RANGELAND POTENTIAL, QUALITY AND RESTORATION STRATEGIES IN NORTH-EASTERN ETHIOPIA: A CASE STUDY CONDUCTED IN THE SOUTHERN AFAR REGION

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Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it to any university for a degree.

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ABSTRACT

Vegetation dynamics and restoration strategies of degraded rangeland were investigated near a watering point in the Allaidege communal grazing area in Administrative Zone 3 of the Afar Region in the northeastern lowlands of Ethiopia. The degradation gradient formed by grazing pressure in the study area was stratified into four different areas based on the vegetation cover; severely degraded (SD), moderately to severely degraded (MSD), moderately degraded (MD) and lightly degraded (LD) areas. The study was initiated at the start of the rainy season in June 2003 and lasted untill December 2004. The objectives were to study the effects of the grazing pressure on plant species composition; on plant biomass production and basal cover; on rangeland forage quality; on the rangeland soil status and to determine and quantify viable restoration strategies for forage species in severely degraded rangelands.

The botanical composition of the different degradation areas was determined by making a 250 point wheel point method survey in each of four 30 m x 30 m quadrats in each degradation area using the nearest plant approach. The botanical composition of each degradation area was determined by measuring the frequency of occurrence of the different life forms (perennial grasses, annual grasses and forbs) of the species recorded in the field. Accordingly, a significant interaction was observed in both seasons between the different degradation areas and life forms considered. A high abundance of annual grasses was evident in SD and MSD areas in both seasons. In the MD and LD areas, a three-fold increase in frequency was recorded for perennial grasses compared to the MSD area in 2003. In 2004, the frequency of annual grasses, forbs and perennial grasses in the MD area was almost similar to that of the LD area. The abundance of perennial grasses in the MD and LD areas was two- and five-fold higher compared to perennial grasses in the MSD and SD areas respectively.

Biomass production was recorded by cutting the vegetation in 1 m x 1 m quadrats in each grazing area at ground level. The dry matter content of subsamples was determined in order to calculate the dry matter production of the quadrat. The differences in dry matter yield recorded in the different degraded areas was not significant for the 2003 season, although an increasing trend in yield was observed from the SD to MD areas. Significant yield differences were however recorded when one outlier in the data was excluded from the analysis. The significant differences occurred between the MD and SD areas where the MD area produced 2.4 t ha^{-1} more dry matter than the SD area. Similarly, in 2004 no significant yield difference was observed between the degradation areas. However, the contribution of different species to dry matter yield varied in the

different degradation areas. *Setaria verticillata*, *Sporobolus ioclados* and *Paspalidium desertorum* were found to be the major species contributing to the dry matter producion in the SD area, *S. verticillata* and *P. desertorum* in the MSD area, *Chrysopogon plumulosus* and *P. desertorum* in the MD area and *C. plumulosus* and *Panicum coloratum* in the LD area.

The percentage basal cover was calculated from the number of basal strikes recorded at 1 000 points in each plot of each degradation area using the wheel point method. The total basal cover percentage did not significantly change along the degradation gradient in any of the seasons. However, data for both seasons showed an increasing trend of total basal cover percentage closer to the watering point compared to areas further away from the watering point, except for the SD area, which had the lowest basal cover percentage. The contribution to percentage basal cover by some species decreased while it increased for some other species in grazing areas near the watering point.

Forage quality was investigated by analysing sub-samples of the forage samples taken to determine biomass production. The forage samples were analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP), lignin, *in vitro* dry matter digestibility (IVDMD), phosphorus (P), and calcium (Ca) content. The forage showed a decrease in NDF and ADF content in areas close to the watering point in both seasons. This decrease in fibre content was accompanied by an increase in CP content close to the watering point. The increase in CP was significant for the SD area in both seasons. Although a similar trend was observed in both seasons, the CP content was found to be significantly higher in 2004 than in 2003. The results of the lignin analysis were inconclusive if the data of both seasons are considered. It does appear however as if the lignin content of the forage was generally higher in 2003. The 2 years pooled average of P content of the forages showed insignificant variation along the degradation gradient. However, an increase in P concentration of the forages was evident in areas far from the watering point. Contrary to this, Ca concentration was significantly higher in the SD area compared to areas further away from the watering point.

Hand clipped forage samples and esophageal collected forage samples were analysed to compare the quality of the samples. Due to the fact that only two animals were available for esophageal collection, differences were in most cases not significant at the 5% level, but trends indicate that animals select higher quality forage than what is assumed based on hand clipping.

Organic carbon (OC) content, total nitrogen (N) content, available phosphorus (P) content, available potassium (K) content, exchangeable calcium (Ca) and magnesium (Mg) contents, cation exchange capacity (CEC), total exchangeable bases (TEB), exchangeable sodium percentage (ESP), soil acidity (pH) and base saturation of soils in the different degradation areas were determined by means of acknowledged laboratory methods. No significant differences in OC, N, P, K, Ca, Mg and K content of soil in the different degradation areas could be observed. There was however an increasing trend for OC and N content with distance from the watering point. Sodium concentration and pH increased significantly in areas close to the watering point. Cation exchange capacity content of the soil was variable and no clear trend could be established. Significantly higher TEB and ESP contents were observed in the SD area.

In general, the differences in plant biomass production and basal cover, botanical composition, forage quality and soil status over the degradation gradient clearly implicates the negative impact of unrestricted grazing pressure on the rangeland around the watering points.

In the rangeland restoration trial, establishment of three local and three exotic grass species in the SD area was investigated. Treatments applied included application of inorganic fertilizer, dry dung organic manure and grass mulch. The mulch treatments caused a significant yield increase for all the sown species. Among all the species, *Ischaemum afrum* and *Tragus berteronianus* performed better and produced significantly higher dry matter yields than *Enteropogon rupestris, Chloris gayana* and *Panicum coloratum*. In general the study indicated the importance of mulching when planning to restore degraded rangeland under arid environmental conditions.

UITTREKSEL

Plategroei dinamika en veldherwinningstegnieke in verswakte veld naby ‘n waterpunt in die Allaidege kommunale weigebied in Administratiewe Sone 3 van die Afar gebied in Noordoos Ethiopië is ondersoek. Die weidingsgradiënt in die studiegebied is gestratifiseer in vier degradasie sones gebaseer op die plantegroei bedekking nl. erg verswakte (SD), matig tot erg verswakte (MSD), matig verswakte (MD) en lig verswakte (LD) gebiede. Die studie het ‘n aanvang geneem aan die begin van die reënseisoen in Junie 2003 en het geduur tot Desember 2004. Die doelwitte van die studie was om die invloed van die weidingsgradiënt op plantspesiesamesteling, plantbiomassa en basale bedekking, kwaliteit van die weiding en grondkwaliteit te bepaal. Verder is verskillende behandelings om oorsaai van grasspesies te optimeer, ondersoek.

Die spesiesamestelling van die verskillende gebiede is bepaal deur ‘n 250 punt opname d.m.v. ‘n wielpuntapparaat te maak in elk van vier 30 m x 30 m persele in elke degradasie sone deur van die naaste plant metode gebruik te maak. Die spesiesamestelling van elke degradasie sone is bepaal deur frekwensie van voorkoms van die verskillende spesies en lewensvorme waarin die spesies verdeel is (meerjarige grasse, eenjarige grasse en ander) te bepaal. In beide seisoene is ‘n betekenisvolle wisselwerking tussen degradasie sones en lewensvorme waargeneem. Eenjarige grasse het in groot getalle voorgekom in die SD en MSD sones en beide seisoene. In die MD en LD sones is daar ‘n drievoudige toename in die voorkoms van meerjarige grasse (relatief tot die MSD sone) waargeneem in 2003. In 2004 was die frekwensie van eenjarige grasse, meerjarige grasse en ander lewensvorme in die MD sone bykans soortgelyk aan die frekwensie in die LD sone. Die voorkoms van meerjarige grasse in die MD en LD sones was tweevoudig en vyfvoudig hoër as in die MSD en SD sones respektiewelik.

Biomassa produksie is bepaal deur die plantegroei in 1 m x 1 m persele in elke degradasie sone op grondvlak te knip en te weeg. Die droëmateriaal inhoud van submonsters is bepaal sodat die droëmassaproduksie ha^{-1} bereken kon word. Die verskille in droëmateriaal produksie tussen die verskillende sones was nie statisties betekenisvol in 2003 nie, maar ‘n stygende tendens is waargeneem in droëmateriaalproduksie van die SD sone na die MD sone. Betekenisvolle verskille is wel waargeneem toe een uitskieter uit die data verwyder is. Die betekenisvolle verskille het voorgekom tussen die MD en SD sones waar die MD sone 2.4 t ha^{-1} meer droëmateriaal produseer het as die SD sone. In 2004 is ook geen betekenisvolle verskille tussen die droëmassaproduksie in die verskillende sones waargeneem nie. Die bydrae van spesifieke

spesies tot die totale droëmassaproduksie in die verskillende sones het egter verskil. *Setaria verticillata*, *Sporobolus ioclados* en *Paspalidium desertorum* het die meeste bygedra tot droëmassaproduksie in die SD sone, *S. verticillata* en *P. desertorum* in die MSD sone, *Chrysopogon plumulosus* en *P. desertorum* in die MD sone en *C. plumulosus* en *Panicum coloratum* in die LD sone.

