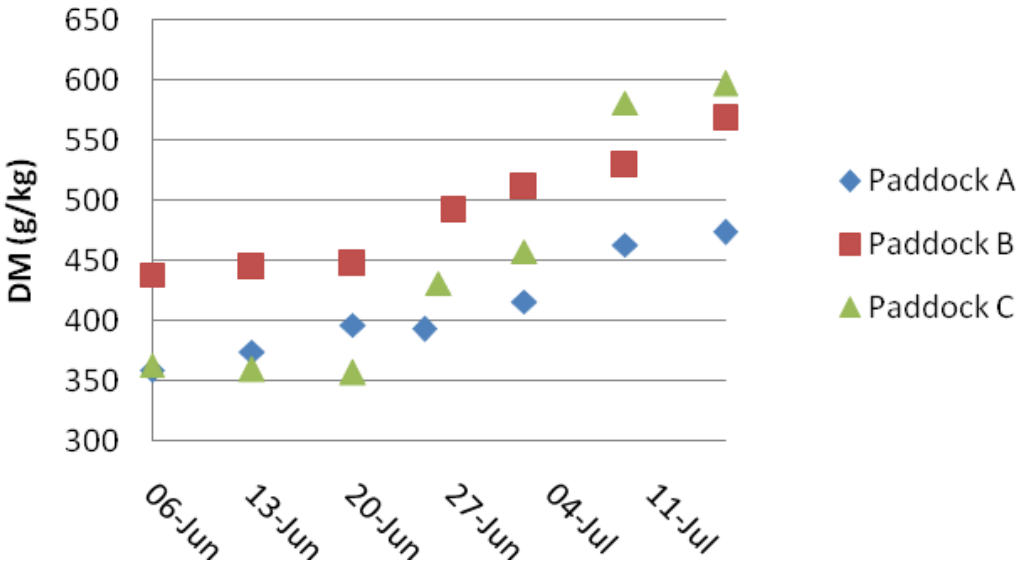

Figure 31: Trends in dry matter content during season 1.

2.2.3.2 Crude protein content

Significant ($P < 0.05$) differences in crude protein (CP) content between paddocks were found at the first sampling date (Table 8), with the highest values in paddock A (high initial N), the lowest values in paddock B (low initial N) and intermediate values in paddock C (low initial N).

Within all the paddocks the CP content was significantly ($P < 0.05$) higher at the first sampling date compared to the last sampling date. A general decreasing trend in CP content was found within each paddock. Compared to the first sampling (6 Jun), CP was significantly ($P < 0.05$) lower a week later (13 Jun) in paddock A. Between 13 June to 9 July, no significant ($P < 0.05$) weekly changes were detected in paddock A, however when comparing samples

taken two weeks apart a significant ($P < 0.05$) reduction is detected. The same trend was detected within paddock C during this period (13 June to 6 July), although the initial reduction in CP content during the first week was not significant ($P < 0.05$). The initial significant ($P < 0.05$) reduction in CP content within paddock B was followed by a plateau, with no significant differences between samples collected either one or two weeks apart. A slight increase in CP content was found during the last week in paddocks A and C, with significant ($P < 0.05$) differences only occurring in paddock A.

Table 8: Pasture crude protein content ($g.kg^{-1}$ DM) during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
06-Jun	$124.0^{a}{}_{1}$	(±5.9)	$75.4^{c}{}_{1}$	(±3.8)	$116.1^{b}{}_{1}$	(±0.9)	105.1_{1}	2.1
13-Jun	$111.6^{a}{}_{2}$	(±16.0)	$61.0^{b}{}_{23}$	(±3.3)	$110.1^{a}{}_{12}$	(±3.1)	94.2_{2}	4.8
20-Jun	$102.1^{a}{}_{23}$	(±6.1)	$69.0^{b}{}_{12}$	(±11.3)	$101.3^{a}{}_{2}$	(±11.2)	90.8_{2}	4.9
25-27 Jun[1]	$95.0^{a}{}_{34}$	(±19.2)	$61.0^{b}{}_{23}$	(±5.0)	$80.0^{a}{}_{3}$	(±3.8)	78.7_{3}	5.8
02-Jul	$87.3^{a}{}_{45}$	(±12.3)	$55.5^{b}{}_{3}$	(±0.9)	$79.5^{a}{}_{3}$	(±4.4)	74.1_{3}	3.8
09-Jul	$78.7^{a}{}_{5}$	(±3.3)	$55.1^{c}{}_{3}$	(±6.5)	$67.9^{b}{}_{4}$	(±4.9)	67.2_{4}	2.5
16-Jul	$87.3^{a}{}_{4}$	(±9.0)	$56.5^{c}{}_{3}$	(±2.3)	$77.0^{b}{}_{34}$	(±3.7)	73.6_{34}	2.9
Mean	98.0^{a}	(±18.0)	61.9^{c}	(±8.8)	90.3^{b}	(±18.2)	83.4	1.5

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

2.2.3.3 Neutral detergent fiber content

Pasture samples collected at the beginning of the trial, were significantly ($P < 0.05$) higher in NDF content for paddock B (low initial N) compared to paddock A (high initial N) and C (low initial N) (Table 9).

Generally the NDF content decreased from the start of the trial up to 2 July and then increased towards the end. Within paddocks A and B, no significant ($P < 0.05$) differences were found between the beginning and end NDF values. However these values were significantly ($P < 0.05$) higher compared to 2 July. End NDF values were significantly ($P <$

0.05) higher than starting values within paddock C, with no significant (P < 0.05) differences during the period from 13 June to 9 July.

Table 9: Pasture neutral detergent fibre content (g.kg^{-1} DM) during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
06-Jun	$618.3^{b}{}_{1}$	(±7.1)	$647.8^{a}{}_{1}$	(±12.1)	$605.4^{b}{}_{2}$	(±10.8)	623.8_{1}	5.1
13-Jun	$611.7^{b}{}_{1}$	(±11.6)	$622.2^{a}{}_{2}$	(±21.0)	$580.3^{b}{}_{3}$	(±27.6)	604.7_{2}	10.6
20-Jun	$608.3^{a}{}_{1}$	(±17.2)	$628.6^{a}{}_{12}$	(±23.4)	$575.5^{b}{}_{3}$	(±15.4)	604.1_{2}	9.5
25-27 Jun[1]	$584.7^{b}{}_{2}$	(±17.6)	$626.3^{a}{}_{12}$	(±20.2)	$566.8^{b}{}_{3}$	(±14.3)	592.6_{2}	8.8
02-Jul	$549.7^{b}{}_{3}$	(±12.7)	$590.9^{a}{}_{3}$	(±8.3)	$562.7^{b}{}_{3}$	(±12.1)	567.8_{3}	5.6
09-Jul	$586.0^{a}{}_{2}$	(±23.7)	$605.1^{a}{}_{23}$	(±6.0)	$586.4^{a}{}_{23}$	(±9.8)	592.5_{2}	7.6
16-Jul	$595.9^{b}{}_{12}$	(±34.0)	$648.3^{a}{}_{1}$	(±11.9)	$638.7^{ab}{}_{1}$	(±16.2)	627.6_{1}	11.4
Mean	593.5^{b}	(±27.8)	624.1^{a}	(±24.3)	588.0^{b}	(±28.7)	601.9	3.3

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

At the beginning of the trial NDF content in paddock B (low initial N, low stocking) was significantly (P < 0.05) higher compared to paddocks A and C, which did not differ significantly from each other. Higher NDF values were found in paddock B than in paddock A throughout the sampling season, with significant (P < 0.05) differences at every sampling date except 20 June and 16 July. In paddock C, significantly (P < 0.05) lower NDF values compared to paddock B were found at the first five sampling dates with no significant (P < 0.05) difference at the last two sampling dates.

The total mean NDF content was the highest at the start and end of the season, with significantly (P < 0.05) lower values detected for the other dates. The total mean NDF as well as NDF within each paddock showed a decreasing trend up to 2 July and increased from there onwards. The lowest NDF values within each paddock were recorded at 2 July. The mean NDF content over the sampling season was significantly higher in paddock B compared to paddocks A and C, which did not differ significantly from each other.

2.2.3.4 In vitro organic matter digestibility

Unlike the NDF content, no significant ($P < 0.05$) differences for *in vitro* organic matter digestibility (IVOMD) was detected between paddocks at the start of the trial (Table 10). This is in part due to the large variation found within paddock B at this time.

Within each paddock, IVOMD at the start and end of the trial did not differ significantly ($P < 0.05$). The initial decrease in digestibility is probably due to removal of less digestible material and the increase in digestibility is probably a result of the increase in maturity of the pasture. The trend in IVOMD within each paddock was the opposite of that observed for NDF.

Table 10: In vitro organic matter digestibility IVOMD ($g.kg^{-1}$ OM) during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
06-Jun	$615.2^{a}{}_{4}$	(±1.6)	$592.3^{a}{}_{23}$	(±43.44)	$608.5^{a}{}_{3}$	(±12.3)	605.3_{3}	13.0
13-Jun	$630.8^{a}{}_{34}$	(±34.3)	$633.5^{a}{}_{1}$	(±19.20)	$669.1^{a}{}_{1}$	(±18.7)	644.5_{2}	12.6
20-Jun	$666.8^{ab}{}_{12}$	(±37.8)	$623.9^{b}{}_{12}$	(±23.07)	$669.0^{a}{}_{1}$	(±15.7)	653.3_{21}	13.6
25-27 Jun[1]	$699.5^{a}{}_{1}$	(±14.3)	$641.6^{b}{}_{1}$	(±19.95)	$665.4^{b}{}_{1}$	(±12.7)	668.9_{1}	8.0
02-Jul	$699.5^{a}{}_{1}$	(±45.1)	$630.2^{b}{}_{1}$	(±22.00)	$649.3^{ab}{}_{12}$	(±29.0)	659.7_{2}	16.7
09-Jul	**$661.2^{a}{}_{23}$**	**(±20.1)**	**$620.2^{b}{}_{13}$**	**(±16.61)**	**$653.3^{a}{}_{12}$**	**(±6.4)**	**644.9_{2}**	**7.8**
16-Jul	**$643.8^{a}{}_{24}$**	**(±22.1)**	**$588.9^{b}{}_{3}$**	**(±12.75)**	**$623.4^{a}{}_{32}$**	**(±22.2)**	**618.7_{3}**	**9.8**
Mean	**659.5^{a}**	**(±39.7)**	**618.7^{b}**	**(±28.7)**	**648.3^{a}**	**(±27.5)**	**642.2**	**4.5**

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

Pasture samples in paddock B were significantly ($P < 0.05$) lower in IVOMD compared paddock A during the last four sampling dates and paddock C during the last two sampling dates. The mean IVOMD values showed the opposite trend than that of the NDF content, with significantly ($P < 0.05$) lower mean IVOMD for paddock B compared to paddocks A and C.

2.2.3.5 Leaf: stem ratio

At the beginning of the trial the leaf: stem ratio in paddock A (high initial N) did not differ significantly from ($P < 0.05$) either paddock B (low initial N) or C (low initial N) (Table 11). Within paddocks A (high initial N, low stocking) and B (low initial N, low stocking) the leaf: stem ratio was significantly ($P < 0.05$) lower the end of the trial period compared to the beginning. Little variation in leaf: stem ratio occurred in paddock C with significantly ($P < 0.05$) lower values only at 26 June and 2 July compared to the beginning of the trial. The mean leaf: stem ratio within paddock B (low initial N, low stocking) was significantly ($P < 0.05$) lower compared to paddock A and significantly ($P < 0.05$) higher compared to paddock C.

Table 11: Leaf: stem ratio during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
06-Jun	$91:9^{ab}{}_{1}$	(±2.8)	$94:6^{a}{}_{1}$	(±1.9)	$91:9^{b}{}_{1}$	(±1.9)	$91:9_{1}$	1.1
13-Jun	$85:15^{a}{}_{2}$	(±1.0)	$88:12^{ab}{}_{2}$	(±2.7)	$89:11^{b}{}_{12}$	(±2.2)	$85:15_{2}$	1.0
20-Jun	$84:16^{a}{}_{2}$	(±1.7)	$88:12^{b}{}_{2}$	(±1.8)	$88:12^{b}{}_{13}$	(±1.7)	$84:16_{2}$	0.9
25 - 27 Jun[1]	$84:16^{a}{}_{2}$	(±1.6)	$92:8^{b}{}_{13}$	(±1.8)	$86:14^{a}{}_{23}$	(±1.3)	$84:16_{2}$	0.8
02-Jul	$89:11^{a}{}_{13}$	(±2.2)	$87:13^{a}{}_{2}$	(±2.8)	$86:14^{a}{}_{3}$	(±5.4)	$89:11_{2}$	1.9
09-Jul	$87:13^{a}{}_{23}$	(±3.1)	$88:12^{a}{}_{2}$	(±1.4)	$89:11^{a}{}_{13}$	(±4.8)	$87:13_{2}$	1.7
16-Jul	$85:15^{a}{}_{2}$	(±1.8)	$89:11^{a}{}_{23}$	(±0.8)	$90:10^{a}{}_{12}$	(±1.3)	$85:15_{2}$	0.7
Mean	$86:14^{a}$	(±3.2)	$89:11^{b}$	(±3.2)	$88:12^{b}$	(±3.2)	88:12	0.5

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

2.2.3.6 Calcium content

Initially the calcium (Ca) content within paddock A (high initial N) and B (low initial N) did not differ significantly ($P < 0.05$) with each other (Table 12), although their Ca content was significantly ($P < 0.05$) lower compared to paddock C (low initial N).

Ca content generally increased within each paddock with significantly ($P < 0.05$) higher Ca content found at the end compared to the beginning of the trial. The same trend was seen for the total mean Ca content.

The mean Ca content within paddock A was significantly ($P < 0.05$) lower compared to that found within either paddock B or C which did not differ significantly ($P < 0.05$) from each other.

Table 12: Calcium content ($g.kg^{-1}$ DM) during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
06-Jun	$4.3^{b}{}_{4}$	(±0.2)	$4.3^{b}{}_{4}$	(±0.2)	$5.3^{a}{}_{3}$	(±1.2)	4.6^{1}	0.4
13-Jun	$5.5^{a}{}_{3}$	(±0.5)	$5.0^{b}{}_{4}$	(±0.4)	$5.6^{a}{}_{3}$	(±0.2)	5.4^{2}	0.2
20-Jun	$5.3^{a}{}_{3}$	(±0.3)	$4.7^{b}{}_{4}$	(±0.2)	$5.2^{ab}{}_{3}$	(±0.6)	5.1^{12}	0.2
25 - 27 Jun[1]	$5.4^{c}{}_{3}$	(±0.4)	$6.6^{a}{}_{3}$	(±0.4)	$6.0^{b}{}_{3}$	(±0.2)	6.0^{3}	0.2
02-Jul	$5.8^{b}{}_{23}$	(±0.3)	$7.0^{a}{}_{3}$	(±0.6)	$6.0^{b}{}_{3}$	(±0.5)	6.3^{3}	0.2
09-Jul	$6.3^{b}{}_{2}$	(±1.3)	$7.9^{a}{}_{2}$	(±0.4)	$8.3^{a}{}_{2}$	(±0.4)	7.5^{4}	0.4
16-Jul	$7.2^{b}{}_{1}$	(±0.7)	$9.9^{a}{}_{1}$	(±0.7)	$9.4^{a}{}_{1}$	(±1.0)	8.8^{5}	0.4
Mean	5.7^{b}	(±1.0)	6.5^{a}	(±1.9)	6.5^{a}	(±1.7)	6.2	0.1

[abc]Row means that do not have a common superscript differ ($P < 0.05$)

[123]Column means that do not have a common subscript differ ($P < 0.05$)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

2.2.3.7 Phosphorous content

At the start of the trial the phosphorous (P) content did not differ significantly ($P < 0.05$) between paddocks (Table 13).

Within paddock A the initial significant ($P < 0.05$) increase in P content was followed by a decreasing trend. Within paddock C the P content decreased gradually after an initial plateau. Apart from 13 June the P content within paddock B generally showed the same trend compared to paddocks A and B, indicating a sampling error at this date within paddock B. Significantly ($P < 0.05$) lower P content was found at the end compared to the start of the trial within both paddocks A and B.

Table 13: Phosphorous content (g.kg^{-1} DM) during season 1.

Fertilization	High initial N		Low initial N		Low initial N			
Stocking	Low		Low		High			
	Paddock A		Paddock B		Paddock C		Total mean	SEM
06-Jun	$1.7^{a}{}_{2}$	(±0.1)	$1.7^{a}{}_{1}$	(±0.2)	$2.1^{a}{}_{123}$	(±0.6)	1.8^{23}	0.2
13-Jun	$2.1^{a}{}_{1}$	(±0.1)	$1.4^{b}{}_{2}$	(±0.1)	$2.2^{a}{}_{1}$	(±0.1)	1.9^{12}	0.1
20-Jun	$2.0^{a}{}_{1}$	(±0.1)	$1.8^{b}{}_{1}$	(±0.1)	$2.1^{a}{}_{12}$	(±0.2)	2.0^{1}	0.1
25 - 27 Jun[1]	$1.7^{a}{}_{2}$	(±0.2)	$1.7^{a}{}_{1}$	(±0.1)	$1.9^{a}{}_{23}$	(±0.2)	1.8^{23}	0.1
02-Jul	$1.5^{a}{}_{23}$	(±0.1)	$1.6^{a}{}_{12}$	(±0.2)	$1.9^{a}{}_{23}$	(±0.2)	1.7^{34}	0.1
09-Jul	$1.5^{a}{}_{23}$	(±0.1)	$1.6^{a}{}_{12}$	(±0.2)	$1.7^{a}{}_{3}$	(±0.1)	1.6^{4}	0.1
16-Jul	$1.4^{a}{}_{3}$	(±0.1)	$1.5^{a}{}_{12}$	(±0.3)	$1.7^{a}{}_{3}$	(±0.1)	1.5^{4}	0.1
Mean	1.7^{b}	(±0.3)	1.6^{b}	(±0.2)	1.9^{a}	(±0.3)	1.7	0.04

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

[1]Paddock A, B and C samples collected 25, 27 and 26 June respectively

Standard deviation indicated in brackets

With the exception of 13 and 20 June, P content did not differ between paddocks. At these dates significantly (P < 0.05) lower P content was found in paddock B (low initial N, low stocking) compared to A (high initial N, low stocking) and C (low initial N, high stocking).

2.2.3.8 Pasture availability

A lower level of nitrogen fertilization is expected to result in lower protein content of the pasture (Eck *et al.,* 1981; Hedtcke *et al.,* 2002; Wolf & Opitz von Boverfeld, 2003;Peyraud & Astigarraga, 1998) and lower yield (Peyraud & Astigarraga, 1998). In this study the effect of nitrogen fertilization was still evident a year later. At the beginning of the trial the CP content in paddock A (higher initial N) was significantly higher compared to that measured in the other two paddocks which received a lower level of nitrogen fertilization at establishment the year before (Table 8). The higher level of fertilization a year before (Paddock A) was also associated with a higher yield per ha (Table 14). Other quality parameters were generally unaffected by the level of initial nitrogen fertilization.

The CP content found in paddock B at the start of the trial was significantly (P < 0.05) lower compared to paddock A (high initial N) as well as C (low initial N). This suggests that the lower CP content within this paddock was not only a result of the lower level of nitrogen

fertilization. The initial increase in pasture availability within paddock A (high initial N, low stocking) and B (low initial N, high stocking) during the first week of the trial indicated a high pasture growth rate during this period.

Table 14: Pasture availability during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**	
Stocking	**Low**		**Low**		**High**	
	Paddock A (3.2 ha)		**Paddock B (3.3 ha)**		**Paddock C (2.5 ha)**	
	kg DM.ha^{-1}	Total DM	kg DM.ha^{-1}	Total DM	kg DM.ha^{-1}	Total DM
03-Jun	4036.8	12917.9	3596.4	11868.3	3490.0	8725.0
13-Jun	4439.2	14205.5	4345.5	14340.1	2843.8	7109.4
20-Jun	4110.0	13152.1	3497.7	11542.6	2242.4	5606.0
27-Jun	3694.8	11823.5	3208.0	10586.5	1998.8	4997.0
04-Jul	3560.8	11394.6	3243.5	10703.5	1837.3	4593.3
11-Jun	3592.4	11495.6	3083.0	10174.0	1757.1	4392.6
18-Jun	2939.5	9406.4	2771.1	9144.6	1456.5	3641.3

The fact that this same trend was not seen in paddock C (low initial N, high stocking) illustrates that at the higher stocking rate animals removed the plant material at a higher rate than it could be replenished by pasture re-growth. After the first week a decrease in pasture availability was found in all the paddocks, indicating a decrease in growth rate due to semi-dormant state of Tall Fescue during mid-winter.