Die basale bedekking is bereken vanaf die aantal basale treffers wat waargeneem is vanaf 'n 1000 punt opname wat m.b.v die wielpuntapparaat in elke 30 m x 30 m perseel in elke degradasie sone gemaak is. Die totale basale bedekking persentasie het nie betekenisvol tussen die degradasie sones verskil in enige van die twee jare nie. Wanneer die data van die twee seisoene egter saamgevoeg word is daar 'n toenemende tendens waargeneem vir sones nader aan die waterpunt vergeleke met sones verder weg, behalwe vir die naaste (SD) sone, waar die basale bedekking drasties gedaal het tot die laagste in die hele degradasie gradiënt. Die bydrae van sommige spesies tot die totale basale bedekking het toegeneem nader aan die waterpunt terwyl die bydrae van ander spesies weer in teenstelling afgeneem het.

Weidingskwaliteit is ondersoek deur submonsters te neem van die materiaal wat geknip is om biomassa bepalings te doen. Die voermonsters is ontleed vir ruproteien (RP), neutraal bestande vesel (NBV), suur bestande vesel (SBV), lignien, *in vitro* droëmateriaal verteerbaarheid (IVDMV), fosfor (P) en kalsium (Ca) inhoud. Die weidings het 'n afname in NBV en SBV getoon in sones naby die waterpunt in albei seisoene. Die afname in vesel het gepaard gegaan met 'n toename in RP nader aan die waterpunt. Die toename in RP in die SD sone vergeleke met die andersones was betekenisvol in beide jare. Alhoewel 'n soortgelyke tendens in RP inhoud in die verskillende sones in beide jare waargeneem is, was die RP inhoud betekenisvol hoër in 2004 as in 2003. Die lignien inhoud het nie veel verskil tussen sones in beide jare nie maar dit wil voorkom asof die lignieninhoud van die weidings in 2003 oor die algemeen hoër was. Die saamgevoegde P waardes vir die twee jare wys geen verskille tussen degradasie sones nie. Dit blyk egter asof P konsentrasies styg in degradasie sones verder weg van die waterpunt. Die teenoorgestelde was waar vir Ca, waar die konsentrasies in die SD sone betekenisvol hoër was as in die sones verder weg vanaf die waterpunt.

Voermonsters wat met die hand versamel is en voermonsters wat per esofageale fistula versamel is, is ook ontleed en vergelyk. Omdat net twee diere beskikbaar was vir esofageale versameling, was die verskille in meeste gevalle nie statisties betekenisvol by die 5% vlak nie. In die meeste gevalle was daar egter betekenisvolle verskille by die 10% vlak en die tendense toon dat die diere beter kwaliteit voer selekteer as wat afgelei kan word vanaf monsters wat met die hand versamel is.

Organiese koolstof (OK) inhoud, totale grondstikstof (N) inhoud, beskikbare fosfor (P), beskikbare kalium (K), uitruilbare kalsium (Ca) en magnesium (Mg) inhoude, katioon uitruil kapasiteit (KUK), uitruilbare katioon persentasie (UKP), uitruilbare natrium persentasie (UNP), grondsuurheid (pH) en basis versadiging van grond in die verskillende degradasie sones is bepaal deur middel van bevestigde laboratorium tegnieke. Geen betekenisvolle verskille in OK, N, P, K, Ca, Mg en K inhoud van die grond in die verskillende sones is waargeneem nie. Daar was egter ‘n toenemende tendens vir OK en N met toenemende afstand vanaf die waterpunt. Natrium inhoud en pH het egter weer betekenisvol toegeneem nader aan die waterpunt. Katian uitruil kapasiteit van die grond het varieer en geen tendens kon waargeneem word nie. Betekenisvolle hoër UKP en UNP konsentrasies is in die SD sone waargeneem.

Oor die algemeen het verskille in spesiesamestelling, biomassa produksie, basale bedekking, voerkwaliteit en grondkwaliteit wat oor die degradasie gradiënt voorgekom het, die negatiewe invloed wat swaar beweiding naby die waterpunt op die weiveld het, weerspieël.

Die vestiging van drie inheemse en drie uitheemse grasspesies is ondersoek in die veldherwinningsproef wat in die SD sone uitgevoer is. Behandelings wat toegepas is, is toediening van anorganiese bemestingstowwe, droë mis en deklaag met grasmateriaal. Die deklaagbehandeling het betekenisvolle toename in droëmassaproduksie vir alle spesies tot gevolg gehad. *Ischaemum afrum* en *Tragus berteronianus* het die beste presteer en betekenisvol meer droëmateriaal geproduser as *Enteropogon rupestris*, *Chloris gayana* en *Panicum coloratum*. Die belangrikheid van deklae met oorsaai van grasspesies is bewys.

Dedication

To my late uncle Colonel Geberetensay Bokere who was highly supportive and was always with encouraging words see me my success in higher qualification.

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List of Abbreviations

ADF = Acid Detergent Fiber

ANOVA = Analysis Of Variance

AOAC = Association of Official Analytical Chemists

ARC = Agricultural Research Council

Av. = Available

Ca = Calcium

Ca^{2+} = calcium ion

CEC = Cation Exchange Capacity

cm = centimeter

CTA = Classification Tree Analysis

ºC = degree centigrade

df = degree of freedom

DM = Dry Matter

Ds m^{-1} = decisiemens per meter

Ec = Electrical Conductivity

ESP = Exchangeable Sodium Percentage

Fig. = Figure

g = gram

g^{-1} = per gram

> = Greater than

ha = hectare

ha^{-1} = per hectare

hrs = hours

K = Potassium

K^{+} = Potassium ion

Kg ha^{-1} = kilogram per hectare

km = kilometer

LD = Lightly Degraded

< = Less than

m = meter

MCE = Metafaria Consultant Engineering

MD = Moderately Degraded

meq = milliequivalent

Meq 100 g^{-1} = milli-equivalent per 100 gram

Mg = Magnesium

Mg^{2+} = Magnesium ion

MS = Mean Square

MSD = Moderately to Severely Degraded

N = Nitrogen

Na = Sodium

Na^{+} = Sodium ion

NDF = Neutral Detergent Fiber

No. = Number

Obs. = Observation

OC = Organic Carbon

OM = Organic Matter

% = Percent

P = Phosphorus

P = probability value

pH = acidity

ppm = parts per million

r = correlation

SD = Severely Degraded

t ha^{-1} = tons per hectare

TEB =Total Exchangeable Base

TLU = Tropical Livestock Unit

v/v = volume by volume

vs. = versus

yr = year

yr^{-1} = per year

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CHAPTER 1
INTRODUCTION

1.1 General introduction

Ethiopia has a total land surface of about 112.3 million hectares, and a human population of about 55.9 million, with an average annual growth rate of 2.9% (CSA, 1998). The country also has the largest livestock population in Africa and in this regard ranks tenth in the world. This livestock includes 30 million cattle, 21.7 million sheep, 16.7 million goats, 7.02 million equines, 1 million camels and 56.5 million chickens (CSA, 1998). Agriculture employs more than 85% of the resident rural population and contributes about 50% to the gross domestic product (GDP) and 90% to the export earnings. The livestock sector contributes about 40% to the total agricultural GDP and 15-20% to the national export earnings (USDA, 1990). It is also a source of high-quality food, cash income, energy and soil fertiliser. At farm level, it is a generator of employment and a means of savings and capital investment. Its contribution to the national economy is, however, limited, which is attributed to a variety of factors. These factors include fodder and nutrition, animal diseases and the inherent low genetic potential of the indigenous stock. Physiological stresses (high temperature and sun radiation), poor management and husbandry practices, poor marketing, with unfair and unattractive commodity prices, poor infrastructure, inadequate inputs and services and absence of policies favouring its promotion add to the problem.

Variable climatic conditions prevail in the country. The cool, temperate highlands, with an altitude above 1 500 m with maximum temperatures rarely exceeding 25 °C and an annual rainfall greater than 1 000 mm, account for approximately half of Africa’s highland zone (Gryseels & Anderson, 1983; Coppock, 1994) and offers a climate conducive to agricultural practices. The vast arid and semi-arid lowlands with pastoralist and agropastoralist production systems lie at an altitude below 1 500 m (NMRD, 1998), and experience high temperatures and erratic, unpredictable annual precipitation, usually less than 700 mm (Tesfaye, 2002). Moisture stress and extreme rainfall variation between locations and years make animal production the only viable farming system.