Weekly weather station data is shown in Table 15. The first frost for the season was observed during the morning of the 26th of June. Considerable browning of the pasture was observed the next day and identified as frost damaged. The only significant ($P < 0.05$) difference in pasture quality corresponding with the frost damage is the increase in DM content (i.e. dehydration) seen in paddock B and C. This is probably due to the fact that cells are dehydrated during frost and when cell membranes are damaged during thawing, water cannot re-enter the cells completely (Salisbury & Ross, 1992). No significant difference in DM content was observed in paddock A. Frost damage in this paddock was less severe. The higher density of plants as well as the higher elevation of paddock A resulted in some degree of protection to frost damage. The samples collected in paddock A were only a week after the frost occurred and some degree of repair occurred during this period.

The general trend seen for DM, NDF, CP and P content as well as for IVOMD, from the first frost onwards corresponds with that expected for maturing plants. Young leafy plants are high in moisture content, as the plant matures the moisture content falls (McDonald *et al.,* 2002). Increasing plant maturity is usually associated with an increase in fibre content of the whole plant (Kilcher, 1981; Cherney *et al.,* 1993; Burns *et al*., 2006) a reduction in CP content (Callow *et al*., 2003; Murray, 1984; McDonald *et al.,* 2002) as well as a decline in most minerals including Ca and P (Murray 1984; McDonald *et al.,* 2002). Unlike the expected decrease, the Ca content increased during the trial, probably due to a build-up of Ca addition from the gypsiferous irrigation water (Table 1).

Table 15: Weather station data during season 1.

	Weekly temperatures (°C)		**Wind speed (m/s)**	
	max	Min	max	min
3- 13 Jun	22.2	-2.0	8.3	0.7
13-20 Jun	23.2	-0.4	9.2	0.6
20 - 27 Jun	20.7	-2.1	8.6	0.8
27 Jun - 4 Jul	21.8	-2.5	9.2	0.9
4 - 11 Jul	22.4	-4.5	12.3	1.2
11 - 18 Jul	21.9	-3.1	6.8	0.8

2.2.3.9 Animal production

Animal production expressed as average daily gain (ADG) for each week is shown in Table 16. Low animal production found during the first week of the study is probably due to the low weight and age of animals used in this study. These early weaned calves needed a longer time to adapt to the pasture conditions. No significant ($P < 0.05$) differences in average daily gain (ADG) were found during the first week of the study.

Significantly ($P < 0.05$) lower average daily gains in week three compared to week two within each paddock is probably the result of increased cost to maintain core body temperature, due to lower temperatures (Table 15).

From the second week of the study the ADG in paddock B (low initial N, low stocking) was consistently lower compared to paddock A (high initial N, low stocking) with

significant ($P < 0.05$) differences found during week two, four and six. During the same period the CP content within paddock B was significantly ($P < 0.05$) lower compared to paddock A (Table 8). Similar results were found when comparing paddock B and C (low initial N, high stocking) from week two to four, with lower ADG and CP found in paddock B. This indicates that CP content and not pasture availability was the main factor limiting production in paddock B during this period.

The ADG in paddock B (low initial N, low stocking) and C (low initial N, high stocking) did not differ significantly ($P < 0.05$) during the last two weeks of the study. The primary limitation on animal production during this time was low CP and availability within paddock B and C respectively.

A significantly (low initial N, low stocking) reduction in ADG was found from week five to six within each paddock. The lowest pasture availability and CP content as well as high NDF and low *in vitro* limited the animals' ability to consume adequate nutrients for optimum production.

Table 16: Weekly average daily gain ($kg.day^{-1}$) during season 1.

Fertilization	**High initial N**		**Low initial N**		**Low initial N**			
Stocking	**Low**		**Low**		**High**			
	Paddock A		**Paddock B**		**Paddock C**		**Total mean**	**SEM**
3-13 Jun	$26.2^{a}{}_{2}$	(±672.1)	$117.1^{a}{}_{34}$	(±804.6)	$58.3^{a}{}_{2}$	(±670.9)	67.2_{3}	73.8
13-20 Jun	$972.8^{a}{}_{1}$	(±785.2)	$484.3^{b}{}_{12}$	(±837.2)	$732.1^{ab}{}_{1}$	(±900.9)	729.8_{1}	73.8
20-27 Jun	$204.1^{a}{}_{2}$	(±825.9)	$-24.4^{a}{}_{34}$	(±950.8)	$145.8^{a}{}_{2}$	(±968.2)	108.5_{3}	73.8
27 Jun - 4 Jul	$676.9^{a}{}_{1}$	(±1210.6)	$240.4^{b}{}_{23}$	(±1049.5)	$544.6^{a}{}_{1}$	(±989.6)	487.3_{2}	73.8
4-11 Jul	$1006.8^{a}{}_{1}$	(±921.5)	$794.4^{ab}{}_{1}$	(±885.3)	$571.4^{b}{}_{1}$	(±799.5)	790.9_{1}	73.8
11-18 Jul	$207.5^{a}{}_{2}$	(±515.8)	$-184.7^{b}{}_{4}$	(±446.4)	$-86.3a^{b}{}_{2}$	(±566.7)	-21.2_{3}	73.8

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

Overall the ADG in paddock A and C was significantly ($P < 0.05$) higher compared to paddock

Table 17: Overall weight data during season 1.

	Paddock A		Paddock B		Paddock C		Mean	SEM
Initial weight (kg)	135.0_a	(±22.6)	134.8_a	(±22.2)	136.0_a	(±23.7)	135.3	3.47
End weight (kg)	157.0_a	(±23.9)	145.6_c	(±21.5)	149.3_b	(±22.8)	150.6	1.14
ADG (g/day)	482.7_a	(±177.2)	229.1_c	(±167.6)	310.6_b	(±165.4)	340.3	25.4

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

Standard deviation indicated in brackets

2.2.4 Methodology (*2nd Season)*

The aim of this study was to quantify pasture quality and animal production at different stocking rates.

Paddock D, E and F (2.5, 2.6, and 4 ha in size) were grazed from 6 August to 28 November 2008. These three paddocks received the same level of fertilization. The grazing pressure applied was the highest in paddock D, intermediate in paddock E and lowest in paddock F. The pivot did not work during the first part of the season up to 8 September and no rain occurred during this period. From 8 September up to the 14th of October the pasture received an average of approximately 20 mm of water (irrigation plus rain) per week. During the period between 14 October and 11 November the pasture received an average of approximately 30 mm of water.

2.2.4.1 Animals and experimental design

The four Beefmaster steers (610 kg) together with the crossbred calves (now weighing 170kg on average) from the previous season were used in order to apply three grazing pressures. The three paddocks were stocked in relation to the estimated pasture availability and predicted growth in order to achieve a pasture allowance of 2, 2.5 and 3% body weight. Pasture availability was determined every second week and adaptations to the number of animals (stocking rate) were made in order to keep a constant grazing pressure (Wheeler et al., 1973). Weights of these "put-and-take" animals were not used in calculations of average daily gain (ADG).

At the start of the trial pasture availability estimates expressed on a dry matter (DM) basis in paddock D, E and F were 3773.7, 3927.4 and 3179.8 ($kg.ha^{-1}$) , respectively. Paddock D and E were stocked with 71 and 62 crossbred calves respectively together with one of the

canulated steers. Two of the canulated steers and 66 crossbred steers were stocked in paddock F. The predicted growth used to determine the stocking rate had been drastically decreased during the 19th and 25th of September, due to slow pasture growth.

Three of the four canulated steers rotated between paddocks on a weekly basis (treatments) following a 3x3 Latin square design (Table 18). The fourth canulated steer was placed in the paddock with the lightest stocking rate (paddock F). Rotation of the canulated steers was needed to take animal effects into account and provision was made for an adaptation period of four days each week. Rumen fluid was collected during the last three days each week.

Figure 32: Canulated steers being prepared to take the necessary rumen samples.

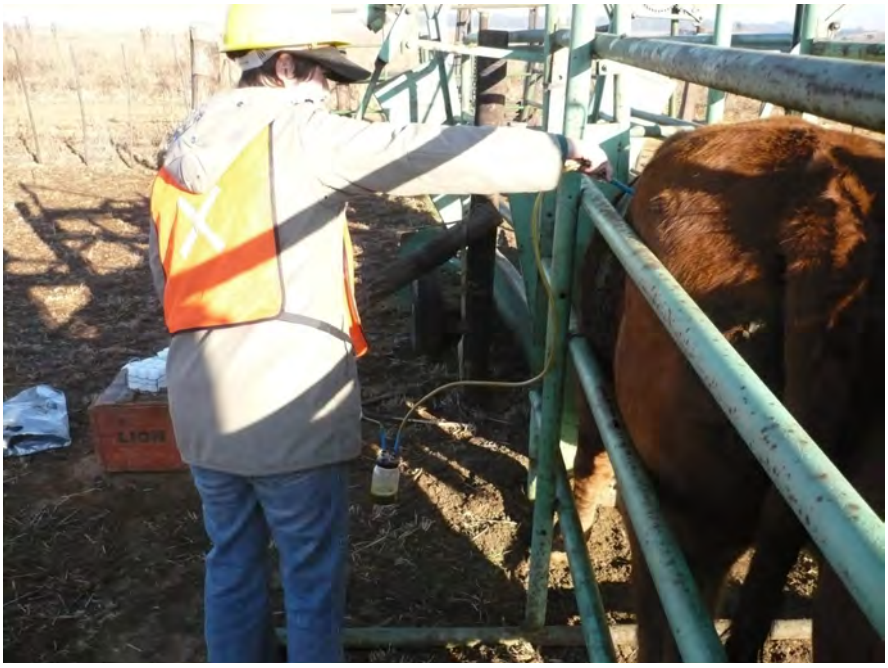

Figure 33: The suction straw is entered into through canula into the rumen of the steer.

Figure 34: Rumen fluid is sucked into the sample bottle.

Figure 35: Different rumen samples are then mixed with different preservatives to do different laboratory analysis on them.

Table 18: Experimental design season 2: Latin square.

	Animal		
Week	**a**	**b**	**c**
1, 4 and 7	Paddock D	Paddock E	Paddock F
2, 5 and 8	Paddock F	Paddock D	Paddock E
3, 6 and 9	Paddock E	Paddock F	Paddock D

Five animals per paddock were dosed with a controlled release device containing alkanes C_{32} and C_{36} (Argenta), during week 1. Faecal grab samples were collected at 9am and 4pm from these animals on day 8-14 after administration of the controlled release device.

Clipped samples of the pasture were taken at the beginning of weeks 3, 6 and 10 from 24 quadrants in each paddock in a random stratified manner. Quadrants were 50 x 100 cm in size and all the herbage in the quadrant clipped 5 cm from the soil surface. Four representative pasture samples were obtained by mixing six random pasture samples.

Figure 36: Random pasture samples taken on the paddocks.

Figure 37: The clipped pasture samples taken and placed into brown paper bags for further processing.

2.2.4.2 Management and parameters measured

Clean drinking water as well as a salt phosphate lick was supplied to the animals *ad libitum*. Pasture samples were sub-sampled to determine leaf: stem ratio while the rest were dried at 60°C for 2 days and used for chemical analyses. Dried pasture samples were milled to pass through a 1mm screen for chemical analyses. Rumen fluid samples were analysed for volatile fatty acid (VFA) content. For each week of sampling, rumen fluid samples were taken from the canulated steers at 6am, 12pm and 18pm on day 5, 8am and 14pm on day 6 and

10am and 16pm during day 7, to obtain samples representative of every two hours of a day. Rumen fluid was collected with the aid of a syringe fitted with a rumen fluid collection tube (Bar Diamond, Inc.).

2.2.4.3 Leaf: stem ratio

Leaf and stem material separated and dried at 60 °C for 2 days. Each component was weighed and the dry matter was determined to calculate leaf: stem ratio. as follows:

$$\text{Leaf \%} = \frac{\text{Dry leaf weight}}{\text{Dry leaf weight + dry stem weight}} \times 100$$

Equation 4: Equation to calculate leaf %.

$$\text{Stem \%} = \frac{\text{Dry stem weight}}{\text{Dry leaf weight + dry stem weight}} \times 100 \quad \text{.....(Eq. 2)}$$

Equation 5: Equation to calculate stem %.

2.2.4.4 Chemical analyses of clipped samples

Pasture samples were analysed at Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria. Analysis was done to determine: dry matter (DM) (934.01 AOAC, 2000), neutral detergent fibre (NDF) (Robertson & Van Soest, 1981) on a Tecator Fibrotec System, in vitro organic matter digestibility (IVOMD) (Tilley & Terry, 1963) using a shaking water bath, calcium (Ca) (Giron, 1973) using a Perken-Elmer 5100 Atomic Absorption Spectrometer and phosphorous (P) (965.17 AOAC, 2000) content using a Specol 1300 Spectrophotometer.

In order to determine the crude protein (CP) concentration (968.06 AOAC, 2000) the nitrogen concentration was determined using a LECO System model (CHN-1000), a block digester was used for sample digestion and a Tecator Kjeltec System Model for distillation. The crude protein concentration was calculated as follows:

%CP = %N x 6.25.

2.2.4.5 Volatile fatty acids production in the rumen

After each sampling rumen fluid was preserved as follows: 20 ml rumen fluid was preserved with 4 ml 25% H_3PO_4 and frozen to determine the volatile fatty acid (VFA) concentration with gas chromatography (GC). Rumen samples for each animal for each week (or each pasture) was mixed and only the representative sample was analyzed by Nutrilab, Department of Animal and Wildlife Sciences, University of Pretoria.

2.2.4.6 Voluntary intake of grazing steers

Faecal grab samples collected for the seven day period were pooled for each animal. Clipped pasture samples were taken on day 4 of each faecal grab sampling period. These samples were dried at 60°C, milled to pass through a sieve with a 1 mm screen and analysed for $C_{32,}$ C_{33} and C_{36}. These samples were analysed by Organic Analysis Laboratory, Queenswood, Pretoria, using the procedure described by Dove and Mayes (2006) with the some modifications. For extraction 0.5 g faecal or pasture sample, C_{16} as internal standard, 4 ml ethanol KOH, 4 ml hexane, 0.5 ml H_2O and 1 ml heptane was used. Analysis was done using a Hewlett-Packard GC. Intake was calculated by using the following equation (Dove & Mayes, 2006):

$$\text{Intake} = \frac{\text{dose rate } C_{32}}{[(\text{faecal content } C_{32}/\text{faecal content } C_{33})\ \text{herbage content } C_{33} - \text{herbage content } C_{32}]}$$

2.2.4.7 In situ rumen degradability

Pasture samples were milled with a laboratory hammer mill through a 2 mm screen. The three Beefmaster steers were fed *Eragrostis* hay: lucerne mix (50:50 on a volume basis) *ad libitum*. For each pasture sample approximately 5 g of feed was weighed into 54 nylon bags (pore size 41 µm, 15 mg material per cm^2 of bag) to allow for rumen incubation of 0, 2, 4, 6, 8, 12, 24, 48 and 72 h, with one replicate for each time frame. The eight bags per pasture were inserted into the rumen at the same time and removed after the different time intervals as described by Cruywagen (2006). When all the bags were removed the replicate bags for each time period were inserted into the steers. Incubated samples were washed for 30 min under running tap water, dried at 60 °C for 48 h and after cooling down in a desiccator it were weighed and the DM (934.01 AOAC, 2000) of the residue was determined.

Dry matter disappearance (DMD) was calculated and fitted into the non-model suggested by Ørskov & McDonald, 1979.

2.2.4.8 Statistical Analyses

Nutritive value, intake and live weight data were statistically analyzed with the GLM model (Statistical Analysis Systems, 2010) to determine the difference between paddocks (treatments) and within paddocks over time. Repeated Measures Analysis of Variance with the GLM model was used for repeated week or period measures. Data of two, four and two animals in paddock A, B and C respectively were identified as outliers due to unrealistic weight changes and were excluded from analyses. Starting weight was tested as co-variant for weight data and when significant ($P < 0.05$) it was included. Rumen VFA concentration was analyzed, using a 3 x 3 Latin Square design, by the GLM model to determine influence of treatment, period and animal. Means and standard deviations were calculated and significance of difference ($P < 0.05$) between means was determined by Fischers test (Samuels, 1989).

2.2.4.9 Treatments

Paddock D, E and F (2.5, 2.6 and 4 ha in size) were grazed from 28 August to 6 November 2008. These three paddocks received the same level of fertilization. The grazing pressure applied was the highest in paddock D, intermediate in paddock E and lowest in paddock F. The pivot did not work during the first part of the season up to 8 September and no rain occurred during this period. From the 8th of September up to the 14th of October the pasture received an average of approximately 20 mm of water (mine waste water irrigation plus rain) per week. During the period between 14 October and 11 November the pasture received an average of approximately 30 mm of water. The minimum and maximum climatic temperatures were 0.3 °C and 31.9 °C respectively.

2.2.5 Results and discussion *(2nd Season)*

2.2.5.1 Dry matter content

No significant ($P < 0.05$) differences in DM content were found between paddocks at the first two sampling dates (Table 19). The significant ($P < 0.05$) increase in DM content from 8th Sep to 6th Oct within each of the paddocks is due to water stress when the pivot was out of order in addition to high temperatures and slow pasture growth during this period.

DM content at the 3rd of Nov within each paddock was significantly ($P < 0.05$) lower than at both 6th Oct and 8th Sep. During the period from 6th Sep to 10th Oct the pasture received higher amounts of water as a result of rainfall. The predicted pasture growth used in the calculation of stocking rate was drastically reduced, therefore stocking rate was in fact lower and the pasture was grazed down slower. This resulted in a higher percentage of pasture which was mainly re-growth.

Table 19: Pasture dry matter content ($g.kg^{-1}$) during season 2.

Stocking	**High**		**Medium**		**Low**			
	Paddock D		**Paddock E**		**Paddock F**		**Total mean**	**SEM**
08-Sep	$521.0^{a}{}_{2}$	(±32.8)	$464.7^{a}{}_{2}$	(±24.0)	$500.2^{a}{}_{2}$	(±64.9)	495.3_{2}	10.9
06-Oct	$583.8^{a}{}_{1}$	(±47.4)	$582.2^{a}{}_{1}$	(±47.6)	$617.4^{a}{}_{1}$	(±42.9)	594.5_{1}	10.9
3-Nov	$456.1^{a}{}_{3}$	(±11.1)	$404.4^{b}{}_{3}$	(±20.0)	$293.4^{c}{}_{3}$	(±12.4)	384.7_{3}	10.9
Mean	520.3^{a}	(±62.5)	483.8^{b}	(±82.6)	470.3^{b}	(±145.8)	491.5	

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

At the end of the trial the three paddocks differed significantly ($P < 0.05$) from each other in DM content. The highest stocking rate was associated with the highest DM content and the lowest stocking rate was associated with the lowest DM content.

2.2.5.2 Crude protein content

The crude protein (CP) content at 8th Sep and 6th Oct did not differ significantly ($P < 0.05$) within and between paddocks (Table 20). Within each paddock a significant ($P < 0.05$) increase in CP content was found from 6th Oct to 3rd Nov. This corresponds with the lower stocking rates and thus lower rate at which pasture re-growth is grazed down. Although CP content did not differ significantly ($P < 0.05$) between 8th Sep and 6th Oct within paddocks D and F, a significant ($P < 0.05$) increase in CP content was found in paddock E during the same period.

Table 20: Pasture crude protein content (g.kg^{-1} DM) during season 2.

Stocking	High		Medium		Low			
	Paddock D		Paddock E		Paddock F		Total mean	SEM
08-Sep	$74.7^{a}{}_{2}$	(±4.1)	$80.3^{a}{}_{3}$	(±4.5)	$82.8^{a}{}_{2}$	(±13.3)	79.2_{2}	4.5
06-Oct	$81.0^{a}{}_{2}$	(±3.3)	$103.0^{a}{}_{2}$	(±38.5)	$77.8^{a}{}_{2}$	(±9.1)	87.3_{2}	4.5
3-Nov	$115.25^{b}{}_{1}$	(±17.4)	$136.2^{a}{}_{1}$	(±4.6)	$157.5^{a}{}_{1}$	(±8.9)	136.3_{1}	4.5
Mean	90.3^{a}	(±20.9)	106.5^{b}	(±31.5)	106.5^{b}	(±39.3)	101.0	4.5

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

2.2.5.3 Neutral detergent fibre content

Paddocks did not differ significantly (P < 0.05) in neutral detergent (NDF) fibre content at the start of the sampling season (Table 21). A significant (P < 0.05) reduction in NDF from 8th Sep to 6th Oct was found in all three paddocks with significantly (P < 0.05) lower values in paddock E. From 6th Oct to 3rd Nov a further significant (P < 0.05) reduction in NDF content was found within paddocks D and E, although no significant (P < 0.05) differences were detected in paddock F during the same period. At the end of the sampling season NDF content was significantly (P < 0.05) lower within paddock F compared to paddocks D and E which did not differ significantly (P < 0.05) from each other.