Estimates of the total area of land inhabited by pastoralists in Ethiopia vary. ILCA (1981) and UNDP/RRC (1984) divide the total surface area of the country into highlands (39%) and lowlands (61%) with an elevation of 1 500 m taken as an arbitrary dividing line. The lowland area, i.e. the 61% of land utilised by pastoralists, amounts to 769 000 km^2. NMRD (1998) estimated that a total area of about 74.12 million hectares, equivalent to nearly 67% of the total land area, is inhabited by pastoralists.

The northeastern pastoral region is located in the northern half of the Rift Valley (UNDP/RRC, 1984). It lies between the eastern and northern escarpments of the central highlands to the west and south of the Rift Valley (Fig. 1). The region covers a total surface area of 75 000 km^2. The lowland plains of the Awash River Basin are found in this region. The southeastern region has a total surface area of 293 000 km^2, which makes it the largest region. It encompasses the Ogaden area and the Ethiopia-Somalia border. Upper limits reach the eastern and southern borders of the highlands of Harerge and Bale. The southern pastoral region, commonly referred to as Borana or the southern rangeland, has a total land area of 95 000 km^2. The southwestern pastoral region is divided into two subregions, the lower Omo Drainage Basin and the Gambella plain. The total area of the region is 63 000 km^2. The western pastoral region encompasses the present-day Benishangual Gumuz administrative region that borders on the Sudan. The lowland areas of the Amhara and Tigray regions that are adjacent to this area also border the region.

There is little accurate information available about either human or livestock population, owing to the practical difficulties involved in establishing a reliable figure. It is estimated that the lowlands account for roughly 12% (5 million) of the national population (Fekadu, 1990). The livestock population is estimated to be about 40% of the cattle, 75% of the goats, 25% of the sheep, 20% of the equines and 100% of the camels of the total livestock population of the country (Fekadu, 1990). In most of these areas nomadic and semi-nomadic people live, who mostly raise livestock for their livelihood. The livestock in turn depend primarily on the feed resources available on the rangelands.

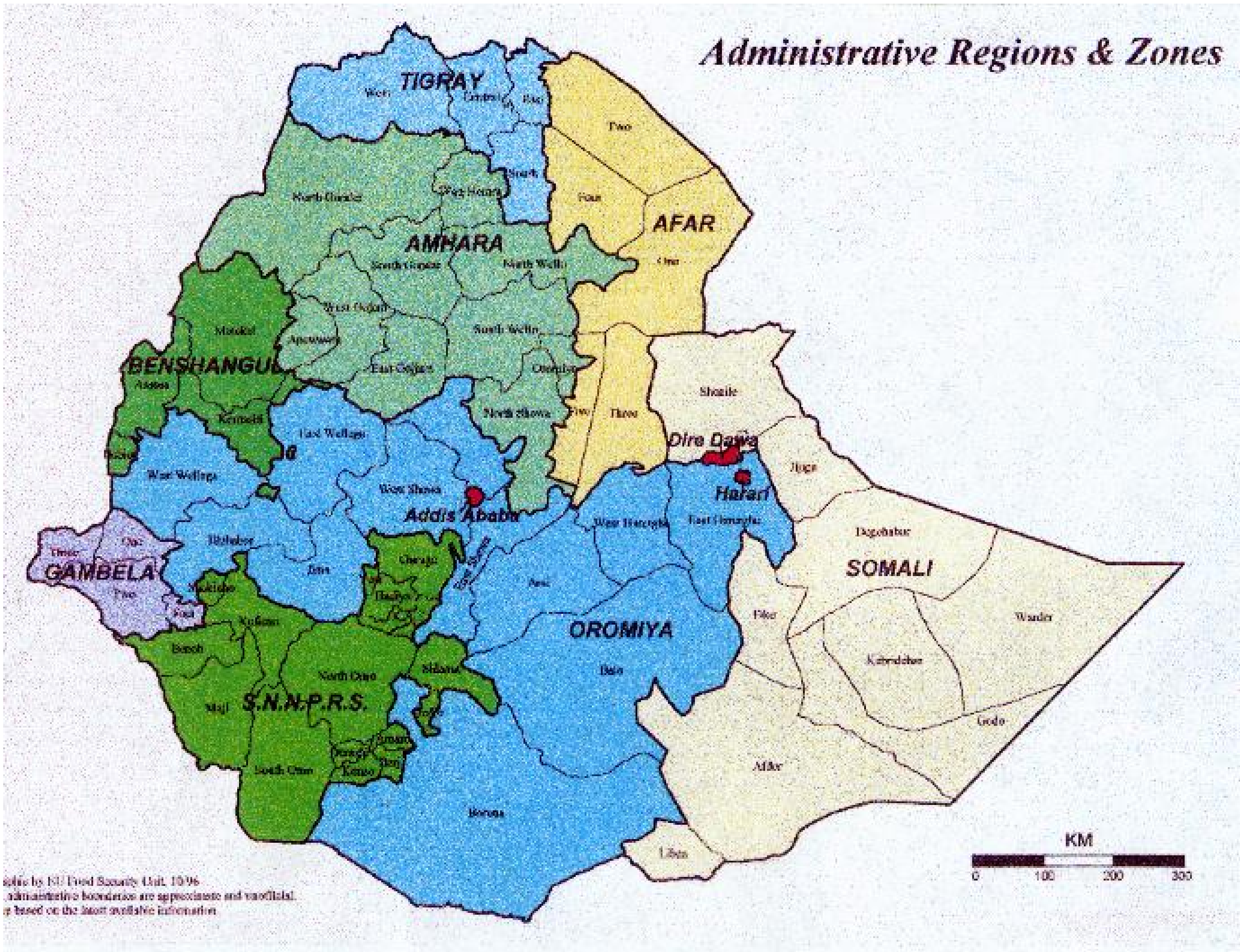

Figure 1.1 Map of Ethiopia showing the pastoral administrative regions. The Afar is the northeastern pastoral region, which is at the northern half of the Rift Valley between eastern and northern escarpments with Central highlands to the west and south of the Rift Valley (Source: MOA, 1996).

1.2 Importance of the production system

The land use in the lowlands is dominated by pastoralism and to a lesser extent by agropastoralism. Although the lowlands have a lower concentration of animals than the highlands, they play a crucial role in the national economy as well as at household level.

According to studies by Girma (1988) and Coppock (1994) the livestock sector constituted 33% of the gross value of agricultural production and 15% of the GDP in the mid-1980s. This means that the pastoral system provides milk, meat, employment and investment opportunities to rural and urban inhabitants of the lowlands. Moreover, the system is a good source of foreign exchange earnings. Livestock and livestock products are the second most important hard-currency-generating commodity in the country. Livestock sales provide the single most prominent cash income for sustaining and ensuring food security for pastoral households, whenever there is drought and failure in milk production.

The same reports by Girma (1988) and Coppock (1994) indicate that cattle and in particular sheep from the lowlands comprised over 90% of the legal export of live animals. A study by Hogg (1997) indicated that more than half a million heads of livestock are illegally trekked to neighbouring countries annually to be marketed there.

1.3 Major constraints of the production system

The pastoral and agropastoral production systems experience many challenges caused by the vagaries of nature and the interferences of man. Moisture stress caused by inadequate and erratic rainfall makes water the most important limiting factor to meet both plant and animal requirements. Moisture shortages are further aggravated by high temperatures, leading to high evapotranspiration. The permanent water supply systems for livestock are not spatially related to the available grazing materials in the rangeland, and the existing watering points are unevenly distributed. Another natural disaster in the lowlands is the frequent recurrence of drought. The drought that took place in the year 1973/74 in the Afar region resulted in livestock mortalities of 90%, 30%, 50%, and 30% for cattle, camels, sheep, and goats respectively (Ali Said, 1994). During the 1991/1992 droughts in the Borana area, the average individual household lost about 79% of its cattle, 95% of its camels, 83% of its equines and 60% of its sheep and goats (Alemayehu, 1998). These numbers exceed the numbers of those that died during the 1984/85-drought period (Claudia, 1997). Livestock mortality during droughts is largely attributed to severe feed shortages and outbreak of diseases.

The erratic and inadequate rainfall in the rangeland leads to forage biomass that is poor in quantity and quality. The herbaceous layer is often more affected than the woody component of the vegetation. This encourages the growth of undesirable and unpalatable plant species.

The human factor also plays a major role in rangeland degradation. It is important to note that rangeland degradation not only decreases biological productivity, but also negatively affects the general environment. Rangeland degradation is generally caused by poor management of rangeland resources. Such management practices relate to the expansion of sedentary agriculture, the expansion of agricultural projects, the expansion of natural parks and game reserves and the conflict among the interethnic and intraethnic groups. This leads to higher livestock pressure on the rangelands and ultimately causes overgrazing and resource degradation that may have irreversible consequences for the environment (Coppock, 1994).

Among the vast lowlands of the country, the northeastern lowland of the Afar region is one of the most important. In Afar the arid ecological zone, which lies at an altitude below 500 m, covers more than 80% of the region. The semi-arid ecological zone, at an altitude of 500-1 500 m, covers 20% of the area of the region (Dawit, 2000). The area sustains over 90% of its inhabitants as pastoralists, with considerable numbers and distribution of livestock (CSA, 1994). Based on the land-use and land-cover study of the Afar National Regional State, the potential vegetation area, which is 24.49% of the region, is classified into grasslands, shrubland, bushland and riverine woodland vegetation types (MCE, 2000).