Table 21: Pasture neutral detergent fibre content (g.kg^{-1}DM) during season 2.

Stocking	High		Medium		Low			
	Paddock D		Paddock E		Paddock F		Total mean	SEM
08-Sep	$580.1^{a}{}_{3}$	(±11.9)	$577.0^{a}{}_{3}$	(±19.1)	$576.7^{a}{}_{2}$	(±7.1)	577.9_{3}	4.2
06-Oct	$663.9^{a}{}_{2}$	(±15.6)	$638.7^{b}{}_{2}$	(±6.7)	$662.1^{a}{}_{1}$	(±6.2)	654.9_{2}	4.2
3-Nov	$700.4^{a}{}_{1}$	(±21.4)	$698.1^{a}{}_{1}$	(±9.8)	$654.7^{b}{}_{1}$	(±21.8)	684.4_{1}	4.2
Mean	648.1^{a}		637.9^{ab}		631.2^{b}		639.1	4.2

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

2.2.5.4 In vitro organic matter digestibility

The *in vitro* organic matter digestibility (IVOMD) at the beginning of the sampling season was significantly ($P < 0.05$) lower in paddock F compared to paddock D and E (Table 22). No significant ($P < 0.05$) differences were found between paddock D and E throughout the sampling season. A significant ($P < 0.05$) reduction from 8th Sep to 6th Oct was found in all the paddocks corresponding with a significant decrease in NDF content during the same period. This is probably due to the removal of older less digestible material during this period. During this time re-growth was grazed down at a high rate and animals were forced to graze more indigestible parts of the pasture.

Table 22: *In vitro* organic matter digestibility ($g.kgOM^{-1}$) during season 2.

Stocking	**High**		**Medium**		**Low**			
	Paddock D		**Paddock E**		**Paddock F**		**Total mean**	**SEM**
08-Sep	$756.2^{b}{}_{1}$	(±7.13)	$762.2^{b}{}_{1}$	(±11.2)	$784.4^{a}{}_{1}$	(±14.3)	767.6_{1}	5.6
06-Oct	$683.1^{a}{}_{2}$	(±17.9)	$686.7^{a}{}_{2}$	(±25.7)	$684.5^{a}{}_{3}$	(±27.3)	689.8_{2}	5.6
3-Nov	$690.0^{b}{}_{2}$	(±23.6)	$686.4^{b}{}_{2}$	(±4.7)	$724.5^{a}{}_{2}$	(±26.4)	700.3_{2}	5.6
Mean	709.7^{b}	(±37.9)	711.8^{b}	(±40.1)	731.1^{a}	(±47.8)	717.5	5.6

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

Within paddocks D and E no significant change in IVOMD was found from 6th Oct to 3rd Nov regardless of a significant increase in NDF content during the same period. This indicates that although the NDF content of the pasture was higher at the end of the sampling season, a large portion was present in more digestible re-growth. A significant ($P < 0.05$) increase in IVOMD was found within paddock F from 6th Oct to 3rd Nov even though the NDF content did not change significantly ($P < 0.05$) during the same period. This is also a result of a higher proportion of the NDF being present in more digestible re-growth.

2.2.5.5 Leaf: stem ratio

A significantly ($P < 0.05$) lower leaf: stem ratio at the start of the sampling season was found in paddock E compared to the other two paddocks which did not differ significantly ($P < 0.05$) from each other (Table 23). No significant ($P < 0.05$) difference in leaf:

stem ratio was found between paddocks at 8 Sep. Paddock F had a significantly ($P < 0.05$) higher leaf: stem ratio at 3 Nov compared to the other two paddocks. At the 3rd of Nov paddock D and E that did not differ significantly in leaf: stem ratio ($P < 0.05$) from each other.

Table 23: Leaf: stem ratio during season 2.

Stocking	**High**		**Medium**		**Low**			
	Paddock D		**Paddock E**		**Paddock F**		**Total mean**	**SEM**
08-Sep	$86:14^{a}{}_{1}$	(±3.9)	$81:19^{b}{}_{2}$	(±4.8)	$88:12^{a}{}_{1}$	(±2.2)	$85:2_{2}$	1.0
06-Oct	$89:11^{a}{}_{1}$	(±0.8)	$91:9^{a}{}_{1}$	(±2.9)	$89:11^{a}{}_{1}$	(±2.4)	$90:1_{1}$	1.0
3-Nov	$75:25^{b}{}_{2}$	(±5.6)	$78:22^{b}{}_{2}$	(±1.3)	$86:14^{a}{}_{1}$	(±2.5)	$80:2_{3}$	1.0
Mean	$83:17^{b}$	(±7.3)	$83:17^{b}$	(±6.5)	$88:12^{a}$	(±2.4)	85:15	0.9

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

2.2.5.6 Calcium content

At the start and the end of the trial a significantly ($P < 0.05$) lower calcium (Ca) content was found in paddock F compared to paddock D and E. In September no significant ($P < 0.05$) differences in Ca content were found between paddocks (Table 24). Throughout the trial the Ca content in paddock D and E did not differ significantly ($P < 0.05$) from each other. Within all the paddocks the Ca content increased significantly ($P < 0.05$) from August to September. This was followed by a significant ($P < 0.05$) decrease the next month. The mean Ca content within paddock D was significantly ($P < 0.05$) higher than paddock F. No significant difference in mean Ca content was found between paddock E and either of the other two paddocks.

Table 24: Calcium content (g.kg^{-1} DM) during season 2.

Stocking	High		Medium		Low		Total	
	Paddock D		Paddock E		Paddock F		mean	SEM
08-Aug	$8.9^{a}{}_{2}$	(±1.2)	$8.5^{a}{}_{12}$	(±0.8)	$6.5^{b}{}_{2}$	(±0.7)	8.0^{2}	0.5
06-Sep	$14.2^{a}{}_{1}$	(±2.3)	$10.8^{a}{}_{1}$	(±3.8)	$13.0^{a}{}_{1}$	(±2.5)	12.7^{1}	0.5
10 Okt	$6.8^{a}{}_{2}$	(±0.7)	$6.7^{a}{}_{2}$	(±0.9)	$5.5^{b}{}_{2}$	(±0.1)	6.3^{3}	0.5
Mean	10.0^{a}	(±3.5)	8.6^{ab}	(±2.7)	8.3^{b}	(±3.7)	8.9	0.5

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

2.2.5.7 Phosphorous content

At the start and the end of the trial the phosphorous (P) content in paddock F was significantly (P < 0.05) higher than in paddock D and E. No significant (P < 0.05) difference in P content was found between the three paddocks in September. The P content in paddock D and E did not differ significantly (P < 0.05) throughout the trial.

Within each of the paddocks the P content tended to increase over the period of the trial, this is as a result of added P from and additional source of nutrients such as cattle manure. The mean P in paddock F was significantly higher compared to paddock D and E which did not differ significantly from each other.

Table 25: Phosphorous content (g.kg^{-1} DM) during season 2.

Stocking	High		Medium		Low		Total	
	D		E		F		mean	SEM
08-Aug	$1.4^{b}{}_{3}$	(±0.1)	$1.5^{b}{}_{2}$	(±0.1)	$1.8^{a}{}_{2}$	(±0.1)	1.6	0.1
06-Sep	$1.9^{a}{}_{2}$	(±0.2)	$1.8^{a}{}_{2}$	(±0.7)	$2.1^{a}{}_{2}$	(±0.2)	1.9	0.1
10 Okt	$2.7^{b}{}_{1}$	(±0.2)	$2.7^{b}{}_{1}$	(±0.2)	$3.4^{a}{}_{1}$	(±0.2)	3.0	0.1
Mean	2.0^{b}	(±0.6)	2.0^{b}	(±0.6)	2.4^{a}	(±0.8)	2.1	0.1

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

2.2.5.8 In situ degradability estimates

At the end of the study the ***a*** value (rapidly soluble fraction of plant material) of paddock F was significantly ($P < 0.05$) lower than for paddock D and E. When excluding the ***a*** value, no significant ($P < 0.05$) differences in degradability estimates were found between paddocks at the end of the trial.

Table 26*: In situ* DM degradability estimates during season 2.

	Paddock							
	D		**E**		**F**		**Total mean**	**SEM**
a	14.7[a]	(±1.0)	15.5[a]	(±1.7)	11.9[b]	(±1.9)	14	0.3
b	157.9[a]	(±100.8)	113.7[a]	(±55.6)	212.6[a]	(±173.5)	161.4	60.9
c	0.02[a]	(±0.02)	0.02[a]	(±0.02)	0.01[a]	(±0.01)	0.01	0.01
PD	172.7[a]	(±101.6)	129.1[a]	(±57.2)	224.5[a]	(±174.9)	175.4	61.1
ED	57.4[a]	(±7.1)	57.4[a]	(±6.6)	53.7[a]	(±5.9)	56.1	2.7

[abc]Row means that do not have a common superscript differ ($P < 0.05$)

Standard deviation indicated in brackets

a – rapidly soluble fraction; b – insoluble but fermentable fraction in time;

c – Degradation rate constant of the b fraction; PD – extent of degradation (a + b)

2.2.5.9 Alkane digestibility estimates

Within paddock D and F the three equations did not show the same significant changes over time (Table 27). Within paddock E all three equations showed a significantly ($P < 0.05$) lower organic matter (OM) digestibility at week ten compared to week two and six, which did not differ significantly ($P < 0.05$) from each other.

Table 27: Organic matter digestibility fraction during season 2.

Stocking	High		Medium		Low		Total	
	Paddock D		Paddock E		Paddock F		mean	SEM
week 2								
(3-9 Sep)								
C_{32}	$0.78^{ab}{}_{1}$	(±0.07)	$0.82^{a}{}_{1}$	(±0.03)	$0.71^{b}{}_{1}$	(±0.06)	0.77	0.02
C_{33}	$0.76^{a}{}_{1}$	(±0.07)	$0.80^{a}{}_{1}$	(±0.04)	$0.66^{b}{}_{12}$	(±0.09)	0.74	0.03
C_{36}	$0.83^{ab}{}_{1}$	(±0.04)	$0.86^{a}{}_{1}$	(±0.04)	$0.76^{b}{}_{1}$	(±0.07)	0.82	0.02
week 6								
(30 Sep – 6 Nov)								
C_{32}	$0.69^{b}{}_{12}$	(±0.04)	$0.79^{a}{}_{1}$	(±0.09)	$0.67^{b}{}_{1}$	(±0.09)	0.72	0.03
C_{33}	$0.64^{ab}{}_{2}$	(±0.05)	$0.76^{a}{}_{1}$	(±0.11)	$0.62^{b}{}_{2}$	(±0.08)	0.67	0.04
C_{36}	$0.75^{b}{}_{1}$	(±0.04)	$0.85^{a}{}_{1}$	(±0.07)	$0.75^{b}{}_{1}$	(±0.07)	0.78	0.03
week 10								
(28 Sep – 3 Nov)								
C_{32}	$0.65^{ab}{}_{2}$	(±0.08)	$0.62^{b}{}_{2}$	(±0.09)	$0.77^{a}{}_{1}$	(±0.12)	0.69	0.04
C_{33}	$0.56^{b}{}_{2}$	(±0.09)	$0.62^{ab}{}_{2}$	(±0.03)	$0.73^{a}{}_{1}$	(±0.12)	0.64	0.04
C_{36}	$0.77^{a}{}_{1}$	(±0.06)	$0.73^{a}{}_{2}$	(±0.06)	$0.78^{a}{}_{1}$	(±0.13)	0.76	0.04

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

During week two and six significantly ($P < 0.05$) higher digestibility was found in paddock E compared to paddock F irrespective of the equation used.

2.2.5.10 Pasture availability and quality discussion

At week two of the trial no significant ($P < 0.05$) differences in DM, CP and NDF content could be found between paddocks. A significantly ($P < 0.05$) higher IVOMD was found in paddock F compared to paddock D and E. However the OM digestibility estimates when using the alkane methods showed a lower digestibility within paddock F. A significantly ($P < 0.05$) lower leaf: stem ratio was found within paddock E compared to paddock D and F which did not differ from each other.

The nutrient concentrations in the soil at 0-20 cm depth (6th Nov 2008) were as follows: Ca (985 $mg.kg^{-1}$) and P (39 $mg.kg^{-1}$) in paddock D, Ca (1006 $mg.kg^{-1}$) and P (62.3 $mg.kg^{-1}$) in paddock E and Ca (2166 $mg.kg^{-1}$) and P (21.7 $mg.kg^{-1}$). The Ca content of the pasture in paddock F was significantly ($P < 0.05$) lower than in paddock E and F at 8th Sep and 3rd Nov, although the Ca content of the soil was the highest for this paddock. The highest P content was found in the soil of paddock F, however significantly ($P < 0.05$) lower P content was associated with the pasture at 8th Sep and 3rd Nov.

On the 6th Nov, NDF content was the only quality parameter, of those measured, that differed significantly between paddocks. The alkane digestibility estimates at the end of the trial were the highest in paddock F. A significantly ($P < 0.05$) higher DM content, IVOMD and leaf: stem ratio as well as a significantly lower NDF content was found in paddock F compared to the other two paddocks. The CP content of paddock F was significantly ($P < 0.05$) higher than for paddock D and did not differ significantly ($P < 0.05$) from paddock E. The higher quality associated with the available pasture within paddock F is probably due a higher proportion of the pasture consisting of younger plant material. Young leafy plants are high in moisture content (McDonald *et al.,* 2002), have a higher digestibility (Minson, 1990), are low in fibre (Kilcher, 1981; Cherney *et al.,* 1993; Burns *et al*., 2006) and have a higher CP content (Murray, 1984; McDonald *et al.,* 2002). Grazing animals tend to select the upper more digestible plant parts (Minson, 1990). This is probably the reason why the available pasture was lower in digestibility at the higher stocking rates.

The pasture availability is shown in Table 28. Throughout the season a general decrease in available pasture was evident. This indicates that the removal of plant material was higher than the growth rate of the grass. Within paddock F this trend started to change when pasture availability stayed constant from 19th to 25th Sep. The lower stocking rate in paddock F resulted in a lower rate of removal of plant material in this paddock and plant removal and growth rate reached a balance.

Table 28: Pasture availability during season 2.

Stocking	High		Medium		Low	
	Paddock D (2.5 ha)		**Paddock E (2.6 ha)**		**Paddock F (4.0 ha)**	
	kg DM.ha^{-1}	**Total DM**	**kg DM.ha^{-1}**	**Total DM**	**kg DM.ha-1**	**Total DM**
27-Aug	3773.7	9434.3	3927.4	10211.4	3179.8	12719.3
04-Sep	2255.7	5639.3	3596.9	9352.0	2785.0	11139.9
11-Sep	2082.2	5205.5	3089.5	8032.7	2303.0	9212.1
19-Sep	1596.7	3991.8	1593.4	4142.9	2268.0	9071.9
25-Sep	1351.5	3378.6	-272799.5	-709278.6	2268.0	9071.9

2.2.5.11 DM (Dry matter) Intake

At week two no significant ($P < 0.05$) differences in intake were detected between paddock D and E (Table 29). Intake in paddock F was significantly ($P < 0.05$) lower than in paddock D and E in week two. In paddock E during week six a significantly ($P < 0.05$) higher intake was found compared to paddocks D and F that did not differ significantly ($P < 0.05$) from each other. Higher intakes are usually associated with higher quality (Minson, 1990; Allen, 1996) and quantity (Jung & Shalu, 1989; Dalley *et al*., 1999; Stakelum & Dillon, 2004) of available plant material. This was not the case in this study. Low intakes associated with low stocking (i.e. high availability) and good quality in paddock F indicates that intake was limited by a factor not measured in this study.

Intake in paddock E at week ten did not differ significantly ($P < 0.05$) from either paddock D or F. During week ten, intakes were significantly ($P < 0.05$) higher in paddock D compared to paddock F. Low intakes in paddock F at week ten is probably a result of the extremely low DM content. Studies have shown a lower DM intake when herbage are lower in DM content (Kenney *et al.* 1984; Butris & Phillips, 1987; Phillips *et al.*, 1991 Cabrera Estrada et al., 2003, 2004).

Table 29: Pasture intake during season 2.

Stocking	High		Medium		Low		Total mean	SEM
	Paddock D		Paddock E		Paddock F			
week 2 (3-9 Sep)								
g DM.kg^{-1} W$^{0.75}$	100.8$^{a}{}_{1}$	(±20.0)	105.5$^{a}{}_{1}$	(±12.8)	74.8$^{b}{}_{1}$	(±11.0)	93.7	3.1
g OM.kg^{-1} W$^{0.75}$	90.2$^{a}{}_{1}$	(±17.9)	94.4$^{a}{}_{1}$	(±11.4)	67.4$^{b}{}_{1}$	(±9.9)	84.0	2.8
g DM.100kg^{-1} BW	2.8$^{a}{}_{1}$	(±0.6)	2.9$^{a}{}_{1}$	(±0.4)	2.1$^{b}{}_{1}$	(±0.3)	2.6	0.1
g digestible OM.kg^{-1} W$^{0.75}$	68.2$^{a}{}_{1}$	(±13.5)	72.0$^{a}{}_{1}$	(±8.7)	52.8$^{b}{}_{1}$	(±7.8)	64.3	2.1
week 6 (30 Sep – 6 Nov)								
g DM.kg^{-1} W$^{0.75}$	61.6$^{b}{}_{2}$	(±6.0)	104.4$^{a}{}_{1}$	(±16.8)	67.2$^{b}{}_{12}$	(±10.4)	77.7	3.1
g OM.kg^{-1} W$^{0.75}$	54.0$^{b}{}_{3}$	(±5.3)	91.9$^{a}{}_{1}$	(±14.8)	59.0$^{b}{}_{12}$	(±9.2)	86.3	2.8
g DM.100kg^{-1} BW	1.8$^{b}{}_{2}$	(±0.2)	2.9$^{a}{}_{1}$	(±0.5)	1.9$^{b}{}_{12}$	(±0.3)	2.2	0.1
g digestible OM.kg^{-1} W$^{0.75}$	36.9$^{b}{}_{2}$	(±3.6)	63.1$^{a}{}_{1}$	(±10.2)	40.4$^{b}{}_{2}$	(±6.3)	46.8	2.1
week 10 (28 Sep – 3 Nov)								
g DM.kg^{-1} W$^{0.75}$	76.2$^{a}{}_{2}$	(±10.5)	62.2$^{ab}{}_{2}$	(±10.5)	56.1$^{b}{}_{2}$	(±5.6)	64.8	3.1
g OM.kg^{-1} W$^{0.75}$	68.3$^{a}{}_{2}$	(±9.4)	55.0$^{ab}{}_{2}$	(±9.3)	49.4$^{b}{}_{2}$	(±4.9)	57.6	2.8
g DM.100kg^{-1} BW	2.1$^{a}{}_{2}$	(±0.3)	1.7$^{ab}{}_{2}$	(±0.3)	1.5$^{b}{}_{2}$	(±0.2)	1.8	0.1
g digestible OM.kg^{-1} W$^{0.75}$	47.1$^{a}{}_{2}$	(±6.5)	37.8$^{ab}{}_{2}$	(±6.4)	35.8$^{b}{}_{2}$	(±3.5)	40.2	2.1

^{abc}Row means that do not have a common superscript differ (P < 0.05)

$_{123}$Column means that do not have a common subscript differ (P < 0.05)

Standard deviation indicated in brackets

Within paddock D intake decreased significantly (P < 0.05) from week two compared to week six. Intake in paddock D showed an increasing trend form week six to week ten, with significant differences only detected for intake expressed as g OM.kg^{-1} W$^{0.75}$. No significant (P < 0.05) differences in intake were detected from week two to six in paddock E. From week six to week ten a significant (P < 0.05) reduction in intake was found in paddock E.

Within each paddock significantly (P < 0.05) lower intakes was found at the end compared to the start of the sampling season. This is probably due to the reduction in available plant material over the season.

2.2.5.12 Animal production

Paddock F with the lowest stocking rate achieved the lowest average daily gains (ADG) at the start of the sampling season (Table 30). This is primarily due to a significantly lower pasture intake for animals in this paddock (Table 29). Although ADG in paddock F ($P < 0.05$) only differed significantly form paddock E during this period.

Losses in body weight during the period from 12th Sept to 24th Oct are primarily due to a limitation in protein. High intake in paddock D and E compensated to some degree for the low CP content of the pasture during 28th Aug – 12th Sep. With the significant increase ($P < 0.05$) in CP content from 6th Oct to 3rd Nov ADG improved.

Table 30: Two-weekly average daily gain (kg.day^{-1}) during season 2.

Stocking	High		Medium		Low			
	Paddock D		**Paddock E**		**Paddock F**		**Total mean**	**SEM**
28 Aug - 12 Sep	489.6^{ab}	(±619.8)	819.4^{a}	(±774.1)	294.6^{b}	(±599.7)	534.6	96.9
12 - 25 Sep	-359.0^{a}	(±452.5)	-282.1^{a}	(±413.8)	-154.8^{a}	(±444.5)	-265	96.9
25 Sep - 10 Oct	-483.3^{b}	(±469.8)	-285.2^{ab}	(±281.7)	71.4^{a}	(±875.7)	232.4	96.9
10 - 24 Oct	95.2^{a}	(±967.6)	198.4^{a}	(±325.5)	112.2^{a}	(±1090.0)	135.3	96.9
24 Oct - 7 Nov	544.4^{a}	(±1011.8)	-48.1^{b}	(±291.8)	485.7^{a}	(±339.4)	327.3	96.9

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

Overall weight data did not show any significant differences between paddocks (Table 31).

Table 31: Overall weight data during season 2

	Paddock D		**Paddock E**		**Paddock F**		**Mean**	**SEM**
Initial weight (kg)	165.5^{a}	(±17.7)	160.4^{a}	(±28.3)	165.0^{a}	(±23.1)	163.3	6.4
End weight (kg)	169.5^{a}	(±19.1)	167.7^{a}	(±22.9)	177.6^{a}	(±19.1)	171.3	5.5
ADG (g/day)	54.8^{a}	(±156.9)	98.9^{a}	(±213.1)	173.2^{a}	(±114.1)	110.5	45.4

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

Standard deviation indicated in brackets

2.2.5.13 Total volatile fatty acids

Throughout sampling season 2, no significant ($P < 0.05$) differences were found in rumen volatile fatty acid (VFA) concentration between paddocks (Table 32). Even though significant ($P < 0.05$) changes in total VFA concentration were observed within paddocks D and E, concentrations remained high within all the paddocks. This is an indication of a healthy rumen environment.

Table 32: Total volatile fatty acids (mM) during season 2.

Stocking	High		Medium		Low	
	Paddock D		**Paddock E**		**Paddock F**	
2 - 22 Sep	81.6^{a}_{1}	(±13.2)	80.6^{a}_{1}	(±5.6)	76.0^{a}_{1}	(±4.1)
23 Sep - 13 Oct	68.5^{a}_{12}	(±11.4)	60.5^{a}_{2}	(±5.1)	71.9^{a}_{1}	(±5.0)
14 Oct - 3 Nov	66.7^{a}_{2}	(±13.1)	70.8^{a}_{12}	(±7.0)	67.5^{a}_{1}	(±14.3)

^{abc}Row means that do not have a common superscript differ ($P < 0.05$)

$_{123}$Column means that do not have a common subscript differ ($P < 0.05$)

Standard deviation indicated in brackets

2.2.6 Conclusion

The results of season 1 highlight the importance of protein in animal production. When protein is limiting, gains will be limited even when a lower stocking rate is applied. Available pasture also plays an important role in animal production. When pasture becomes limiting animals will not be able to sustain high gains. Data illustrates that for rehabilitated mine land conditions, higher fertilization rates at pasture establishment should be considered. Further studies are needed on the economic and environmental implications of higher fertilization rates under these conditions. Pasture quality and intake are influenced by animal characteristics, pasture characteristics and the environment. Management of stocking and N fertilization influence animal production through its effect on pasture quality and intake.

During the September and October (first half of season two) animal production was limited by CP content of the pasture. The stocking rates used in this study was not able to sustain satisfactory gains during this period and a protein supplement should be considered.

2.3 Experimental study 3 – *In vitro digestibility influenced by cutting frequency and level of N fertilization*

2.3.1 Introduction

This study was conducted to establish how various fertilization rates applied at different physiological stages of Tall Fescue, could influence the digestibility of the forage utilized by the steers in the animal production system. This information is imperative to determine when and how the fescue pastures should be fertilized during the dry matter utilization periods and growth cycle. This information is also valuable in determining how the Tall Fescue plant will respond to various levels of utilization and fertilizer treatments.

Figure 38: The fertilization plots indicated by the pegs and orange rope between them.

2.3.2 Methodology

Grass was cut at different cutting frequencies; every 2 weeks, 4 weeks, 6 weeks and when 10% of the grass had developed an inflorescence (10% blooming stage). Sampling started in September 2008 and continued up to August 2009.

Nitrogen fertilizer in the form of LAN with 28% N was applied to the grass after each cutting. Levels of N applied after each cutting were; 0 kg $N.ha^{-1}$, 75 kg $N.ha^{-1}$, 150 kg $N.ha^{-1}$, 300 kg $N.ha^{-1}$ and 600 kg $N.ha^{-1}$. The total fertilizer application was calculated over a 9 month period. For example: the 150 kg $N.ha^{-1}$ with 4 week cutting had 9 cuttings over a 9

month period. Thus the fertilizer application every 4 weeks was 1/9 x 150 kg N.ha^{-1}. The 10% blooming stage fertilizer application was done every 6 weeks regardless on when the cutting was done.

The time period over which samples were taken can be divided into 4 different seasons. One cutting per season was selected for each cutting frequency, which was used for lab analyses to give an idea of the changes in quality of the grass during the different growing seasons. The 10 % blooming stage cutting had no sampling for spring since cattle were grazing these plots. Sample seasons were as follows:

- Spring (Oct 2008)
- Summer (January 2009)
- Autumn (April 2009)
- Winter (Aug 2009)

2.3.3 Results and discussion

The following results presented represent one of the most important parameters to measure to determine the quality of the pasture. This was done for the different cutting frequencies to establish the best fertilization rate for the best cutting frequency applicable to the relevant season.

2.3.3.1 2-Week cutting frequency

With the two week cutting frequency (Figure 39) it was clear from the results that the plant material was more digestible in spring at a 150 kg N.ha^{-1} than any other fertilizer treatments.

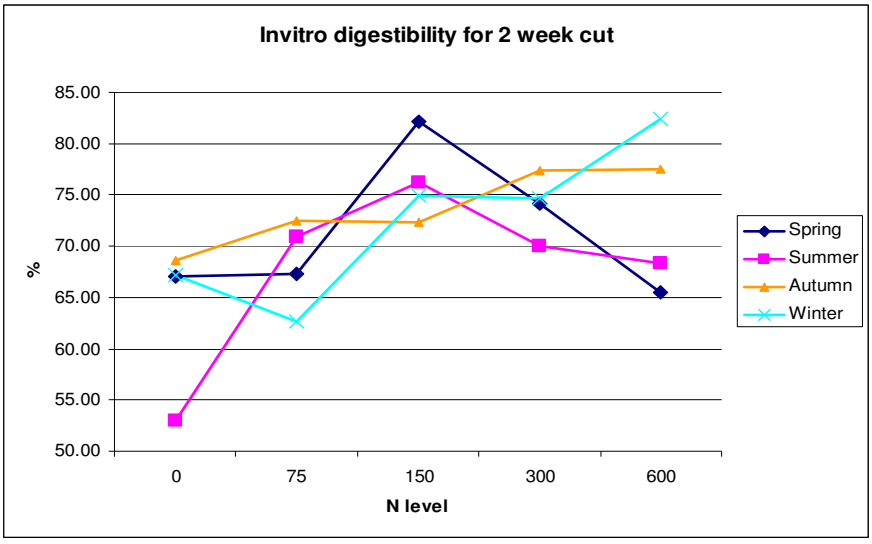

Figure 39: *In vitro* Digestibility for 2 week cut.

It is noted that as soon as the climatic conditions became more suitable for optimal growth for Fescue, the digestibility of the material increased in conjunction with the increase in fertilizer application.

2.3.3.2 4-Week cutting frequency

The four week cutting frequency (Figure 40) once again highlighted that there were no major differences between the 150 kg N.ha^{-1} in the months where the climatic conditions were suitable for fescue growth. It is interesting to note that in Autumn fescue fertilized with 75 kg N.ha^{-1}, Tall fescue had the best digestibility, and as soon as winter kicked in 150 kg N.ha^{-1} was required to obtain similar digestibility.

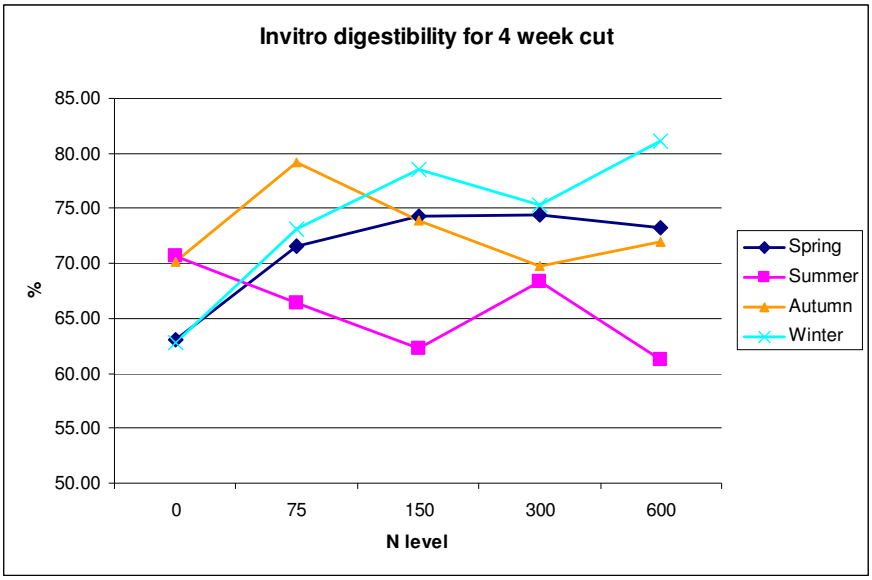

Figure 40: *In vitro* digestibility for 4 week cut.

2.3.3.3 6-Week cutting frequency

It was evident from the 6 week cutting frequency data (Figure 41), that as soon as temperatures became extreme, more than 150 kg N.ha^{-1} of N, resulted in a decline in digestibility, and then as soon as the season became more suitable for growth (Autumn) and when more irrigation was applied (Summer) the higher than 300 kg N.ha^{-1} treatments provided a better digestible material.

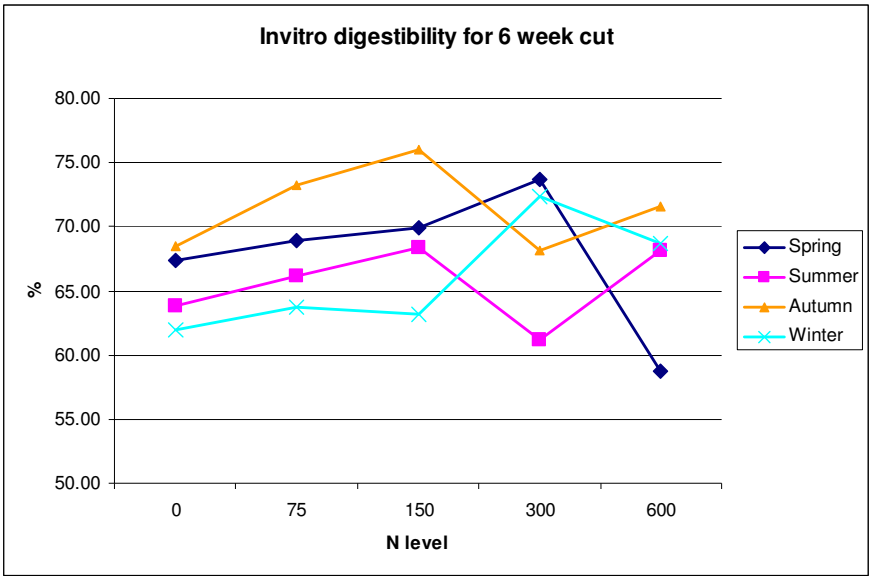

Figure 41: *In vitro* digestibility for 6 week cut.

2.3.3.4 10% blooming stage cut

At the 10% blooming stage cut (Figure 42), the plant is already mature and it is evident that the best digestible material can be expected in winter at 75 kg N.ha^{-1}, however, the data illustrates that this stage of cut is very late in terms of obtaining the best quality material.

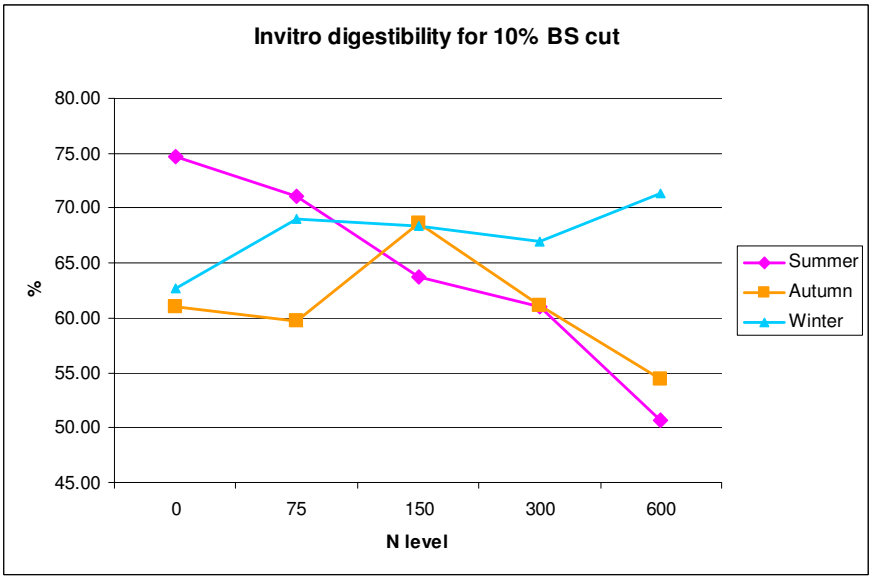

Figure 42: *In vitro* digestibility for 10% blooming stage (BS) cut.

For all the data presented in Figure 39, Figure 40, Figure 41 and Figure 42, when an increase in *in vitro* digestibility is seen, a definite decrease in fibre content is observed. The autumn season sampling showed a higher *in vitro* digestibility with a lower N level compared

to the other seasons. The reason for this being is that Tall Fescue is a temperate species, and that this season is the most favourable time for Tall Fescue growth.

2.3.4 Conclusion

For each of the different cutting frequencies different levels of N are needed for optimum *in vitro* digestibility per season, to achieve a maximum digestibility all year round. The following conclusions can be made from the study, which serves as a recommendation for fertilization, to obtain the best quality Tall Fescue under these irrigated conditions for the different seasons.

2 week cutting

Spring 150 kg N.ha^{-1}
Summer 150 kg N.ha^{-1}
Autumn 300 kg N.ha^{-1}
Winter 600 kg N.ha^{-1}

4 week cutting

Spring 150 kg N.ha^{-1}
Summer 0 kg N.ha^{-1}
Autumn 75 kg N.ha^{-1}
Winter 600 kg N.ha^{-1}

6 week cutting

Spring 300 kg N.ha^{-1}
Summer 150 kg N.ha^{-1}
Autumn 150 kg N.ha^{-1}
Winter 300 kg N.ha^{-1}

10 % blooming stage cutting

Summer 0 kg N.ha^{-1}
Autumn 150 kg N.ha^{-1}
Winter 600 kg N.ha^{-1}

2.4 Experimental study 4 - *Salinity effects on seed germination of different forage grass species*

2.4.1 Introduction

Ionic imbalance and the toxic effects of ions like Na^+ impair germination of seeds. Salinity tolerance of seedlings is often lower compared to the established plant. Germination of most species was delayed with an increase in salinity. Germination started earlier at high salinity in the more salt-tolerant species than in the less tolerant species. The salt-tolerant species also had a higher germination rate.

Plants can be classified into halophytes (salt tolerant) and glycophytes (salt sensitive) according to their behaviour in saline conditions. Halophytes maintain a high turgor potential by accumulation of ions and glycophytes are unable to adapt osmotically under salt stress (Ashraf, 2004). Some of the non-halophytes can germinate under high salinity conditions, but they cannot sustain growth under these conditions (Hanslin & Eggen, 2005).

The timing of germination is found to be a very important part in the life cycle of halophytes. Germination in a salt stressed environment will expose the seedling to a high risk of mortality. Excess salt reduces the seedling's ability to extract water from its surroundings and will lead to wilting and death (Easton et al., 2009). High salt concentrations are detrimental to seed germination due to a decrease in osmotic potential of the soil solution with the increasing salt concentration. Seeds will begin to shrink after a few days in soil with a very high salt concentration and will not further be viable (Muscolo et al., 2003).

Germination and early growth stages are critical stages for the establishment of plant populations under saline conditions. Grasses were found to differ in their upper limit of salinity tolerance as well as an increase in salinity leads to a delayed and a reduction on seed germination (Al-Khateeb, 2006).

The main salt components in saline soils are Na^{+}, Mg^{2+}, Ca^{2+}, Cl^{-} and SO^{4-}. It was found in most studies that the effects of salinity on plants were studied using only sodium chloride (NaCl) or dilution of seawater (Tobe et al., 2000). NaCl was used in this study since it is a common salt found to adversely affect plant growth under natural conditions, even though no single salt solutions are found in nature (Bayuelo-Jimènez et al., 2002).

Germination can be affected by salinity through the lower osmotic potential, thus the decrease in entry of water, and also the intake of ions at toxic levels. Francois & Maas (1994) found the percentage of germination was not generally decreased by salinity, but found the rate of germination and emergence has been delayed.

Salinity is becoming a big problem in irrigated lands of arid and semi-arid regions. 10% of the total land surface is affected by salt-related problems that are of man-made and natural origin (Pasternak *et al*., 1993). Degraded lands are usually left for the use of pastures, but the forage produced from these lands is usually low and unstable. This shortage of fodder can be overcome by growing salt-tolerant forage species if the saline underground water or if saline drainage water could be used for irrigation purposes.

The use of saline water for irrigation can also lead to the rehabilitation of arid or degraded lands being more productive (Tomar *et al*., 2003). Good quality water for

irrigation is becoming scarcer, thus the use of salinity water is becoming to play an important role. To evaluate the quality of water means that all the individual concentration of specific ions contributing to salinity and not only the total of salt concentration must be evaluated (Grieve *et al*., 2004).

Salinity can reduce plant growth or damage the plant through (Ramoliya & Pandey, 2002): 1) Osmotic effect, 2) Toxic effect of ions and 3) Imbalance of the uptake of essential nutrients. An increase in salinity causes alterations in the soil structure that will result in a decrease of plant cover and lead to soil erosion. Thus the use of salt-tolerant plants may reduce these negative effects of salinity. Salt-tolerant implies the preservation of a basic ionic balance in the cells and metabolic changes that decreases salt injury (Radhakrishnan *et al*., 2006). Salt-tolerance in plants is very complex since it involves morphological and developmental changes as well as the physiological and biochemical processes (Muscolo *et al*., 2003).

Plants are found to be the most sensitive to salinity during the following stages; emergence and early seedling stages. Levels of tolerance to salinity are found to increase as growth proceeds from the vegetative to the reproductive stages (Francois & Maas, 1994).

Root growth was found to be less affected by increasing salinity levels compared to shoot growth (Munns & Termaat, 1986). An adaptive mechanism to salt stress observed for the plant is to develop a larger root system. Thus the shoot to root ratio is reduced under salt stress (Zhao *et al*, 2007).

During salt stress an increase in energy is needed to extract water from the soil and to make the adaptations (physical and biochemical) needed to grow. Thus energy is being diverted from processes needed for normal growth to these adaptive mechanisms (Rhoades & Loveday, 1990).

Due to the variability of soil conditions found on the rehabilitated land, and especially under the intensive management of a pivotal irrigation system, it is imperative to determine the most optimally adapted grass species that can grow under these systems. The one most determinant factor of plant growth is moisture, and these pasture systems on the rehabilitated mine land are irrigated with gypsiferous water. This water is saline and can affect the germination potential of grass species. Therefore, it is imperative to investigate to what extent the salinity of this water can have on this management system. The research component reported on in this report, focuses on species selected from previous research trials, which have shown the most potential for such systems. The germination rate of 21 different grasses were evaluated using water solutions of different levels of electrical

conductivity (salinity). This was done to determine why there are establishment problems under saline conditions and also to recommend species and cultivars for future use.