The northeastern lowland is also affected by climatic factors and poor management of the rangelands. Both these factors put a great deal of pressure on the feed resources of the region, causing overgrazing and degradation of the range (Beruk, 2000). Among the rangelands affected by this phenomenon is the Zone 3 rangeland of the Afar region, with a land cover of 1 184 817 ha (CEDEP, 1998, as cited by Beruk, 2000). This area was once deemed to have an excess feed balance of 354 915 tons relative to the other zones that had negative feed balances (Beruk, 2000). The main animal feed source of the region is entirely based on natural vegetation, dominated by deciduous acacia bushland growing mostly along the flood plains of the Awash River. The higher areas, up the bottomlands, which are relatively dry, vary from closed thicket to open shrublands with occasional scattered trees, to open grass plains. The open grasslands are the predominant feed source of the grazing animals.

Among the prominent, extensive grasslands of the region is the Alaidege rangeland which covers an area of 200 000 ha (Halcrow, 1989). The rangeland is characterised as open grassland, dominated by tufted perennial grass with periodic growth of annual grasses and forbs in the rainy season. This is the grazing area where the Afar tribesmen keep animals to graze for extended periods throughout different seasons. This grazing system has resulted in overgrazing of the area, causing an eventual decline in the vegetation cover. According to the pastoralists' perception, this was due to the disruption of the traditional rules and regulations they practised on grazing areas for decades, as well as to the recent intervention and expansion of agriculture, which shrinks the alternative dry season grazing area used in the system (personal communication, clan leaders, 2003).

In the past no actions were taken to create awareness of the root cause of overgrazing and degradation in the country as a whole. No extension services existed to advocate the application of improved and sustainable rangeland management practices. Consequently, concentration of animals in particular areas of the rangeland, especially around watering points, caused gradual deterioration of the grazing area in terms of production potential and reduced cover, in particular cover of palatable species. In extreme cases some parts of the grazing areas have been completely denuded. The problem of complete degradation is therefore the major existing constraint observed in the rangelands. The importance of conducting research to restore rangeland productivity must be emphasised. In the past, research on restoration techniques of degraded rangeland was not carried out in the country and it was not on the agenda of the national agricultural research system of the country. The paucity of information on these facets at national level in general and at regional level in particular necessitates a close understanding of the restoration technique of denuded land. The impact of grazing pressure on the vegetation and soil status of the rangeland in general and around watering points of the project area in particular needed to be investigated. These aspects, as well as the investigation of some restoration techniques, were addressed in this study that was carried out between the coordinates of 9º 35' 17.170" N; 40º 11' 4.161" E, 9º 35' 12.996" N; 40º 29' 6.947" E, 9º 3' 16.271" N; 40º 10' 58.144" E and 9º 3' 12.33" N; 40º 28' 58.83" E in the Afar region of Ethiopia.

1.4 Study objectives and thesis outlay

The main objective of this study was to investigate the effect of grazing pressure at various distances from a watering point on the botanical composition and vegetation cover and to make recommendations to alleviating the possible negative effect on the rangeland and the well-being of the community. The following primary hypothesis is tested:

> There is no difference in botanical composition and vegetation cover at increasing distances from the watering point.

Secondary hypotheses are tested in the different chapters as outlined below. The outline of the thesis is as follows:

1. Chapter 1 is a general introduction and gives the outline of the thesis as well as the hypotheses tested.
2. Chapter 2 is a literature review on rangeland degradation and restoration techniques.
3. Chapter 3 gives a description of the study area as well as the major techniques used.
4. Chapter 4 is a study of the impact of livestock grazing around watering points on plant species composition. The secondary hypothesis tested is:

   There is no difference in plant species composition at increasing distances from the watering point.
5. Chapter 5 is a study of the impact of livestock grazing around watering points on plant biomass production and basal cover. The secondary hypothesis tested is:

   There is no difference in plant biomass production and basal cover at increasing distances from the watering point.

6. Chapter 6 is a study of the impact of livestock grazing around watering points on rangeland forage quality. The secondary hypothesis tested is:

   There is no difference in rangeland forage quality at increasing distances from the watering point.
7. Chapter 7 is a study of the impact of livestock grazing around watering points on the rangeland soil status. The secondary hypothesis tested is:

There is no difference in the rangeland soil status at increasing distances from the watering point.

8. Chapter 8 is a study to determine and quantify viable restoration strategies for forage species on degraded rangelands. The secondary hypothesis tested is:

   There is no difference in the success rate of different restoration techniques in a severely degraded area.

9. Chapter 9 is a concluding chapter highlighting the most important findings and shortcomings of the study and identifying possible follow-up studies.

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CHAPTER 2

LITERATURE REVIEW

2.1 Range ecology

Ecology involves the study of the interrelationships between organisms and their environments. Range management is applied ecology because it deals with the environment, with the goal of increasing its output to man. A fundamental concept in range management is that the welfare of plants and animals depends on each other. Inputs by man associated with regulating animals (control of grazing animal numbers, timing of grazing, frequency of grazing, etc.) are generally much lower than those for directly regulating plants. Therefore range management has focused on manipulating vegetation and soil by control of the grazing animal (Holecheck, Pieper & Herbel, 2000).

2.1.1 Impact of grazing on botanical composition

The botanical composition of rangeland is important because individual species may differ in feeding value, in content of harmful substances and in their reaction to environmental and management factors. Measurement of botanical composition may be in terms of the yield of the species components, the frequency of occurrence of different species, the number of plants present or the area covered by different species. The first measure has direct relevance in relation to animal production, because it describes the feed available. The other measures have only indirect relevance to animal production; because the relations between yield and frequency, number or area will differ between species, their role is mainly to describe and quantify the population of plants in the pasture (Mannetje, Jones & Stobbs, 1976).

Classical plant succession theory has postulated that, in the absence of disturbing factors, there is a directional change in botanical composition to a “climax” stage in the vegetation. Besides botanical changes due to such successional trends, vegetation also changes according to the way it is treated (Du Toit & Aucamp, 1985).

In South Africa, rangeland has traditionally been assessed on the basis of its species composition and basal cover, quantified in terms of a veld condition score (Foran, Tainton & Booysen, 1978; Thurow, Blackburn & Taylor, 1988). Until recently, condition scores derived from botanical composition were conventionally supplemented by a rangeland condition assessment with basal cover evaluations. To this effect, species composition was intensively used to predict animal production on South African rangelands (Tainton, 1986).

Theoretically, species composition could affect animal production at two levels. At the plant level, species could differ in quality in terms of their degree of animal nutrition and hence in their yield of metabolisable energy. Species could also differ in their potential intake rate owing to differences in bite size or bite rate arising from differences in plant morphology or growth form (O'Reagain, 1996). At the patch or community level, animal production could also be affected by the abundance, proportion and distribution of the different species present (O'Reagain, 1996).

The other aspect of botanical composition/species composition is a means of correcting faulty managerial applications by using the change in botanical composition as an index of rangeland degradation. This happens when undesirable species increase at the expense of desirable species (Kirkman, 1995). Walker (1974), as cited by Thurow, Blackburn and Taylor (1986) pointed out that compositional shifts in perennial plants are an important indicator of range condition. Kelly and Walker (1977) and Shackleton (1993) indicated, however, that the use of botanical composition alone as a single measurement parameter of rangeland condition may be misleading, especially in vegetation types that have a high proportion of pioneer plants that increase or decrease rapidly in response to rainfall.

Rangelands are the major feed resource for livestock and wildlife in semi-arid ecosystems. They are characterised by having a continuous herbage layer dominated by perennial grasses and sedges (Sarmento, 1992). A range of management practices, including burning (Bond, 1997) and livestock/herbivore stocking rate (Owen-Smith & Danckwerts, 1997), effect the negative changes in species composition in rangelands and bush clump savanna. This decrease in palatable grasses is attributed to selective herbivore grazing, where large bulk grazers select palatable perennial species until they disappear from the grazing area. This differential defoliation of plants by livestock induces shifts in species composition (Noy-Meir, Gutman & Kaplan, 1989).

The impact of heavy grazing has caused a shift in species composition, which has removed the more palatable, high-producing grasses from the range (Hanson, 1924, and Costelo & Schwan, 1946, as cited by Johnson, 1956). Grasses of lower palatability, usually sod-forming, and unpalatable weeds and shrubs have replaced these. Similar studies by Dyksterhuis (1949) and Cottam and Evans (1945) showed that heavy grazing pressure tends to damage the most palatable species and reduce their abundance. Other investigations by Johnson (1956) showed that grasses and sedges comprised 48%, 70% and 75% of the total herbage on heavily, moderately, and lightly grazed areas respectively.