2.4.2 Methodology

Using ISTA (International Seed Testing Authority) guidelines of 1985 were used for the germination trial. One hundred seeds of each grass in Table 32 were placed in a Petri dish (90mm) on a double layer of Whatman number two filter paper. The filter paper was kept wet with the appropriate water treatment. These treatments were made from adding $CaSO_4$ in different amounts to distilled water to achieve the following EC solutions: distilled water (A), 100 $mS.m^{-1}$ (C), 200 $mS.m^{-1}$ (D), 400 $mS.m^{-1}$ (E), 600 $mS.m^{-1}$ (F), 800 $mS.m^{-1}$ (G), 1000 $mS.m^{-1}$ (H) and the gypsiferous mine water from Kleinkopje colliery pivot, Tweefontein, near Witbank (B) which had a water quality of approximately 435 $mS.m^{-1}$. The treatment B contained high levels of Ca^{2+} and $SO4^{2-}$ salts; a full chemical analyses is given in Table 33.

Tests were done in a growth chamber on the experimental farm of the University of Pretoria. A constant 25 °C and a twelve-hour light and dark intervals were kept in the growth chamber for 36 days. Seeds germinated were counted and then removed each day. The germination trial was done twice with four replications each. A complete randomized design was followed.

Table 33: List of species tested.

Specie	Cultivar
Antephora pubescens	Wollie
Brachiaria	
Cenchrus ciliaris	Gayndalt 226
Cenchrus ciliaris	Molopo
Chloris gyana	Katambora
Cynodon dactylon	Bermuda grass
Dactylis glomerata	Cristobal
Digitaria eriantha	Irene
Eragrostis curvula	Ermelo
Eragrostis curvula	Agpal
Festuca arundinacea	Fuego
Festuca arundinacea	Dovey

Lolium multiflorum	Agriton
Lolium multiflorum	Archie
Lolium perenne	Bronsyn
Lolium perenne	Bealey
Panicum coloratum	Klein vrede
Panicum maximum	PUK 8
Panicum maximum	Gatton
Paspaum notatum	Pensacola
Pennisetum clandestinum	Whittet

Table 34: Chemical analyses of water taken from Kleinkopje colliery pivot, Tweefontein, near Witbank.

pH	7.6	Zn ($mg.L^{-1}$)	0.005
EC ($mS.m^{-1}$)	435.25	P ($mg.L^{-1}$)	0.075
Ca ($mg.L^{-1}$)	563	S ($mg.L^{-1}$)	1176.75
Mg ($mg.L^{-1}$)	498.75	B ($mg.L^{-1}$)	0.1
K ($mg.L^{-1}$)	37.07	Cl ($mg.L^{-1}$)	38.9
Na ($mg.L^{-1}$)	96.75	CO_3 ($mg.L^{-1}$)	0
Fe ($mg.L^{-1}$)	0.008	HCO_3 ($mg.L^{-1}$)	0
Cu ($mg.L^{-1}$)	0	NH_4 ($mg.L^{-1}$)	18.25
Mn ($mg.L^{-1}$)	0.005	NO_3 ($mg.L^{-1}$)	53.25

2.4.3 Results and discussion

It can be noted from the species presented in this report that different species have different affinities to the various saline solutions used in the trial. It is noted that there are differences between different types of grasses, such the creeping grass (*Cynodon dactylon)* versus tufted grasses *(all the other grasses presented)* as well as temperate species (*Festuca arundinaceae)* and the sub-tropical grasses *(all the other grasses presented).* It is therefore important to note that the pasture selected for the purpose of rehabilitation should take into consideration the adaptability of the species to the extra ordinary growing conditions (growth medium and moisture regime), the climatic conditions as well as the post mining

land capability which will determine the type (creeping versus tufted specie) used for these land use systems.

To illustrate the effects of saline water on the germination of the different species evaluated, the data is presented as the final germination percentage after seeds are affected by the treatments.

2.4.3.1 Final germination percentage (FGP)

Figure 43 represents the species with the **highest** final germination percentage. With an increase in salinity a slight decrease in final germination percentage can be seen. This can be as an indication of the species tolerance to salinity.

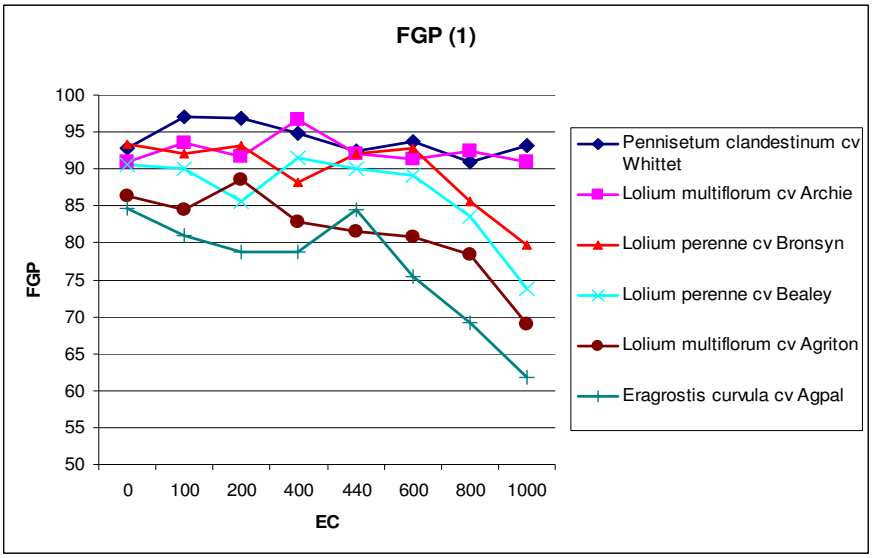

Figure 43: The group of species with the highest FGP.

It is evident from this data, that Kikuyu (*Pennisetum clandestinum*), showed the highest germination tolerance to saline conditions, and followed by the temeperate *Lolium* species. It was interesting to note, that the locally adapted species *Eragrostis curvula* also performed well up and till the approximate 450 $m.Sm^{-1}$ level. Figure 44, however, represents the species with an **intermediate** final germination percentage. A decrease in final germination percentage is greater with increased levels of salinity compared to species in Figure 43.

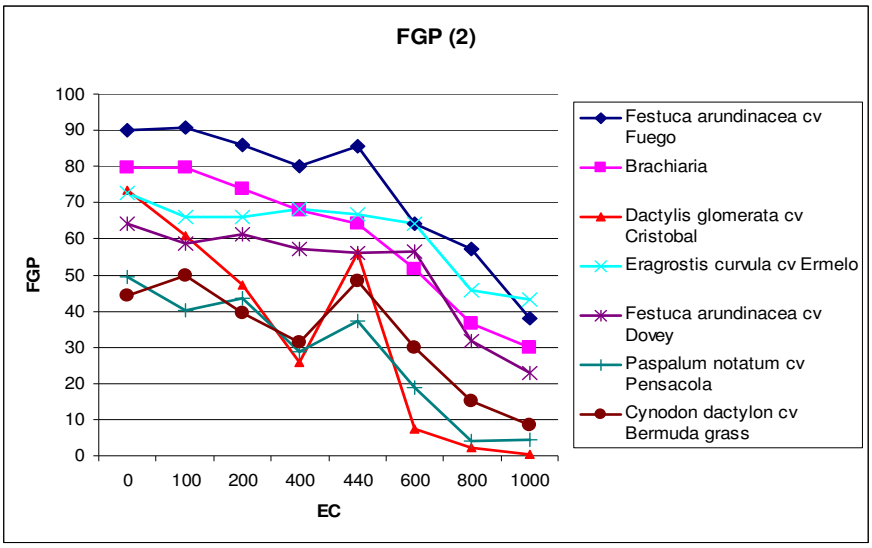

Figure 44: The group of species with an intermediate FGP.

It is shown in the data in Figure 44, that the three species showing the most potential are the species currently used in research trials and in practice providing good responses overall. A decrease in FGP can be seen for species in Figure 44 with increased levels of salinity. This decrease in FGP is greater compared to Figure 43 with increased levels of salinity. From 600 $mS.m^{-1}$ and higher a sharp decrease in FGP is observed for all species in Figure 44. The species, which had the lowest final germination percentages, are grouped together in Figure 45. Here a definite decrease in final germination percentage with increasing levels of salinity can be observed.

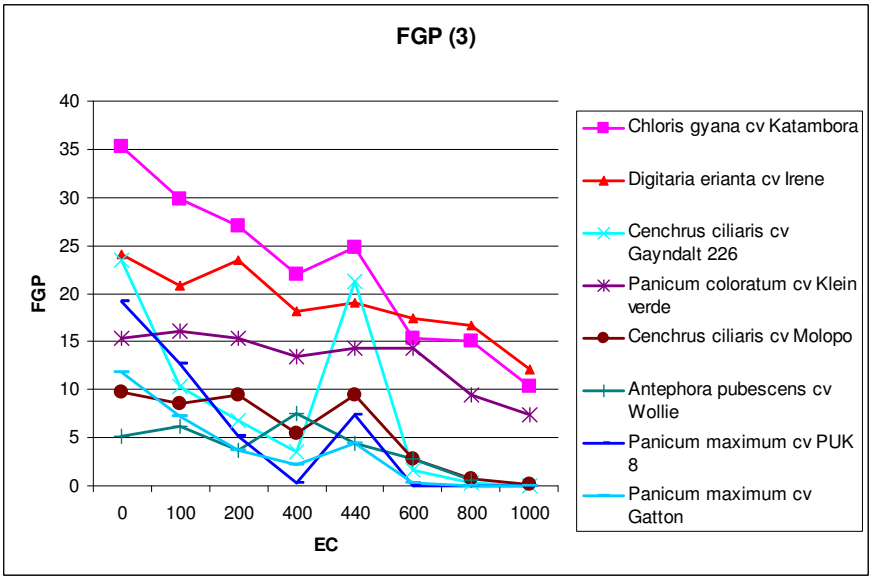

Figure 45: The group of species with the lowest FGP.

These species shown in Figure 45, were the most sensitive to increased levels of salinity, with some species where no germination is observed for treatments 600 ms.m^{-1} and higher.

2.4.3.2 Onset of germination

The day when germination starts can also be influenced by level of salinity. In Figure 46 & Figure 47, germination was only delayed with a day or less. For these species increased levels of salinity did not have a great impact on start of germination.

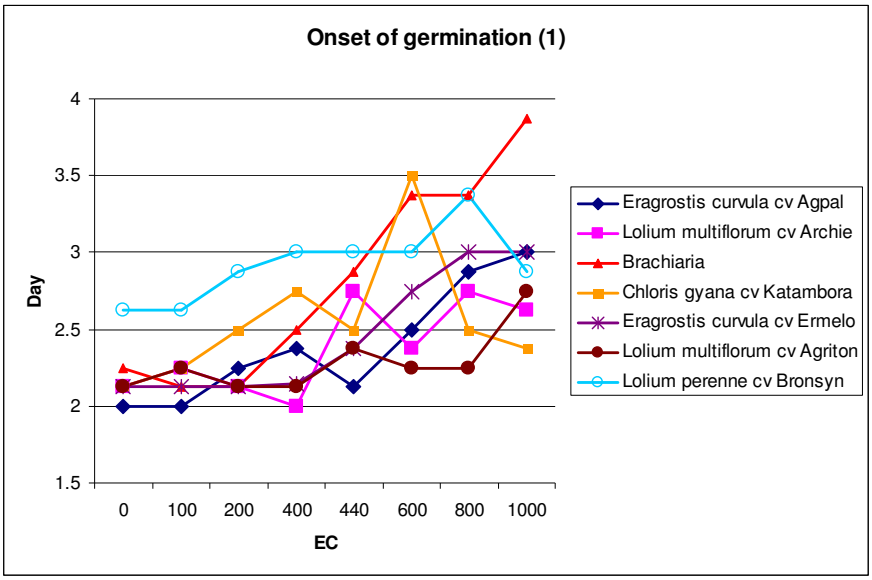

Figure 46: Onset of germination for Group 1.

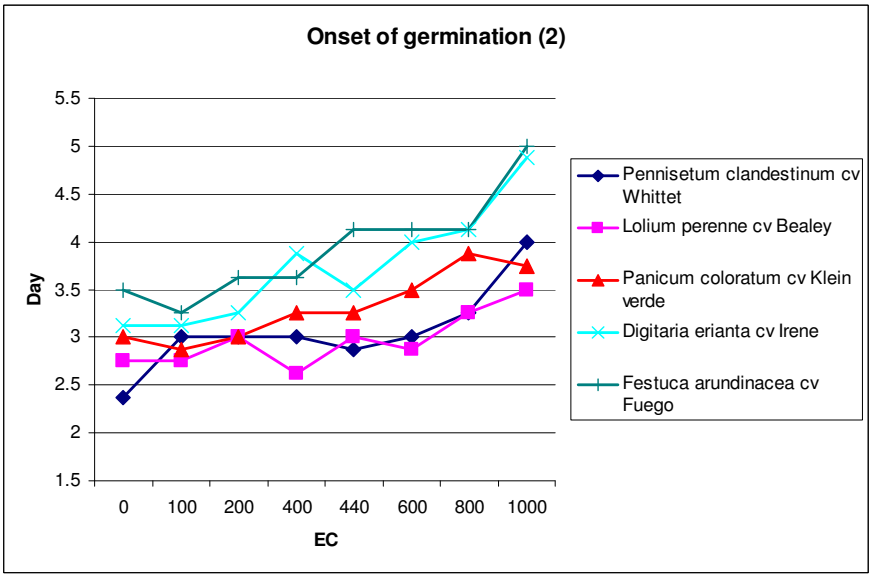

Figure 47: Onset of germination for Group 2.

In Figure 48 the start of germination was greatly delayed with increasing levels of salinity. For some species no germination occurred from 600 mS.m^{-1} and higher. *Panicum maximum* cv PUK 8 germination only started at day 11.

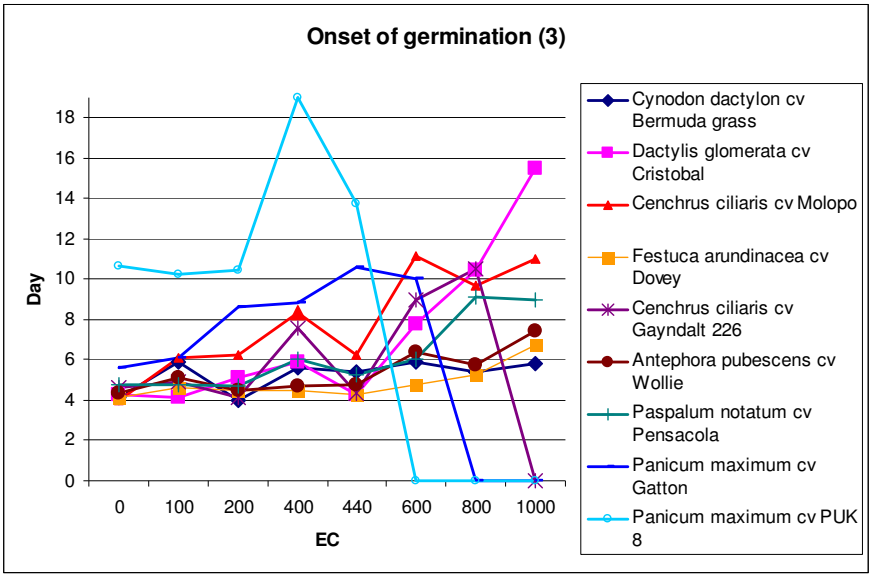

Figure 48: Onset of germination for Group 3.

2.4.3.3 T50

T50 is the time needed for 50% of the final germination percentage of seeds to germinate. In Figure 49. Figure 50 & Figure 51, T50 was reached at a later time with increased levels of salinity. In the three graphs the different levels of tolerance to salinity can be seen, with Figure 49 having the most tolerance and Figure 51 having the lowest tolerance to salinity.

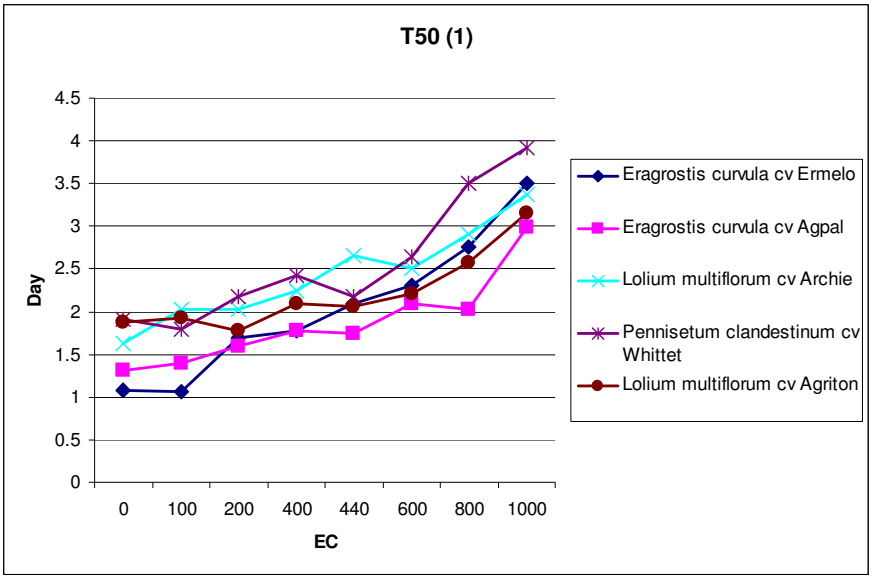

Figure 49: T50 of Group 1.

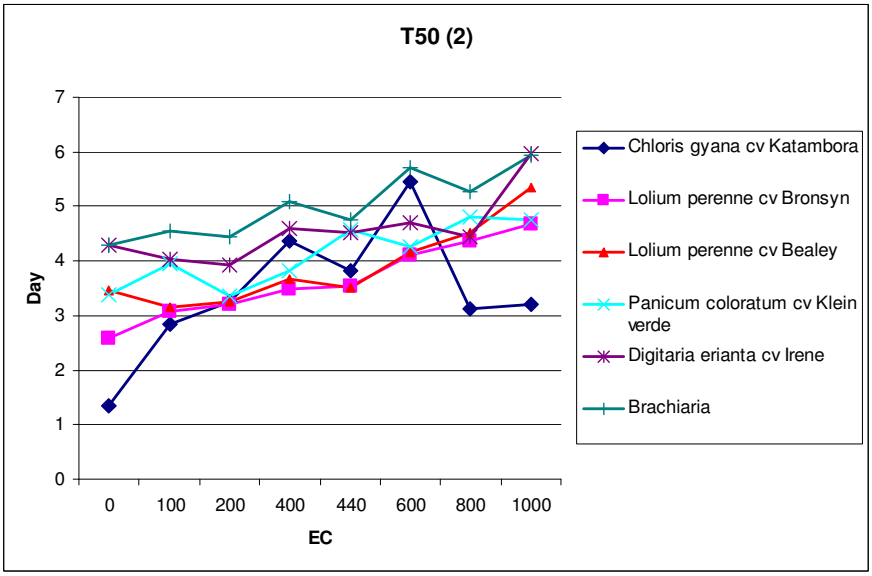

Figure 50: T50 of Group 2.

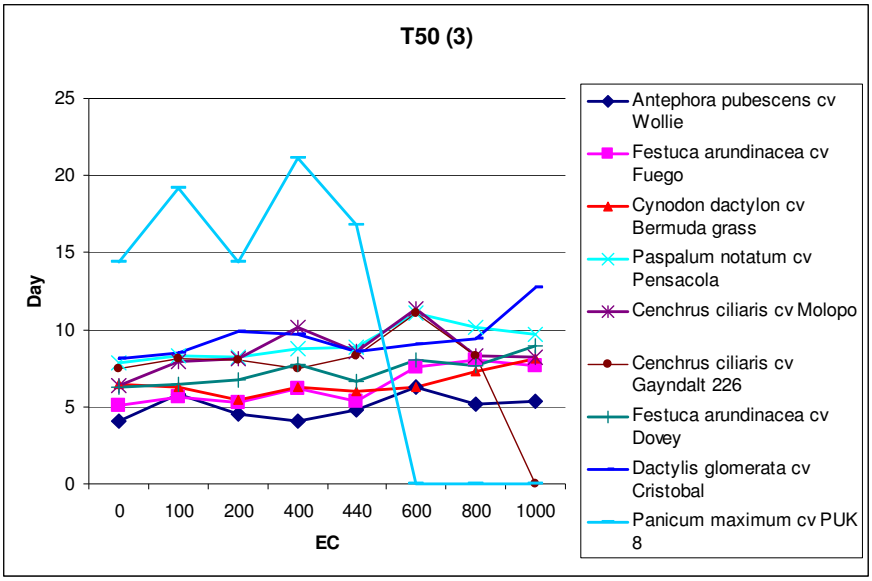

Figure 51: T50 of Group 3.