Substantiating this finding, Johnston, Dormaar and Smoliak (1971) observed the change of desirable species dominance to undesirable species dominance under heavy grazing intensity, where dominance of desirable species remains unchanged in the lightly grazed areas. Similarly Pluttar, Knight and Heitschmidt (1987) observed a change in plant species composition from desirable mid-grass species to undesirable short-grass species. Ellison (1960) concluded that successional trends in plant communities are proportional to grazing intensity, with the most severe changes occurring under heavy grazing.

Contrary to these findings, reports on species composition in South Africa by McKenzie (1982) revealed that there was little change in species composition under heavy, continuous stocking over several decades, and the changes that occurred were transitory and readily reversible. This was supported by Venter *et al.* (1989), who failed to detect differences in species composition between communal grasslands and the sward within a game reserve. Findings by other researchers lend circumstantial support to the possibility of little change in species composition under such conditions. In line with this, Du Toit and Aucamp (1985) found that species composition of Dohne sourveld was remarkably stable after 36 years of continuous, heavy grazing. This was validated by a trial of 45 years of continuous grazing in mixed sourveld (Donaldson & Rootman, 1983, as cited by Shackleton, 1993).

Similarly, Acocks (1988) suggested that few changes in species composition were observed under continuous, heavy grazing and identified selective grazing as the major cause of range deterioration. However, Tainton (1972) emphasised that heavy grazing did cause a rapid deterioration of species composition in the tall grassveld of Natal but did not overlook the profound effect of selective grazing on species composition, which in extreme cases could encourage range degradation.

Barnes (1992) also mentioned the degradation of sourveld through grazing, which happens to decrease the proportion of grass species preferred by livestock, with an accompanying increase of the proportion of less preferred or non-grazed grass species. Most of these observations were, however, made in the sourveld areas of South Africa, which are less arid and considered to be stable (Hardy *et al.*, 1999).

In contrast, the findings from arid and semi-arid grasslands support the evidence of change in species composition of the rangelands. Among these were Kelly and Walker (1977), who disclosed the significant reduction of perennial species and replacement of annuals under communal grazing in Zimbabwe. Heady (1966) also detected significant changes in species composition along several grazing gradients in a continuous grazing system in East Africa. Similarly, O'Connor and Pickett (1992) recorded a change in species composition of semi-arid areas in communal land subjected to continuous, heavy grazing. Changes included a reduction in tuft size and an ultimate replacement of perennials by annuals and a replacement of palatable species by unpalatable ones. Supporting this finding, Dahl (1986) and Reece (1986), as cited by Hart *et al*. (1988) suggested that changes in species composition are not affected immediately by grazing systems unless aggravated by weather change. Thurow *et al*. (1988) confirmed a shift in species composition in both heavily stocked, short-duration grazing systems and continuously grazed systems.

In conjunction with grazing, water provision has its own impact on the herbaceous vegetation because of the congregation of animals around watering points (Child *et al*., 1971). Similar results were obtained by Valentine (1947), Holscher and Woolfolk (1953), Pinchak *et al*. (1991) and Hart *et al*. (1991, 1993), who stated that livestock utilise forage plants more heavily around watering points compared with areas further away. This data exhibited a reduction in perennial grass standing crop as distance from water decreases from 1 700 m away to the watering point. Other studies by Friedel (1988), Friedel and Blackmore (1988) and Tolsma, Ernst and Verwey (1987) reported the formation of a herbaceous composition gradient around water supplied to livestock. Similarly, a shift of species from perennials to annuals was observed closer to permanent water troughs provided for large herbivores in the Kruger National Park. The area, consisting mostly of annual plants, was identified to extend from 20-300 m away from the trough (Thrash, Theron & Bothma, 1993).

In addition, Foran (1980) and Tolsma *et al*. (1987) also suggested that the provision of drinking water for large herbivores does influence herbaceous composition through selective grazing of preferred species, trampling, dung and urine deposition.

Apart from the effect of grazing, climate and soil characteristics are also primary determinants of species composition of herbaceous communities in semi-arid and arid areas. The influence of soil-available nutrients on species composition of arid and semi-arid rangelands was stressed by Effershank *et al*. (1978).

An important aspect of range management is the influence of grazing on herbaceous layer compositional changes. However, long-term data accumulation in the savanna grasslands of southern Africa suggested that the effect of grazing is contingent upon rainfall (O'Connor, 1985). Rainfall variability has been identified as a primary determinant of compositional change in southern Africa's savannas (O'Connor, 1985). These studies illustrated that rainfall variability over only one or two years could induce substantial changes in species composition. O'Connor (1991a) on further ratification of his study confirmed that annual rainfall variation has an important influence on species compositional change, which is further mediated by the grazing regime because of differential mortality and recruitment patterns in response to them.

2.1.2 Impact of grazing on forage production and basal cover

Forage production of rangeland is an important resource to pastoralists having an animal-based economy. Multifaceted problems, however, play vital roles in range resource management. The production potential of rangeland is directly related to the productivity of the grazing plants present (Fourie, Opperman & Roberts, 1985). The most important variables affecting production potential are water supply and nutrients from the soil (Effershank *et al*., 1978; Barnes & Denny, 1991). Spatial heterogeneity in nutrient availability affects not only the spatial patterns of vegetative cover but also productivity (McNaughton, Wallace & Coughenour, 1983; Schlesinger *et al*., 1990). Barnes and Denny (1991) showed empirically that 77% of the variation in yield could be attributed to variations in the supply of water, nitrogen, cations and clay content of the topsoil.

The productivity of a rangeland depends not only on water and nutrients, but also on the rangeland's composition in terms of the dominant/desirable plant types (Cowling *et al.*, 1994). Many criteria have been used in the past to define dominant/desirable grasses, but according to Cowling *et al*. (1994) palatability (acceptability), productivity and perenniality are the most important. To these could be added nutritive value and ability to withstand biotic stress (grazing, fire and insects) and drought (Roberts, Anderson & Fourie, 1975). Fourie and Roberts (1980), as cited by Fourie *et al*. (1985), supported the finding that the productivity of forage species is related to palatability, aboveground biomass production, nutritive value, perenniality, resistance to grazing and drought.

Optimum forage production is a consequence of different range management actions and climatic conditions that can bring changes in animal performance in the short and long term. Among the problems identified in the short term are temporal climatic variability, livestock number (stocking rate), land tenure and communal grazing, the problem of dry season grazing, drought, burning, animal type and development of livestock water sources. On the other hand, prevention of range deterioration is what is required in optimising forage production in the long term (Danckwerts & Tainton, 1996).

The factors affecting any range system are classed as edaphic, climatic or biotic. The climatic factor that is most likely to impose limitations on biomass production in arid and semi-arid areas is rainfall. Apparently much of the debate about ecological change in the dry land rangelands of Africa has revolved around the relative importance of climate and grazing as underlying forcing factors (Behnke, Scoones & Kerven, 1993; De Queiroz, 1993; Dodd, 1994). The argument *per se* was that climate could mask the effects of grazing practices on total herbage yield. Confirming this study, Turner (1998) revealed that the interactions between the two are so strong that it is difficult to talk about grazing impact independent of rainfall effects. This does not mean that grazing effects are minimal. The effect of grazing on production potential of rangeland is, however, highly contingent on rainfall.

Vegetation response to livestock grazing observed in grazing experiments is well documented for many arid and semi-arid parts of the world (Wood & Blackburn, 1984; Hart *et al*., 1988; Thurow *et al.,* 1988; Skarpe, 1990; Barnes & Denny, 1991; Milchunas, Forewood & Lauenroth, 1994).

In addition, comparisons between grazed and ungrazed areas were made (Bock & Bock, 1993; Olsvig-Whittaker *et al*., 1993). Heady (1964) and Herbel and Pieper (1991), as cited by Guevara *et al*. (1997), stated that universal conclusions are inappropriate, because the results of grazing studies are specific to a given site and closely related to the rate of stocking. Anthony and Peterson (1955), Fusco *et al*. (1995) and Todd and Hoffman (2000) also disclosed that prolonged heavy grazing of rangelands resulted in rangeland degradation, manifested by a permanent decrease in primary productivity. Additionally, overstocking of animals on the same grazing lands year after year affects herbage production of the range. Studies by Tainton (1972), Barnes (1989) and Shackleton (1993) implicated overstocking as a cause of rapid deterioration in herbage production.

Different researchers have studied the impacts of stocking rates together with grazing systems. Hart *et al.* (1988) found that no significant difference in total herbage production was measured between grazing systems and stocking rates. In contrast, Wood and Blackburn (1984) observed high yields in deferred rotational grazing and exclosures and low yield in the high-intensity, low-frequency, moderately stocked, continuously grazed pastures. Very low yield was recorded for continuously grazed pastures. Pluttar *et al.* (1987) found a reduction of yield in heavily stocked rotational grazing and moderately stocked deferred rotational grazing systems.