2.4.3.4 Speed of germination (S)

Speed of germination (no. of seeds germinated per day) can be seen to decrease with increasing levels of salinity. In Figure 52 a significant decrease in speed of germination can be seen from 600 $mS.m^{-1}$ and higher. This data is presented in Figure 52, Figure 53 & Figure 54, and clearly highlights which species germinate the quickest.

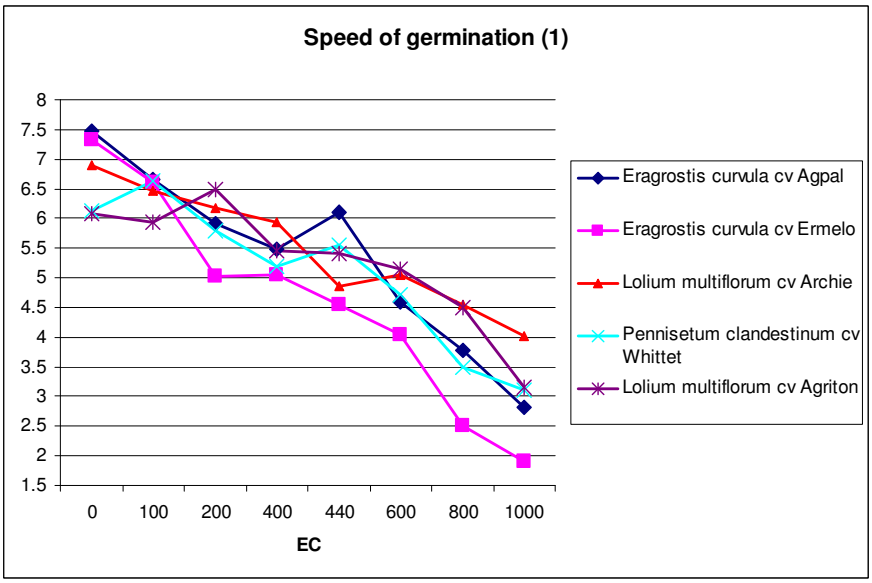

Figure 52: Speed of germination of Group 1

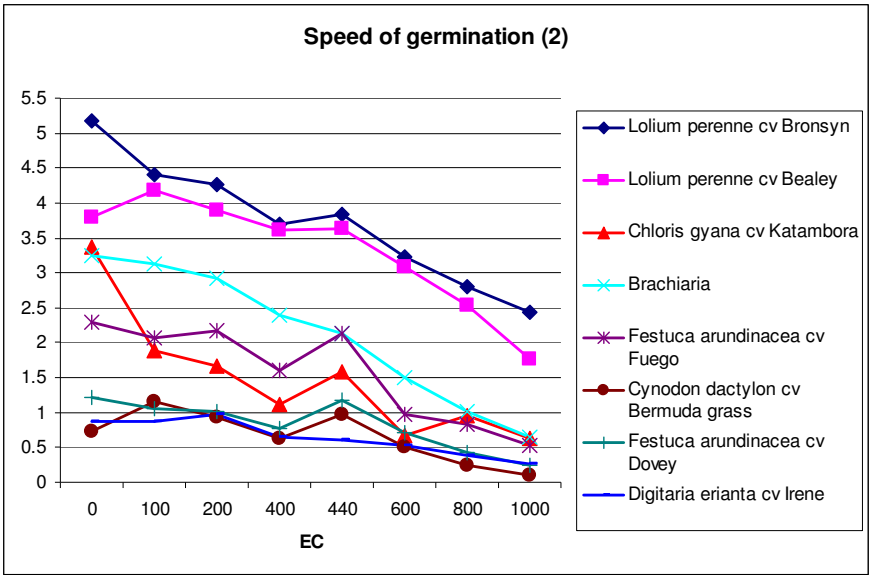

Figure 53: Speed of germination of Group 2.

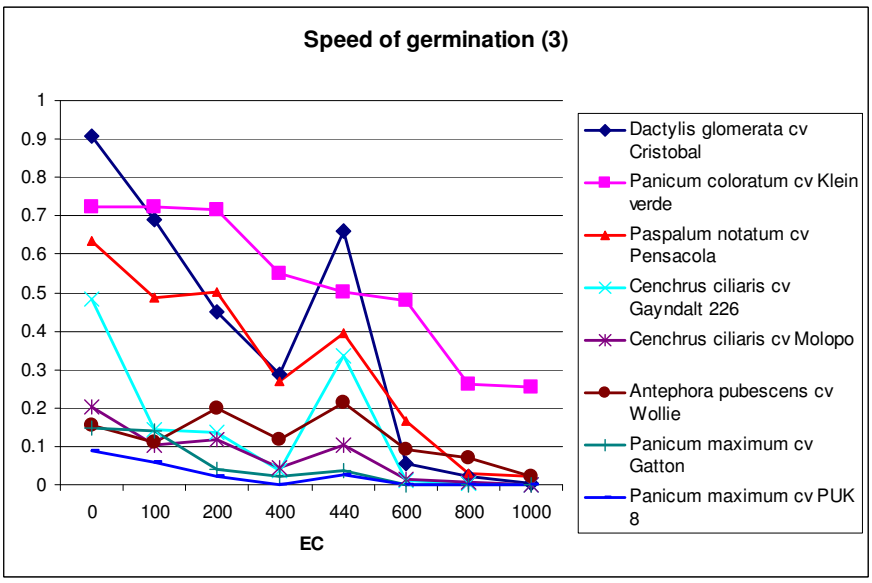

Figure 54: Speed of germination of Group 3.

2.4.3.5 Germination %

Of all the species tested previously, it was decided to do a more detailed germination and survival study on the species commonly used on rehabilitated areas. These species included *Cynodon dactylon, Digitaria eriantha, Eragrostis curvula* and *Festuca arundinacea.* These species were not only germinated using the ISTA germination procedure, but were also germinated in a pot trial, using soil imported from a surface coal mine.

It is clear from the results presented in Figure 55, that three of the four species tested, had a 50% germination at around 400 mS.m^{-1}.

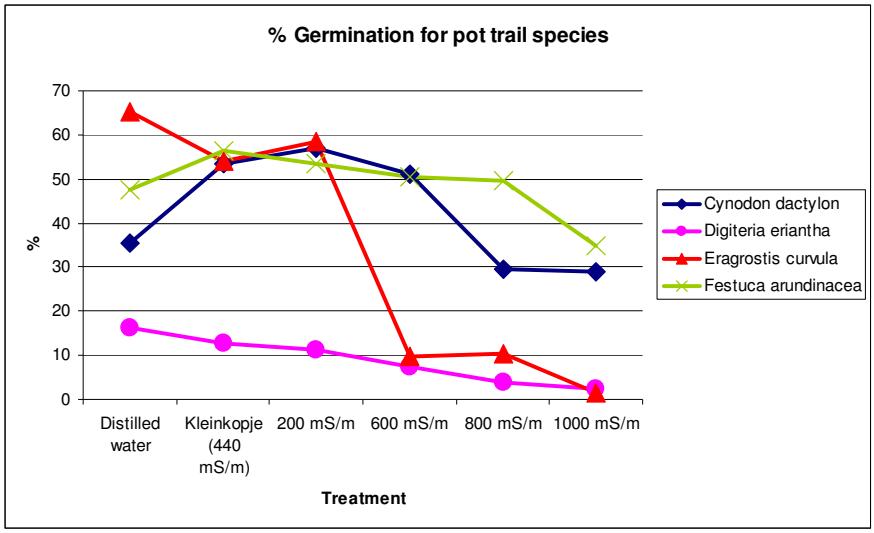

Figure 55: % Germination for *Cynodon dactylon, Digitaria eriantha, Eragrostis curvula* and *Festuca arundinacea* during pot trial with increasing levels of salinity.

2.4.3.5.1 Cynodon dactylon

Cynodon dactylon had similar results for the Kleinkopje (440 mS.m^{-1}), 200 mS.m^{-1} and 600 mS.m^{-1} treatments. A decrease in % germination can be seen for treatments 800 mS.m^{-1} and 1000 mS.m^{-1}. Distilled water also showed a lower % germination compared to the salinity treatments of Kleinkopje (440 mS.m^{-1}) and 200 mS.m^{-1}.

2.4.3.5.2 Digitaria eriantha

*Digitaria eriantha h*ad the lowest % germination in Figure 55 of all the species used during the trial. A decrease in % germination is seen with increasing levels of salinity.

2.4.3.5.3 Eragrostis curvula

Eragrostis curvula had the highest germination % of all species for the distilled water treatment as seen in Figure 55. For treatments Kleinkopje (440 $mS.m^{-1}$) and 200 $mS.m^{-1}$ the % germination had been between 50% and 60%. Treatments 600 $mS.m^{-1}$ and higher salinity levels illustrated a big decrease in % germination (10% - 0%) compared to the other salinity treatments. Thus salinity levels of 600 $mS.m^{-1}$ and higher decreases % germination significantly for *Eragrostis curvula*

2.4.3.5.4 Festuca arundinacea

Festuca arundinacea had a germination % of between 47% and 57% excluding the 1000 $mS.m^{-1}$ treatment. With increasing levels of salinity a small decrease in % germination is seen compared to the other species. Treatment 1000 $mS.m^{-1}$ showed a decrease in % germination but this % germination was higher (35%) than the other species at this very high salinity level. Increasing levels of salinity affects % germination of *Festuca arundinacea* the least of all the species tested.

2.4.3.6 Survival

The % germination obtained during the germination trial done previously is compared to the % germination obtained during the duration of the pot trial. The pot trial % germination is an indication of how many plants will survive the salinity treatments over time. The pot trial was also done over a longer time period (70 days) compared to the germination trial (30 days). This gave seeds that were delayed in the germination trial time to germinate during the pot trial.

2.4.3.6.1 Cynodon dactylon

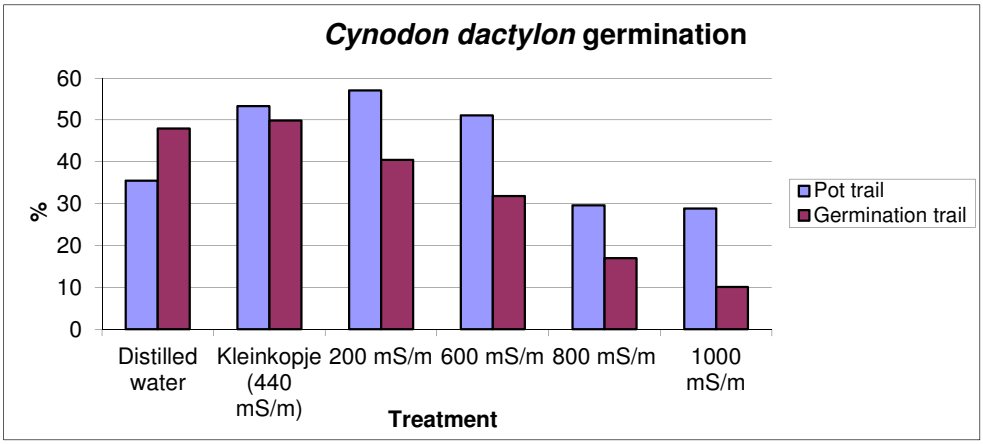

Figure 56: % Germination for *Cynodon dactylon* obtained during the pot trial and germination trial.

For all the salinity treatments in Figure 56 the % germination was higher in the pot trial compared to the germination trial. This can be explained by the delayed germination by increasing levels of salinity. When looking at the distilled water treatment the % germination is lower for the pot trial compared to the germination trial. This shows a decrease in survival of *Cynodon dactylon* over time and not a delay in germination since the distilled water contained no added salts.

2.4.3.6.2 Digitaria eriantha

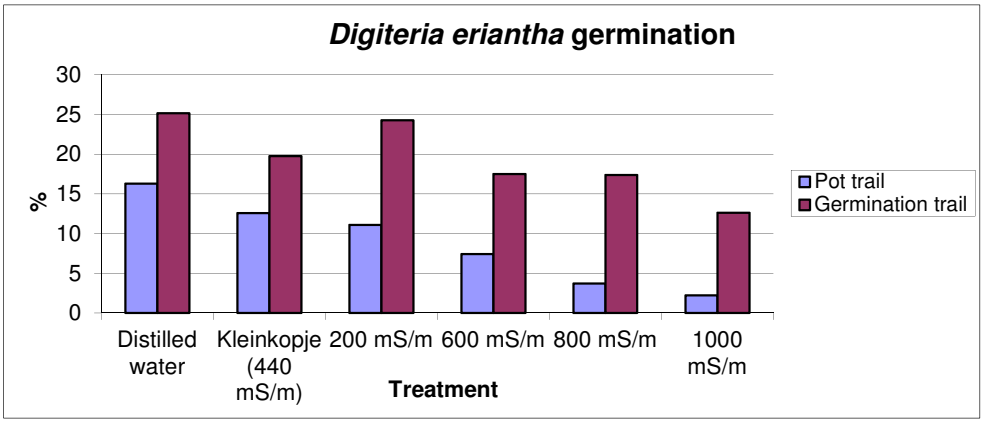

Figure 57: % Germination for *Digitaria eriantha* obtained during the pot trial and germination trial.

For all the treatments the % germination was lower in the pot trial compared to the germination trial in Figure 56, Figure 57, Figure 58 & Figure 59. This indicates the survival of *Digitaria eriantha* being negatively affected by increasing levels of salinity.

2.4.3.6.3 Eragrostis curvula

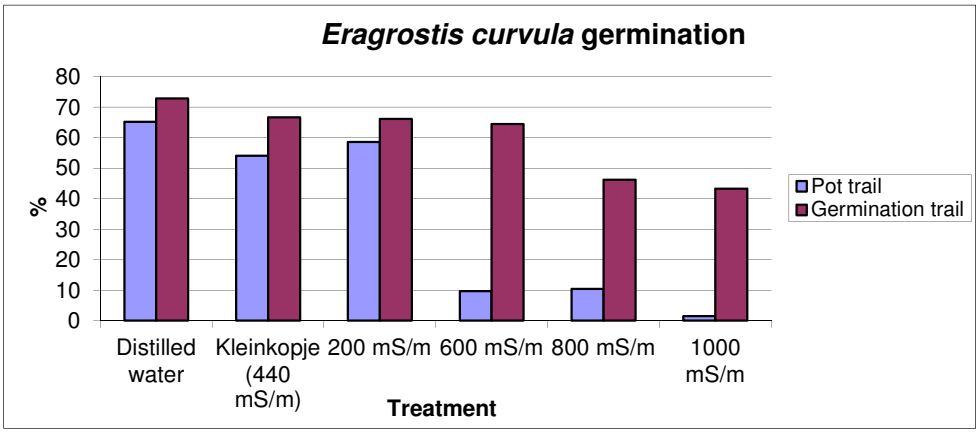

Figure 58: % Germination for *Eragrostis curvula* obtained during the pot trial and germination trial.

For all treatments the pot trial had lower % germination compared to the pot trial. With treatments 600 mS.m^{-1}, 800 mS.m^{-1} and 1000 mS.m^{-1} a big decrease in % germination can be seen in Figure 58 compared to the germination trial % germination.

2.4.3.6.4 Festuca arundinacea

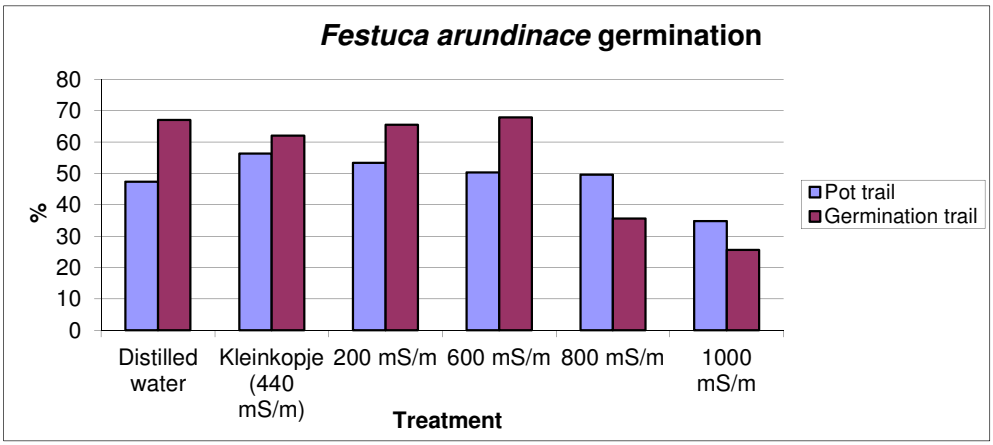

Figure 59: % Germination obtained during the pot trial and germination trial.

It can thus be said that the survival of *Eragrostis curvula* is significantly decreased with salinity levels from 600 $mS.m^{-1}$ and higher.

Percentage germination was a bit lower in the pot trial compared to the germination trial in Figure 59 for treatments: distilled water, Kleinkopje (440 $mS.m^{-1}$), 200 $mS.m^{-1}$ and 600 $mS.m^{-1}$. Thus survival of *Festuca arundinacea* decreases with increased levels of salinity. During the pot trial the % germination was higher compared to the germination trial for treatments 800 $mS.m^{-1}$ and 1000 $mS.m^{-1}$, this can be due to the high levels of salinity delaying the germination process and if give more time the seeds have a chance to germinate during the pot trial.

2.4.4 Conclusion

Increasing levels of salinity is seen to have an effect on plant growth. The biggest problem during establishment is germination and survival of the plant. The root growth is seen to be more sensitive to increasing levels of salinity for all four the species used. During the pot trial *Festuca arundinacea* was seen to have the most root growth of the species used. This can be seen as having the highest tolerance to increasing levels of salinity. *Eragrostis curvula* on the other hand had the lowest root growth of all, indicating being the most sensitive to increasing levels of salinity.

Survival can also be considered in selection of which specie to be use. *Festuca arundinacea* (first) and *Cynodon dactylon* (second) can be used under saline conditions for pasture establishment. *Eragrostis curvula* will not be recommended to be used with salinity levels of 600 $mS.m^{-1}$ and higher. *Digitaria eriantha* had the lowest survival of all four species, thus if wanted to use then more seeds than usual will be needed for establishment.

Final germination percentage (FGP) and speed of germination (S) for all species decreased with an increase in salinity. The same was found in the study done by Dai et al in 2009. With an increase in salinity all species were seen to have a delay in onset of germination, this can be explained by looking at the three different phases of germination discussed by Kebreab and Murdoch in 1999:

- Uptake of water by the seed (an increase in water potential will decrease rate of water uptake)
- Lag phase (metabolic processes in preparation for radicle emergence)
- Radicle elongation

The delay in onset of germination with increased levels of salinity was also observed by Bayuelo-Jimènez et al in 2002. The time to reach 50% of FGP (T50) was also found to be reached later with increased levels of salinity. From the results *Panicum maximum* no germination was observed from 600 $mS.m^{-1}$ and higher. This specie also had the lowest germination percentage of all. This might be due to it having a dormancy period of 3 to 5 years.

Lolium sp had the highest germination percentage all over and can thus be considered to be used under saline conditions. *Festuca* also did well under these conditions, but a clear difference can be seen between the 2 cultivars. Fuego cultivar outperformed the Dovey cultivar.

In Table 34, a ranking of species has been compiled from all the tests done, to illustrate which species are most adapted to the conditions prevalent for an irrigation system using gypsiferous mine water.

Table 35: Species ranked according to tolerance to salinity. Rank 1 being the most tolerant and 3 least tolerant.

Specie	Cultivar	Rank
Eragrostis curvula	Ermelo	1
Eragrostis curvula	Agpal	1
Lolium multiflorum	Agriton	1
Lolium multiflorum	Archie	1
Lolium perenne	Bealey	1
Pennisetum clandestinum	Whittet	1
Brachiaria		2
Cynodon dactylon	Bermuda grass	2
Digitaria eriantha	Irene	2
Festuca arundinacea	Fuego	2
Festuca arundinacea	Dovey	2
Lolium perenne	Bronsyn	2
Antephora pubescens	Wollie	3
Cenchrus ciliaris	Gayndalt 226	3
Cenchrus ciliaris	Molopo	3
Chloris gyana	Katambora	3

Dactylis glomerata	Cristobal	3
Panicum coloratum	Klein vrede	3
Panicum maximum	PUK 8	3
Panicum maximum	Gatton	3
Paspaum notatum	Pensacola	3

2.5 Experimental study 5 - *Seedling growth of Cynodon dactylon, Eragrostis curvula, Festuca arundinacea and Digitaria eriantha affected by level of salinity*

2.5.1 Introduction

To determine which grass specie is best adapted to be used for irrigation with saline water (gypsiferous mine water) where difficulties with the establishment of the pasture are observed. The study concentrates on the following criteria before making a selection: (1) Shoot to root ratio with increasing levels of salinity (2) Total plant growth over the trial period

Seedling growth of *Cynodon dactylon, Eragrostis curvula, Festuca arundinacea and Digitaria eriantha* were observed with increased levels of salinity. The shoot and root masses were measured separately to determine the inhibition of salinity on the growth of each of these plant components over a time period.

2.5.2 Methodology

The four most frequently used grass species (*Cynodon dactylon* cv Bermuda, *Eragrostis curvula* cv Ermelo, *Festuca arundinacea* cv Dovey and *Digitaria eriantha* cv Irene) used in mine land rehabilitation were grown in seedling trays in one of the glasshouses on the experimental farm of the University of Pretoria. The trays were watered once a day with the appropriate water treatment for 4 weeks and there after only watered twice a week with treatment and once a week all plants received the same nutrient solution. These treatments were made from adding $CaSO_4$ in different amounts to distilled water to achieve the following EC solutions: distilled water

(A), 200 mS.m^{-1}

(B) water for Kleinkopje colliery pivot, Tweefontein, near Witbank

(D) 400 mS.m^{-1},

(F) 600 mS.m^{-1},

(G) 800 mS.m^{-1},

(H) 1000 mS.m^{-1} and

Treatment B is approximately, 435 mS.m^{-1}. The treatment B contained high levels of Ca^{2+} and $SO4^{2-}$ salts; a full chemical analysis is given in Table 35. Plants were allowed to grow for 6 weeks before being harvested for 5 consecutive weeks. At each harvest three cells in a tray containing the same species were removed from each of the three replicated. Root mass and shoot mass were measured separately at each harvest. The trial was a randomized block design.

Table 36: Chemical analysis of water taken from Kleinkopje colliery pivot, Tweefontein, near Witbank.

pH	7.6	Zn (mg.L^{-1})	0.005
EC (mS.m^{-1})	435.25	P (mg.L^{-1})	0.075
Ca (mg.L^{-1})	563	S (mg.L^{-1})	1176.75
Mg (mg.L^{-1})	498.75	B (mg.L^{-1})	0.1
K (mg.L^{-1})	37.07	Cl (mg.L^{-1})	38.9
Na (mg.L^{-1})	96.75	CO_3 (mg.L^{-1})	0
Fe (mg.L^{-1})	0.008	HCO_3 (mg.L^{-1})	0
Cu (mg.L^{-1})	0	NH_4 (mg.L^{-1})	18.25
Mn (mg.L^{-1})	0.005	NO_3 (mg.L^{-1})	53.25

2.5.3 Results and discussion

With respect to some of the data, results for a few species will be presented and discussed.

2.5.3.1 Cynodon dactylon

In Figure 60 we can observe an increase in root mass only from week 9 for all treatments. The most significant increase in root mass on week 10 is for treatment D (0.5g)

and for F (0.28g). On week 10, treatment F has the highest increase in root mass (0.7g), then D (0.55g) and B (0.48g). All other treatments had a root mass of less than 0.2g.

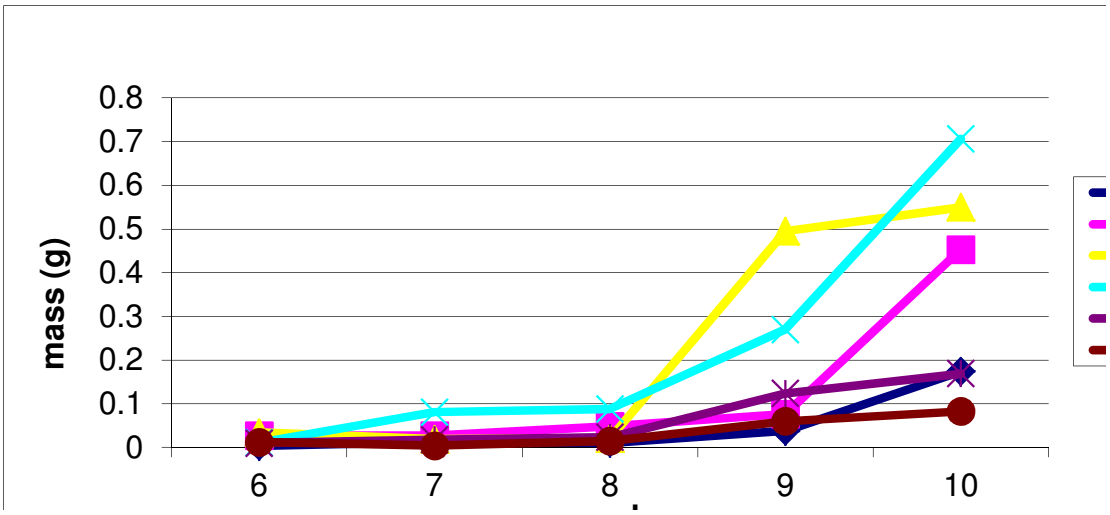

Figure 60: Average root mass for *Cynodon dactylon*.

Shoot mass seen in Figure 61 started to increase from week 7 for treatment F and on week 8 for the other treatments.

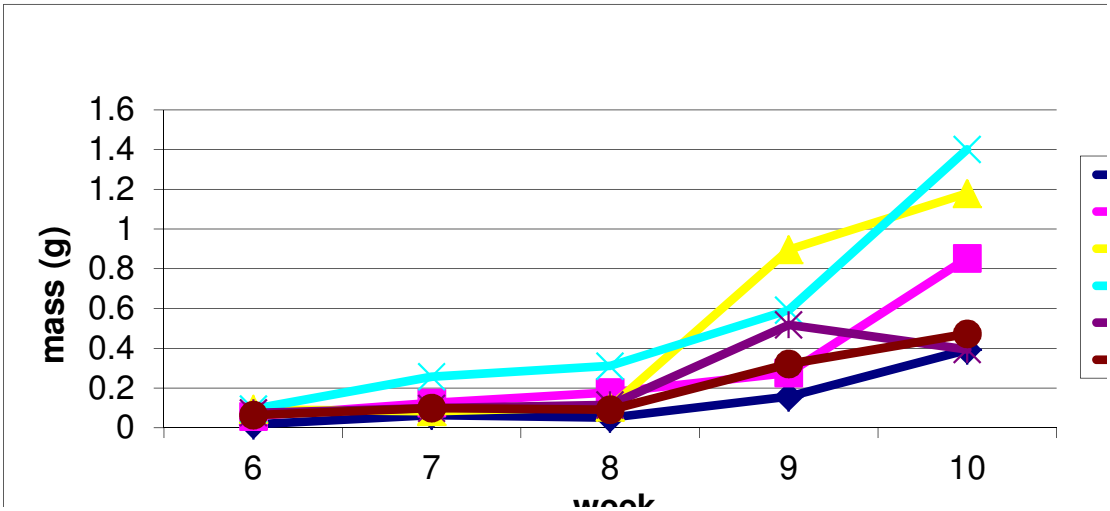

Figure 61: Average shoots mass for *Cynodon dactylon.*

Shoot mass for treatment F continued to increase steadily until week 9 and for week 10 shoot mass a huge increase is observed. The root mass and shoot mass are almost equal on week 10 for treatment F (. Little root growth observed for treatment H. Root growth is found to be sensitive to EC higher than 800 $mS.m^{-1}$, but root growth is at its highest with EC between 400 – 600 $mS.m^{-1.}$

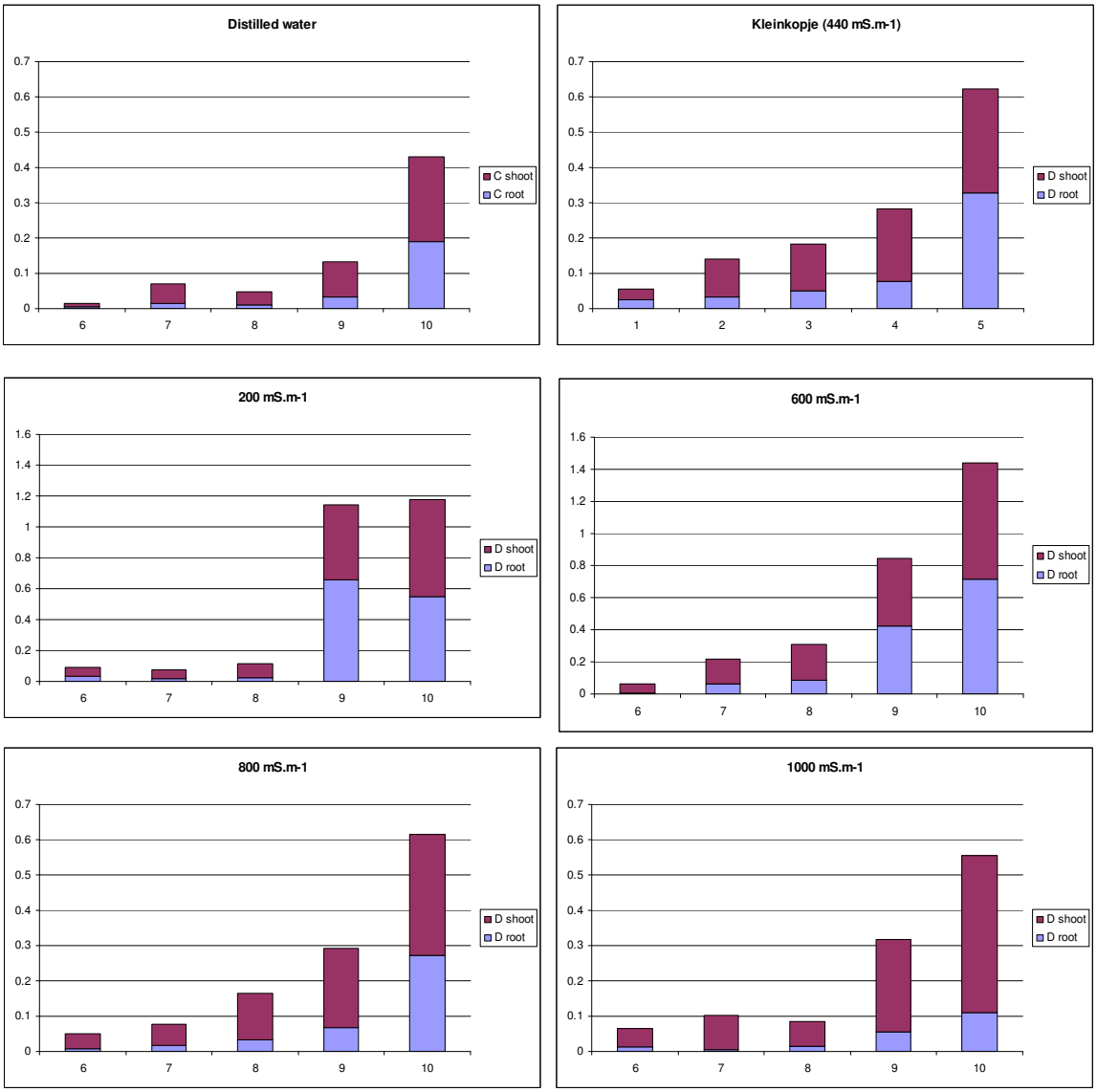

Figure 62: Average root and shoot ratios (g.plant^{-1}) graphs for *Cynodon dactylon*.

2.5.3.2 Digitaria eriantha

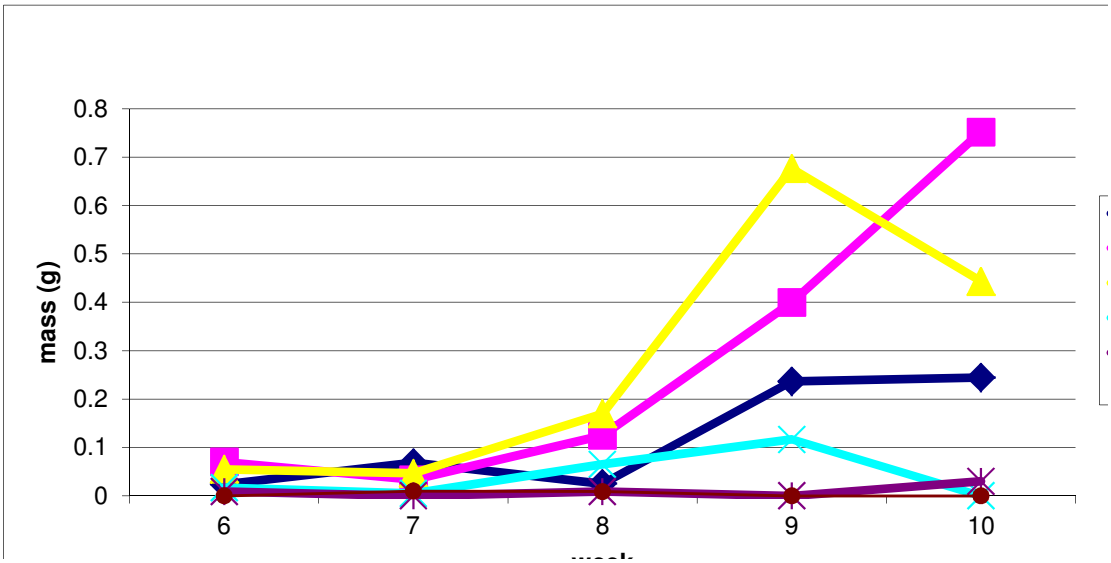

Figure 63: Average root mass for *Digitaria eriantha*.

Root mass increases are seen in Figure 63 at week 8 for treatment D and B more the 0.1g. Week 9, a huge increase in root mass is seen for treatment D (0.68g), but decreases at week 10. Treatment B had a steady increase over the trial period and resulted in the greatest overall root mass. Treatment A and F only show an increase in root mass at week 9, but is less compared to D and B. Treatment H showed almost no root growth. Shoot mass started to increase from week 6 for treatments D, F and B in Figure 64. Treatment D showed the biggest increase in shoot mass on week 8 followed by Treatments B and F. Treatment A had a very high increase in shoot mass on week 9 but failed to maintain this increase to week 10. Reason might be due to the lack of increase in root mass during this time period. Treatments G and H showed little increase in shoot mass over the trial period. Seedling growth for *Digitaria eriantha* is sensitive for EC higher as 400 $mS.m^{-1}$ and is at its optimum with levels between 200 $mS.m^{-1}$ and 400 $mS.m^{-1}$.

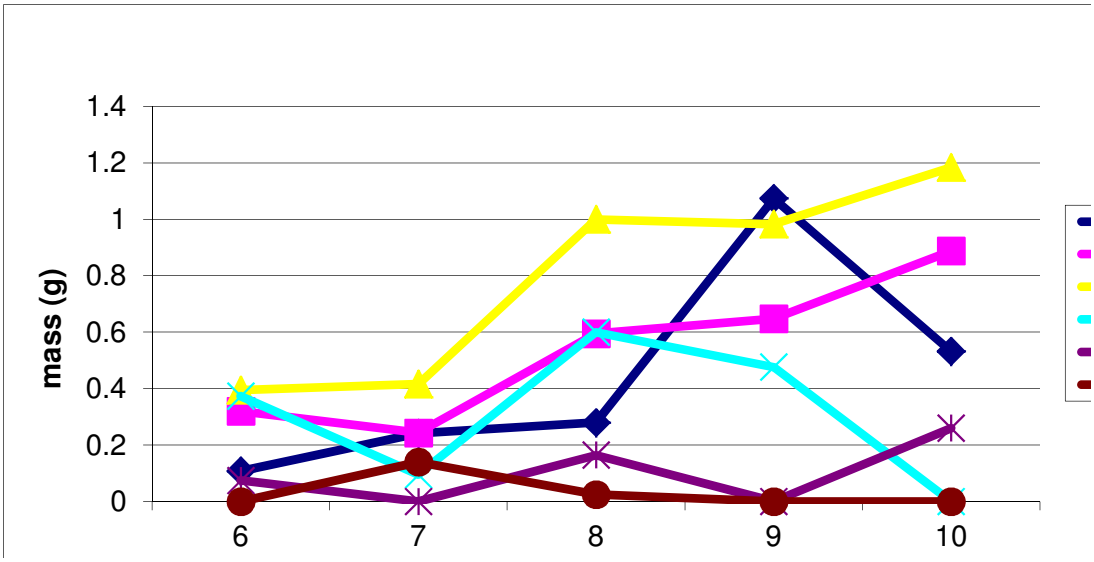

Figure 64: Average shoots mass for *Digitaria eriantha*.

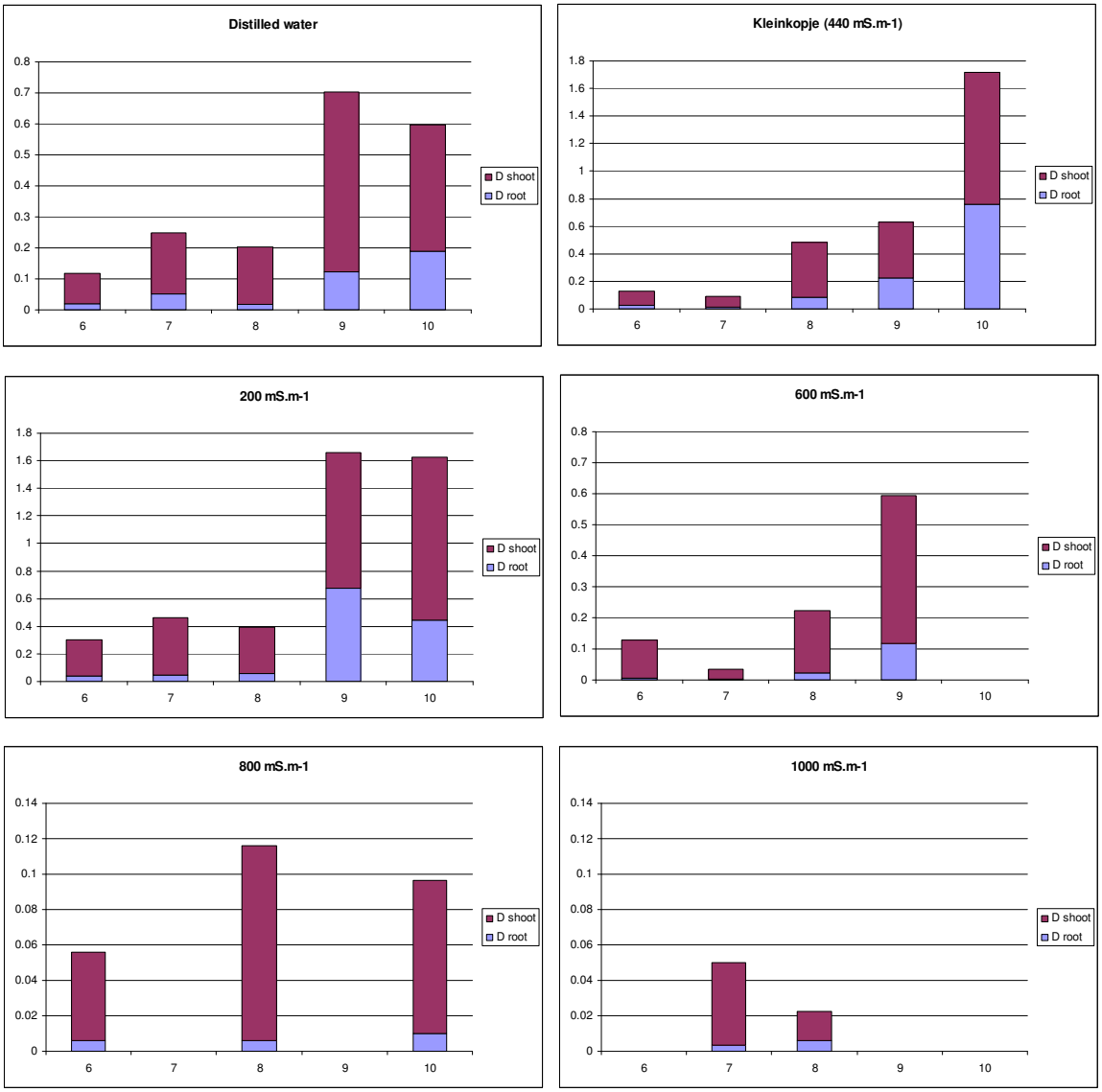

Figure 65: Average root and ratios (g.plant^{-1}) for *Digitaria eriantha*.

2.5.3.3 Eragrostis curvula

Root mass only started to increase significantly from week 9 for most of the treatments in Figure 66. Treatment B showed the highest increase in root mass on week 10 (0.4g), while treatments D and A increased to just less than 0.2g. Very little root growth is seen for treatments F, G and H.