The effect was pronouncedly observed in range areas around watering points, because water is among the factors that cause uneven distribution of animals in rangeland use (Holechek, Pieper & Herbel, 1989) and high levels of herbivore grazing pressure occur near the watering points, compared with areas away from water (Valentine, 1947; Lange, 1969; Pinchak *et al*., 1991; Hart *et al*., 1991; Hart *et al*., 1993). From this, it is easy to deduce that forage production generally increases with distance from water (Martin & Ward, 1970). Thus the virtue of having water evenly distributed contributes positively to the cattle utilisation pattern of the rangeland (Pinchak *et al*., 1991). The grazing pressure near watering points holds true also for wildlife reserves. Thrash (1998) confirmed the negative impact on herbaceous forage production by provision of water in troughs for large herbivores and the radii of impact extended between 25 and 250 m from the watering point.

Other researchers have also documented long-term interactions of livestock grazing and distance from water on forage production: total grass production was significantly related to distance from water on rangelands in good condition (Fusco *et al*., 1995).

However, this association diminished for most species on rangeland in fair condition (Fusco *et al.*, 1995). Soltero, Bryant and Melgoza (1989) reported that the total grass production in the zone less than 600 m from water was reduced by about 50% compared with the zone 600-1 500 m from water under a short-duration grazing system. Comparisons of distances between 900 and 1 500 m from water showed no differences in grass production. Studies by Fusco *et al*. (1995) on long-term, conservative, continuous cattle grazing on upland sandy sites showed severe reduction of total grass production in the zone less than 1 000 m from water.

Basal cover is most often used as a parameter to describe the occurrence of herbaceous plants, since it has been assumed that basal cover area is not influenced by prior grazing and seasonal conditions (Holecheck *et al*., 1989; Whalley & Hardy, 2000), particularly in the case of perennial species. To avoid ambiguity in basal cover studies, current basal cover studies consider the proportion of the soil covered by the bases of the individual species (Whalley & Hardy, 2000). Moreover, basal cover measurement was considered a good indicator of potential herbage production by Snyman and Van Rensburg (1986), as reported by Thrash (1998). However, earlier findings by Merill and Reardon (1966), as cited by Reardon and Merrill (1976), showed that high basal cover percentages do not necessarily indicate high forage production. This is due to the prevalence of relatively low forage producing species.

Apparently basal cover is one of the yardsticks for assessing range condition, since it is one of the more sensitive indicators of ecosystem change (Holecheck *et al*., 1989). This sensitivity is influenced by a high stocking rate and continuous grazing pressure exerted on the rangeland (Thurow *et al*., 1988), where the impact signifies a sharp decline in total basal cover (O'Connor, 1985; Thurow *et al*., 1988). A report by Du Toit and Aucamp (1985) on 36 years of continuous grazing in South Africa emphasised the steady and significant decline in total grass cover.

However, the decrease in cover was confined to a few species, while the basal cover of the remaining species did not change significantly, although a marked difference in their relative contribution to total basal cover was observed. Hurd (1961) found that total basal cover of grasses, sedges and forbs was similar in both grazed and protected areas (deferred grazing areas). However, basal cover of individual species varied considerably between grazed and protected areas.

Similarly, Vogel and Van Dyne (1966) found that neither moderate grazing nor complete protection from grazing caused a significant change in total basal cover. Nevertheless, the basal cover of several species and groups of species changed significantly throughout the experimental period.

Smoliak, Dormaar and Johnston (1972) also observed the increase of basal cover of undesirable species with increased grazing pressure from light to moderate and heavy, whereas basal cover of the desirable species was found to decrease. Naeth *et al.* (1991) also confirmed the decrease in basal cover of desirable species with heavy grazing intensity. The decrease in basal cover of desirable species is also observed in grazing systems. Pluttar *et al*. (1987) demonstrated the decrease of basal cover of desirable species and the increase of bare ground on heavily stocked rotational grazing and moderately stocked deferred rotation grazing treatments.

Guevara *et al*. (1997) observed the response of perennial grass to cattle grazing in semi-arid areas. Treatments included a yearlong continuous and four-pasture one-herd grazing system under heavily stocked, moderately stocked and lightly stocked conditions (80%, 50%, and 20% removal of the annual production of perennial grasses respectively). Treatments, years and their interaction had significant effects ($P < 0.05$) on total live basal cover. However, no significant differences among treatments, including the enclosures, were observed until 1993. In 1994, lightly stocked treatments on rotational grazing systems had a basal cover significantly higher than the heavily stocked treatments on the same grazing system. Total live basal cover began to decrease under continuous grazing one or two years earlier than under the rotational grazing system. Additionally, there was a significant effect of enclosure and lightly stocked treatment of the rotational grazing system on total basal cover. At the end of the study period, total live basal cover on rotational grazing treatments was lower than the values reported by Skarpe (1990) for a similar environment in Botswana for the ungrazed, moderately grazed and heavily grazed areas.

Complementary to these studies Mworia *et al*. (1998) conducted a study in semi-arid rangelands in Kenya to determine recovery of a rangeland grazed at different grazing intensities during a two-year rest period. The study revealed that the most highly stocked grazing treatments had a significantly lower herbaceous basal cover than the more lightly stocked grazing treatments. At the end of the recovery period a declining trend of herbaceous basal cover with increasing stocking density was still evident.

The root cause of basal cover decline is the uneven use of rangeland by livestock, a problem particularly severe in arid or desert areas (Holechek *et al.*, 1989). This is mostly caused by water sources, as water is often a nucleus of attraction for herbivore/livestock concentrations (Child, Parris & Le Riche, 1971). In arid zones, the animals forage outwards from a watering point, to which they are obliged to return frequently to drink (Lange, 1969). In areas where available watering points are infrequent, large sacrifice areas around watering points caused by high levels of livestock impact on vegetation cover were observed, decreasing with distance from water (Lange, 1969; Thrash *et al*., 1993).

Similar studies on the use of watering points in Arizona inevitably showed that basal cover of perennial grasses was lower near the watering points (Martin & Ward, 1970). Van Rooyen *et al*. (1990) also found evidence of changes in basal cover of certain species relative to distance from man-made watering points when monitoring vegetation changes in the Kalahari Gemsbok National Park. In addition, a study carried out to investigate changes in basal cover in relation to distance from water in the Kruger National Park in South Africa concluded that the provision of a permanent supply of drinking water for game in the Wik-en-Weeg Dam had an impact on the basal cover of the herbaceous vegetation in the vicinity (Thrash *et al*., 1991). In the same study area Thrash (1998) revealed that provision of water for large herbivores in troughs has a negative impact on herbaceous forage basal cover and the radii of impact extended between 25 and 250 m from water for the different watering points surveyed in the study.

2.1.3 Impact of grazing on forage quality

A conventional approach to viewing pasture quality is in terms of its digestibility and intake, nitrogen level, availability of minerals and vitamins and the occurrence of toxicities and imbalances. The composition of the feed may then be considered in relation to the structure of the sward and the manner in which grazing behaviour and selective grazing modify the diet ingested (Humphreys, 1991). On the other hand, Robbins (1983) and McNaughton and Georgiadis (1986) stressed the importance of protein and fibre contents as forage quality determinants.

Forage contains a variety of chemical constituents, which serve as nutrients for livestock/large herbivores. Some nutrients are sources of energy while others satisfy a specific requirement in the animals’ bodies.

These chemical components can be divided into cell wall constituents (CWC) and cell contents (CC), and into digestible, indigestible or poorly digestible fractions (Van Soest, 1982). Associations of soluble carbohydrates, starch, organic acids, cellulose and hemicellulose, together with lipids (fats), contribute to the energy content of forages. Proteins, vitamins and minerals provide essential components of the animals' diet and are required in an appropriate balance if animals are to perform adequately.

Among the essential components is crude protein, which is the primary measure of quality and is often the main limiting nutrient for livestock in the tropics (Norton, 1982). This is because the protein content of forages imposes a severe physical restriction by limiting intake when total protein content is less than 6-7% (Milford & Haydock, 1965). Norton (1982) reported that more than 50% of all tropical grasses contain less than 9% crude protein and less than 20% of them have crude protein contents above 15%. Generally, it is reported that many tropical grasses have only modest levels of crude protein when green, and this falls to very low values following maturity (Norton, 1982).

Apart from protein, minerals could be in short supply in rangeland and this could lead to physiological disorders and suppression of animal performance. The soil minerals of the tropics are highly leached and weathered and are mainly of low base-exchange capacity. In consequence, the mineral content of tropical forages is relatively low in some of the minerals needed by animals, particularly phosphorus, sodium and calcium (McDowell et al., 1977; Norton, 1982; Minson, 1990; Humphreys, 1991). The essential dietary minerals are classified as either macro or trace element nutrients, depending upon the quantity required by the animal. The macro elements are mainly utilised either for structural purposes (calcium, phosphorus and sulphur) or in the maintenance of acid base balance (sodium, potassium and chlorine). In addition, they make vital contributions to energy transfer, nerve impulse transmission and enzyme activation (potassium, calcium and magnesium).