Shoot mass started to increase in Figure 67 from week 7 for treatments A, D and B (highest), while little growth is seen for the other. Treatment B showed a steady increase for the trial period and outperformed the other treatments. This was followed by treatment D and then treatment A. Treatments F, G and H showed very little shoot growth over the trial period. Seedling growth of *Eragrostis curvula* is sensitive for EC higher than 400 $mS.m^{-1}$ and performs best at values closer to 400 $mS.m^{-1}$

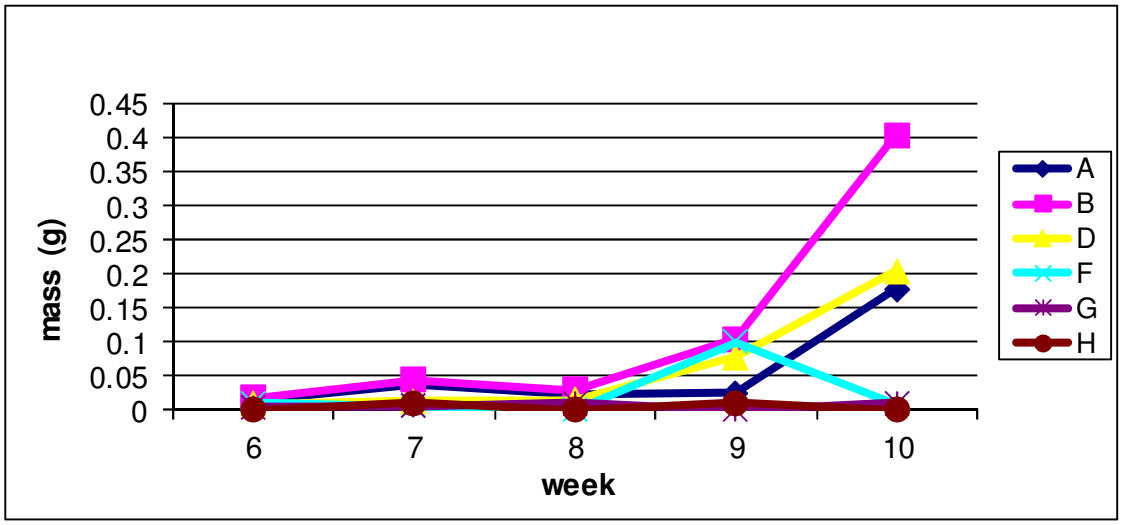

Figure 66: Average root mass for *Eragrostis curvula.*

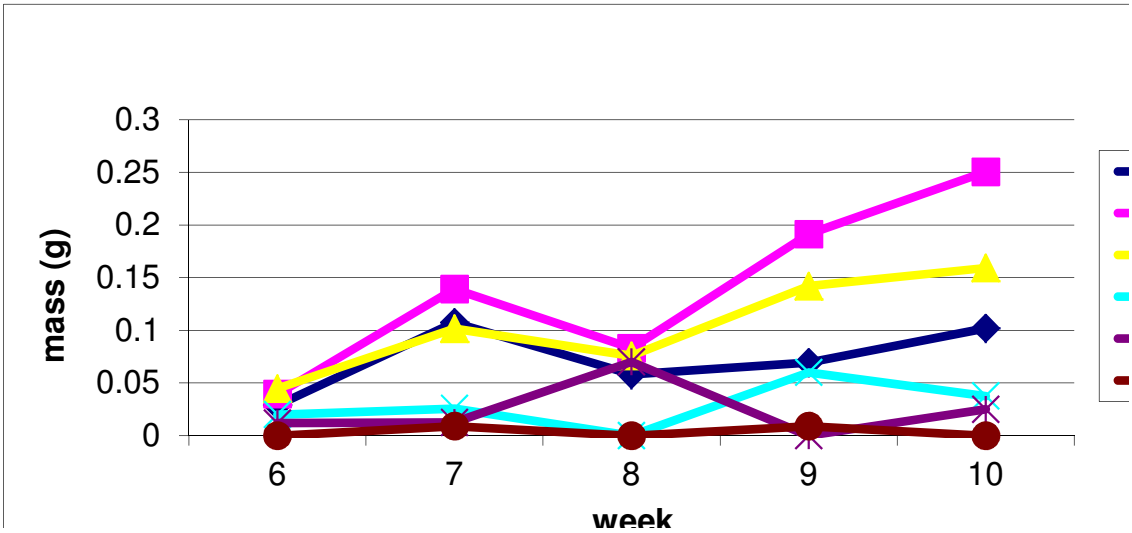

Figure 67: Average shoot mass for *Eragrostis curvula*.

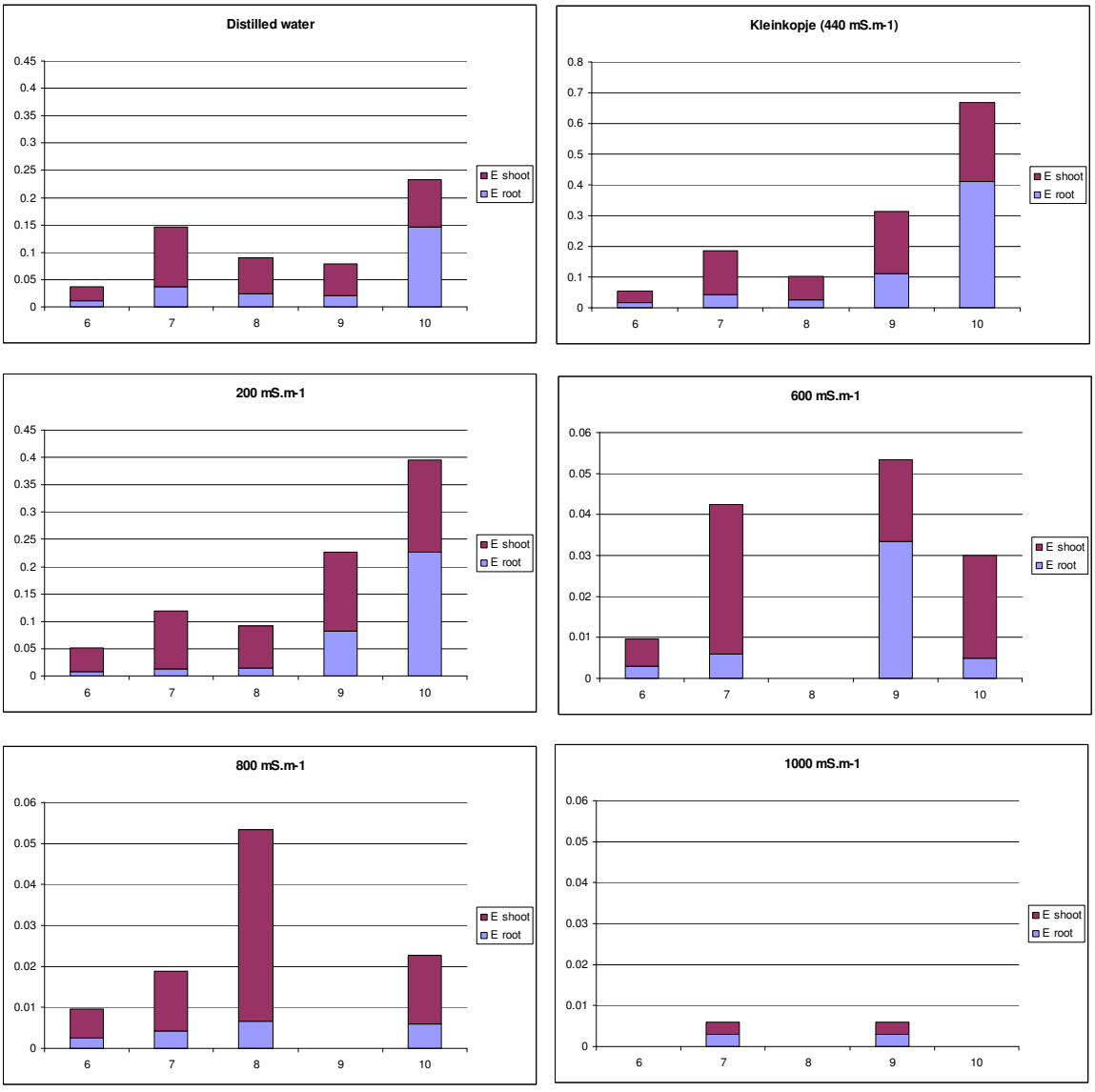

Figure 68: Average root and shoot ratios (g.plant-1) for Eragrostis curvula.

2.5.3.4 Festuca arundinacea

Up to week 8, no significant increase in root mass is observed in Figure 69. Week 9 showed a big increase in root mass for treatment D and B compared to the others. Treatments B, A, D and F showed increase in root mass on week 10. Total increases in root mass for these 4 treatments were higher than the other grass species in the trial.

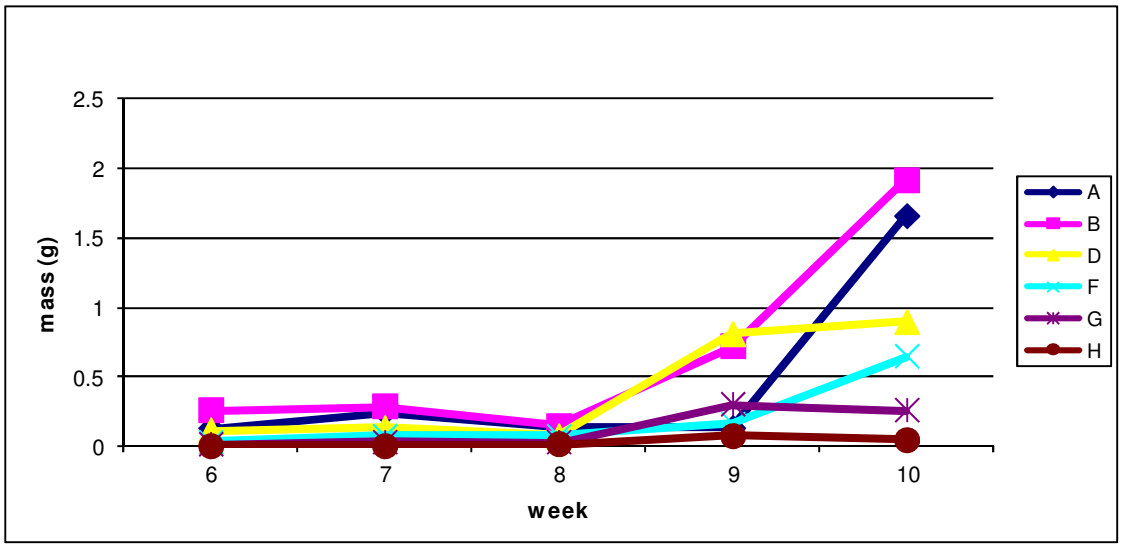

Figure 69: Average root mass for *Festuca arundinacea*.

Shoot mass for all treatments can be seen to increase in Figure 70 at week 6 with treatment A, B and D being the greatest. Treatment F showed a steady increase in shoot mass over the trial period and also showed similar shoot growth at the end of trial compared to treatment B. Treatment G and H both showed an increase in shoot mass, but treatment G's were much steadier increase compared to H which only started to increase from week 9. Root growth of *Festuca arundinacea* is seen to be sensitive to EC higher than, 600 $mS.m^{-1}$, while shoot growth was less sensitive to these higher EC values. This can be seen in the increase in shoot growth at EC levels of 1000 $mS.m^{-1}$.

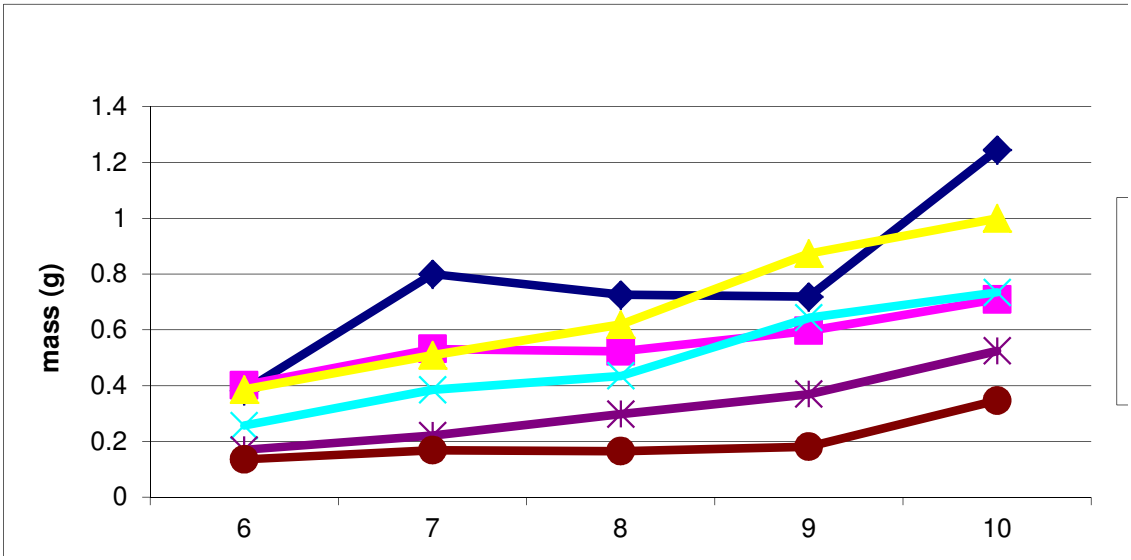

Figure 70: Average shoots mass for *Festuca arundinacea*.

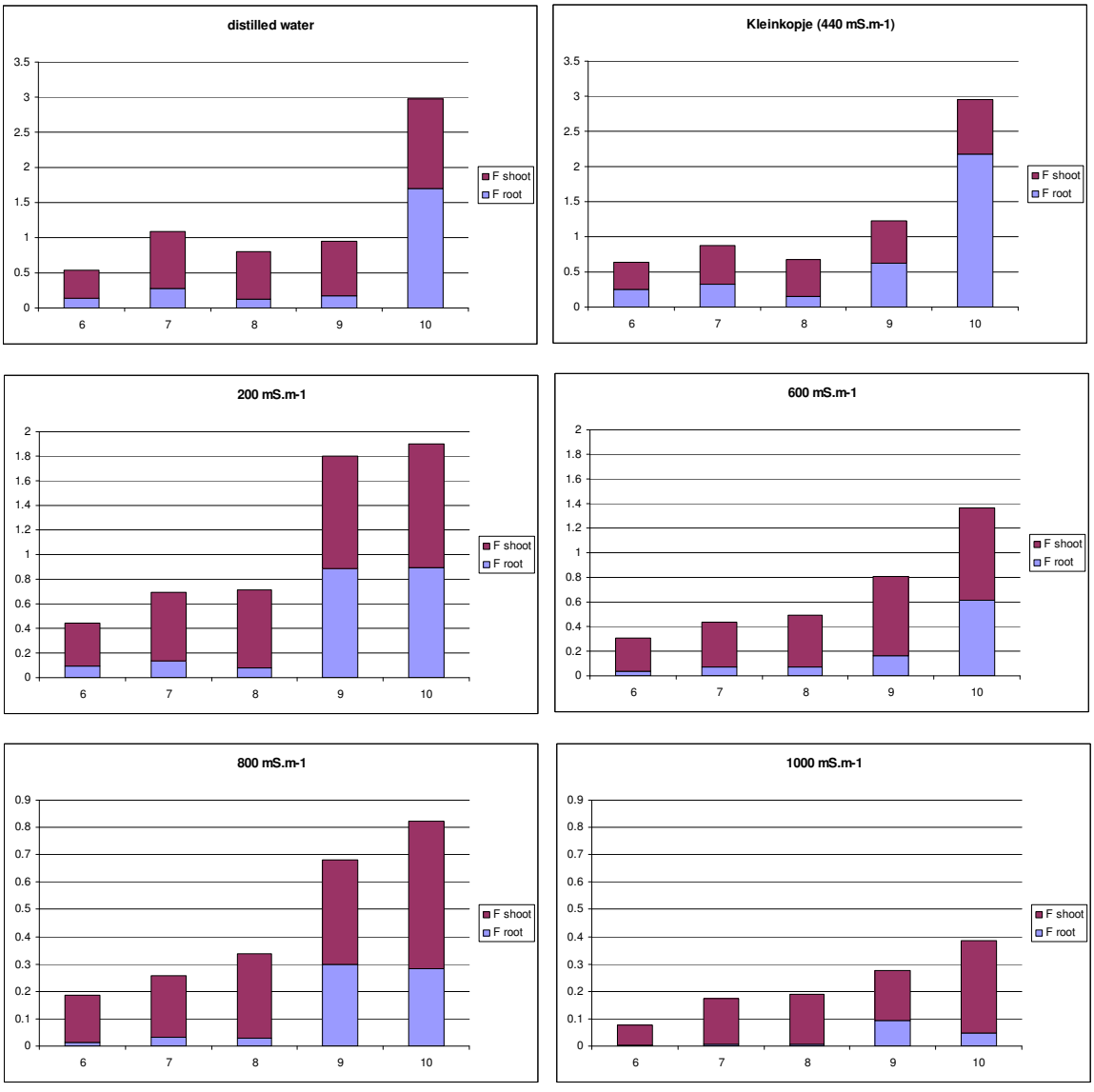

Figure 71: Average root and shoot ratios (g.plant^{-1}) for *Festuca arundinacea*.

2.5.4 Conclusion

An increase in shoot mass can be seen before an increase in root mass, but shoot mass only continues to increase if root mass increases enough to support this increase. If root mass does not increase sufficiently rate of shoot mass increase will decline. *Festuca arundinacea* was seen to have the highest level of tolerance to increase in salinity level. *Digitaria eriantha* was seen to have the lowest level of tolerance to increased level of salinity Other studies found with increased levels of salinity hypocotyl growth were inhibited more than radicle growth (Bayuelo-Jimènez et al, 2002). This statement contradicts findings in the trial done, which suggests root growth was more sensitive to increases levels of salinity compared to shoot mass.

Plants are found to develop a larger root system to cope with an increase in salinity (Zhao et al, 2007). This response to salt stress can be seen in all four species, where an increase in root mass is needed to support the above ground growth. This increase in root growth under saline conditions can be considered an adaptive mechanism to the osmotic stress and nutrient deficiencies associated with salinity stress (Dai et al, 2009).

3 GENERAL CONCLUSIONS AND RECOMMENDATIONS

This research programme has resulted in many data collected. All these data sets that have been interpreted and synthesized have brought about many conclusions that highlight to what extent this rehabilitated land use management option is viable. From the first study on the determination of the most efficient stocking rate which can be used on the irrigation pivot to get optimal use and subsequently optimal animal production from the pastures irrigated with poor quality mine water (gypsiferous). It was concluded that the best stocking rate for an irrigation pivot being irrigated with gypsiferous mine water is 5.45 AU ha^{-1}. This stocking rate should be applied once there is sufficient dry matter available to allow animals to graze for 50-70 days, depending on the size of the pivot as well as the growth rate of the pasture which in turn is determined by the frequency of irrigation and the amount of fertilizer applied under the circumstances. The results obtained are for weaner cattle weighing between 150-200kg. A cost estimate will be calculated and provided in a summarized document.

With respect to the quality of pasture, it is evident from the research conducted that the quality of pasture is determined by the level of fertilization as well as the level of irrigation. It was noted that the stocking rates also play a role in the ultimate quality of

pasture as utilized by the animals. It is evident from the results of this section of the research trial, that the quality of material as determined by the aforementioned reasons, will determine the intake of the animals which in affect influences the animals ability to grow well or not. The Tall Fescue which was used for this research project delivered some good results under the difficult management conditions regarding the operation of the pivot. This system as was evaluated shows much promise, and with effective management of such a system, even better results can be expected. To make recommendations, a correct fodderflow program needs to be designed for such an animal production system, but the process of grazing etc. will be included in the practical summarised document to follow.

Regarding the species evaluation under the irrigation system and the adaptability of other species, and the effects of gypsiferous mine water on the germination potential of grass species, it was clear from the data, which species were most tolerant and least tolerant to the quality of the water. A good ranking table was put together which will help establish which species to for future use under saline conditions. This study, however, clearly concluded that the species currently selected for irrigation, were a good selection, and explains why this species has the ability to make use of the conditions created through the rehabilitation process. It is also quite clear that at the time of the year when the mine normally has excess water, which is normally winter, there are more than one species that have high water requirements and will grow that time of the year. This component of the project supports the grazing trial of this project, highlighting that both the poor quality mine water, and rehabilitated land of a particular condition, can be used together to grow and provided a resource which animals and in effect humans can benefit from, by providing feed for animal growth and thus protein production.

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