It is known that variations in nutrient content occur between and within plant species and that livestock select forages to obtain a nutritionally balanced diet (Hardy & Mentis, 1986; McNaughton, 1988; O'Reagain & Mentis, 1989). The forage species selection by animals has been shown to be positively associated with the content of protein, potassium and phosphorous but negatively correlated to fibre content (Heady, 1964). This refers to the plant species that are most palatable and tend to decrease and disappear during heavy grazing pressure and are replaced by less palatable and unpalatable species.

The effect of repeated severe grazing induced by a high stocking rate was reported by Van Niekerk et al. (1984) as well as Chapman and Lemaire (1993), indicating that overgrazing reduces the ability of the vegetation to produce, and to continue producing herbage. Hardy and Hurt (1989) and Morris, Tainton and Hardy (1992) obtained similar results, revealing the change in the botanical composition of rangeland both in humid and in semi-arid grasslands.

The fact that animals graze preferred plants selectively has been well documented (Theron & Booysen, 1966; Tainton, 1972; Heady, 1975; Danckwerts, Aucamp & Barnard, 1983). Boudet (1975) also confirmed that the loss of animal-preferred species is usually associated with a decline in the nutritional value (feed value/forage quality) of the available forage. A decline in available forage is also caused by severe grazing pressure.

It has long been recognised that grazing pressure around watering points leads to severe rangeland degradation. Ellison (1960) also concluded that successional trends in plant communities are proportional to grazing intensity. The most severe changes occur under heavy grazing, where good quality forage species decrease. Accordingly, high grazing pressure near watering points causes sacrifice areas in which perennial herbaceous plants cannot survive (Lange, 1969; Van der Schijff, 1957, as cited by Thrash, 1998). In view of this, Westoby (1980), O'Connor (1991b) and Thrash et al. (1993) supported the theory of the destruction of selectively grazed perennial forage plants and their replacement by other perennials, which are less acceptable to mammalian herbivores. Although grazing brings negative changes in the relative abundance of perennial plant species, they are seldom reversed by withdrawing livestock to enhance forage seed recruitment on the range (Westoby, Walker & Noy-Meir, 1989).

Beyond these sacrifice areas there is a zone where the impact of large herbivores tapers off, until an upper asymptote is reached (Thrash et al., 1993). This pattern results in sigmoid-shaped relationships between range parameters like quality and distance from water (Thrash, 1998). Any trends in the herbaceous vegetation detected along the gradient of increasing distance from water would thus be, either directly or indirectly, due to the influence of the presence of the water on the pattern of herbivore use intensity (Thrash et al., 1991). Successional trends leading to the reduction of desirable forage species around watering points were confirmed by Lange (1969), Martin and Ward (1970) and Foran and Bastin (1984).

Studies by Fusco et al. (1995) identified three key forage grasses being affected by distance from water, where the greatest reduction was observed in the most preferred forage species, followed by the intermediate palatable ones.

It has long been recognised that livestock grazing reduces the preferred quality forage species around watering points (Martin & Ward, 1970; Foran & Bastin, 1984).

Fusco et al. (1995) and Soltero et al. (1989) tried to define to what extent the grazing effect reduces the desirable perennial forage grasses. Fusco et al. (1995) confirmed that perennial forage grasses diminish in the zone less than 1 000 m from the water source. Soltero et al. (1989) showed that the reduction of perennial grasses closer than 600 m to the water source was about 50% higher compared with other zones further away from the water source. Others have found a reduction of the desirable grasses within two kilometres of stock watering points, owing to heavy utilisation by livestock (Bosch & Gauch, 1991; Perkins & Thomas, 1993). These findings in general entail the reduction of quality forages (preferred species), owing to heavy grazing intensity around watering points.

In relative terms tropical forages usually contain very low levels of crude protein and high levels of fibre (Ostrowski, 1969; Bishnoi, Oka & Fearon, 1993). Therefore, crude protein is a valuable resource in many tropical and subtropical feeding systems, where seasonal variation in pasture growth rate is extremely large (Sere & Steinfeld, 1996). Each plant species shows a highly distinctive chemical composition profile, distinctions that are maintained between sites and over time. McNaughton (1988) noted that species composition at a given site is of fundamental importance in determining the availability of nutritive elements to livestock. Many studies have reported a high concentration of nitrogen, phosphorus and other nutrients and a low concentration of fibre, soon after growth resumes at the onset of the rainy season (Hardy & Mentis, 1986; O'Reagain & Mentis, 1989). The quality of forage on a rangeland must therefore be seen in the context of the stage of development of the forage.

2.1.4 Impact of grazing on soil physical and chemical status

The knowledge of soil characteristics and classification is essential for rangeland management because soil is the primary factor determining the potential for forage production of an area within a particular climate (Holecheck *et al*., 1989). High yields of quality forage and a nutrient-sufficient status of forage crops are attributes of soil productivity.

Productivity is a function of natural soil fertility, soil physical properties, climate, management and other non-inherent factors used to produce crops (Follett & Wilkinson, 1995). Barnes *et al.* (1991) tried to correlate the variations in yield of natural grassland with soil water content, nitrogen (N) supply and the cation exchange capacity. The major factors associated with yield variations were soil water content, N supply and cation exchange capacity, in order of importance.

Next to water, fertility is the second most limiting factor of forage production in arid rangelands. The concept of "soil quality" has recognised soil organic matter as an important attribute that has a great deal of control over many of the key soil functions (Doran & Parkin, 1994). The same concept was reflected by Foth and Turk (1972) and Mokwunye (1996) as cited by Ward *et al. (*1998), who emphasised that soil organic carbon is a good measure of overall soil quality. Soil texture determines the fertility of the soil to a considerable degree. Soils with high clay content retain nutrients such as N, phosphorus (P) and potassium (K) much better than sands (Holecheck *et al*., 1989). Low soil fertility is a major problem, limiting forage and livestock production in tropical rangelands in many parts of Africa. Nitrogen is the most deficient element in rangeland soils. Phosphorus, potassium and sulphur (S) are also deficient in most of the rangeland soils (Holecheck *et al*., 1989). These deficiencies result in tropical forages being low in mineral content (Humphery, 1962).

Among the important physical properties of soils, soil texture and structure are to be considered. Together these properties modify the physical environment for plant growth by determining the availability of water and oxygen and nutrient-supplying ability of soil solids (Brady, 1990; Humphreys, 1994). Water enters coarse, sandy soils much more rapidly than fine clay because there is more space between particles. On the other hand, clay soils retain water much better than do sandy soils (Holecheck *et al*., 1989). Humphreys (1994) also considered water retention to be the most important physical property. Plant yields were linearly related to stored water and to water usage during the growing season. These characteristics were related to soil structure, organic matter content, macro porosity and rate of infiltration.

Organic matter also influences physical and chemical properties of soils. It binds mineral particles into granules and increases the amount of water a soil can hold. It is also a major soil source of P and S and the primary source of N. Ward *et al*. (1998) showed organic matter frequently to be highly correlated with two of the most important soil nutrients, N and P, in many African soils.

Organic matter is also a source of energy for soil organisms - without it biochemical activity would come to a near standstill. Soil N, P and pH are positively related to soil carbon (C) and the level of soil organic matter (OM), which largely determines the fertility and pH of sandy soils (Jones, 1973; Wilding & Hossner, 1989).

In general, the organic contents of soil are important in providing energy, substrates and the biological diversity necessary to sustain numerous soil functions. A sandy soil carries less organic matter than finer textured soil. This is probably because of the lower moisture content and greater oxidation occurring in lighter soils (Brady, 1990). Oades (1984), emphasising the importance of OM, suggested its management to maintain soil structure for water infiltration, active root growth and soil stabilisation in dry land agriculture.

The effect of soil pH on nutrient availability is important. The availability of nutrients such as N and P and the solubility of nutrients such as K, P and other essential elements are strongly influenced by soil pH. A pH of 6 to 7 is best for P availability and for most nutrients needed for plant growth (Follett & Wilkinson, 1995). In soil of arid and semi-arid regions, lack of extensive leaching leaves the level of base-forming cations quite high. As a result the pH is commonly 7 or above (Brady, 1990). Grasses tend to use more of the bases present in soil and prevent the soil pH from dropping by depositing plant parts on the soil surface (Thompson & Troeh, 1978).

Another characteristic of soil is cation exchange capacity (CEC), which is a measure of the number of negatively charged sites on soil particles that attract exchangeable cations. That is, positively charged ions are replaced by other such ions in the soil. OM content as well as the amount and type of clay influence CEC. Finer-textured soils also have higher CEC than sandy soils.

Grazing studies have emphasised plant-animal relationships and have usually considered range soils only in relation to damage by erosion. However, the kind of vegetation affects and modifies the soil in which it grows (Humpherey, 1962). Studies of long-term grazing effects on fescue grassland soils (Johnston *et al*., 1971) showed that very heavy grazing by cattle on a range that had previously been lightly grazed changed the pH from 5.7 to 6.2, reduced the percentage of OM, decreased the percentage of soil moisture, reduced the total P percentage, but increased available P. In contrast, Smoliak *et al*. (1972) indicated that increased grazing pressure had little effect on physical characteristics of the soil such as texture and moisture, and on total and available P and N content. However, the soil pH and exchangeable calcium (Ca) and sodium (Na) decreased with increased grazing intensity, but there were no significant differences in texture, moisture, N, total and available P, exchangeable K and CEC. Total C also increased with increasing grazing pressure. Similarly, Simpson, Bromfield and Jones (1974) indicated the increase of P and exchangeable K under all treatments, with no evidence of any grazing pressure effects.

As far as OM is concerned, many factors determine the response of soil OM to livestock grazing. Floate (1981) summarised these factors as the initial status of vegetation and soil, environmental factors, especially moisture, and temperature and grazing history (intensity, frequency, duration and type of animal). Many studies have evaluated the effect of grazing on soil OM. Smoliak *et al*. (1972), Ruess and McNaughton (1987) and Dormaar, Smoliak and Willms (1990) reported increases in both soil organic C and N, while other studies by Simpson *et al*. (1974), Mathews *et al*. (1994) and Milchunas and Laurenroth (1993) indicated no response in soil organic C and N to grazing.

Considering different grazing systems, McGinty, Smeins and Merrill (1979) found similar results in OM content for heavily stocked, continuously grazed, deferred rotation and livestock excluded range pasture. Similarly, Manley *et al.* (1995), taking samples at different soil depths observed different values of soil organic C and N for the different grazing systems considered. However, C and N contents remained lower in the exclosures.

The other parameters to be investigated are the animal trampling effect and infiltration. Reduction in pasture productivity is attributed to the animal trampling effect on soil physical properties (McCalla, Blackburn & Merill, 1984; Holt, Bristow & McIvor, 1996). The cause is stresses exerted by the hooves of grazing animals (Willatt & Pullar, 1983). To this effect, two processes occur in response to trampling. One is soil compaction, which affects the structural form of the soil through the loss of pore volume, and the second is soil remoulding, which affects structural stability through the progressive weakening of the soil aggregates as rain water incorporated and bonded between particles is disturbed (Mullins & Fraser, 1980; Willatt & Pullar, 1983; Chanasyk & Naeth, 1995). The magnitude of the trampling effect depends on several factors, such as stocking rate, grazing system, soil texture and soil moisture content (Van Haveren, 1983; McCalla *et al.*, 1984). This change in physical soil property contributes to the reduction of water transmission through the soil profile (Proffitt *et. al.*, 1993; Dreccer & Lavado, 1993).

Water transmission or infiltration is the process by which water enters the soil. Infiltration rate is the quantity of water absorbed in the soil per unit of time. The infiltration rate influences the soil water content, which satisfies the evapotranspiration requirements of growing plants and also acts as solvent to dissolve nutrients. Infiltration rates are controlled by vegetative, edaphic, climatic and topographic influences. The kind of vegetation and amount of cover modify the soil water relationship of a site. Grazing systems are often used to improve both vegetation cover and infiltration rates (Wood & Blackburn, 1981). Many researchers have studied the influence of grazing on infiltration. Pluttar *et al*. (1987) investigated the decline in infiltration rates in heavily stocked rotational grazing and moderately stocked deferred rotational grazing treatments, but an insignificant difference was observed with moderately stocked continuous and deferred rotation treatment. Thurow *et al*. (1986) observed that both heavily stocked short-duration and continuous grazing recorded a low infiltration rate, compared with moderately stocked continuous grazing and livestock exclosure pastures. In general, a high stocking rate affected soil physical properties accompanied by lower hydraulic conductivities (Proffitt *et al*., 1993).

Tolsma *et al*. (1987), who studied soil nutrients around artificial watering points, revealed that the concentration of all nutrients was higher in the vicinity of the borehole (0 -100 m). No significant change in soil nutrients was observed between 100 and 1 500 m from the borehole, except for K and Ca, where concentrations decreased with increasing distance from the borehole. Similar studies by Turner (1998) revealed that gradients in nutrient availability around older boreholes are observed not simply within “sacrifice zones” of up to 500 m from the water sources, as has been found in the case of more newly established boreholes, but over a wider scale, up to a 5 km radius.

Other studies confirmed that the concentration of total N, C and P is elevated only in very close proximity (< 200 m) to livestock accumulation points (Valentine, 1985; Andrew & Lange, 1986; Tolsma *et al*., 1987; Barker, Thurow & Herlocker, 1990). Likewise West *et al*. (1989) observed substantial gradients of extractable P, exchangeable K, and total N in soil near the watering areas. The enhanced nutrient zone extended approximately 10-20 m from the water source. Similarly, Perkins and Thomas (1993) revealed that beyond 50 m from boreholes, the nutrient concentration was comparable to the control site far away from the watering point. Marked increases in concentration of nutrients were observed in the inner 50 m radius.

A recent study of vegetation gradients from water sources in Mongolia depicted that concentrations of P, K, N and C were usually highest on the plots close to water (Maria & Barbara, 2001). Since distance from water and concentrations of P and K were negatively correlated, it is possible that livestock mediated the redistribution of nutrients along a gradient from water sources. Other investigators (Moleele & Perkins, 1998; Turner, 1998) observed the same pattern of nutrient redistribution around watering points. Soil pH change was also indicated by Turner (1998). In the rainy season the soil pH decreased by half a pH unit for every kilometre away from a watering point.

Numerous studies on the effects of grazing on soil physical parameters have been carried out during the past two decades. Linnartz, Chung-Yun and Dunval (1966) found that 10 years of grazing during spring and summer resulted in sufficient soil compaction to restrict water movement in the soil profile during intensive rainstorms. In line with this, Rauzi and Hanson (1966) found that water intake rates decreased almost linearly as the intensity of grazing increased. Similarly Rauzi and Smith (1973) concluded that the infiltration rate was higher on lightly and moderately grazed pastures than on heavily grazed pastures. Bryant, Blaser and Peterson (1972) reported that soil compaction increased linearly with increased grazing intensity. Thurow *et al*. (1986) found that water infiltration rates under short-duration grazing were lower than rates under moderately stocked continuous grazing on bunch or sod grass. Infiltration under heavily stocked continuous grazing was slower than under short-duration grazing on sod grass. Subsequently, Abdel-Magid, Schuman and Hart (1987) observed that grazing systems (continuous, rotational deferred and short-duration rotation grazing systems) did not affect the water infiltration in a consistent manner. However, increased stocking rates resulted in reduced infiltration during the grazing season.

2.1.5 Restoration of degraded rangeland

Rangeland degradation is the reduction in or loss of productivity and the ability to produce sustainable activities pertinent to the system of land use. In a later definition of rangeland degradation by Abel and Blaike (1990), an area is considered effectively degraded if the loss of production is beyond the bounds of resilience. This differs from the conventional approach, where a change in composition from palatable to less palatable species and an increase in bare ground are considered degradation. Degradation is a phenomenon occurring mainly in arid, semi-arid and dry, humid areas. The causes of land degradation are many: the abuse of the environment through ignorance, injudicious management practices, climatic variability, as well as political, industrial and historical issues. Degradation starts with the formation of smaller areas of bare patches, which expand or join together to form large, bare and denuded areas in the long term (Kellner & Bosch, 1992).

Owing to worldwide interest in nature, land restoration on degraded rangeland is becoming an increasingly popular topic for scientists, land managers and land users, especially in arid and semi-arid regions. This is due to the deteriorating condition of the environment, which leads to a loss in food security and to poverty and economic losses, especially in rural, communally managed and underdeveloped areas of the African arid and semi-arid lands (Dumanski & Pieri, 2000).

The potential of rangeland improvement by natural or artificial re-vegetation depends upon the kinds and amounts of vegetation remaining, climatic conditions, the feasibility of using grazing management practices or range improvement practices to accelerate successional processes, the expected recovery rate and the cost of alternative approaches (Valentine, 1980). These restoration procedures include active (browsing, burning, clearing, reseeding and cultivation) (Van der Merwe, 1997) and passive methods (withdrawal of livestock/game) (Milton & Dean, 1995).

Natural re-vegetation implies improved management, particularly of grazing, to restore vigour and accelerate the spread of the remaining desirable plants (Valentine, 1980). Although vegetation responses to improved management vary from site to site, a minimum of 15% of desirable perennial species in the vegetal cover is often used as an index to indicate the potential for successful natural improvement on semi-arid range areas (Valentine, 1980). In certain instances rangeland deterioration is so far advanced that not even the use of sound management practices can restore it to its original grazing potential (Hassanyar, 1977; West *et al*., 1989; Jordaan, 1997). Consequently, manipulation of competing vegetation and artificial re-vegetation may be the only recourse if rapid range improvement is desired.

On the other hand, artificial re-vegetation involves the establishment of adapted species by planting harvested seed or by transplanting seedlings or vegetal segments. This is practised when insufficient desirable forage plants remain (Valentine, 1989).

This method of revegetation works against normal successional processes by attempting to hold the plant community in some artificial stage (Box, 1984, as cited by Valentine, 1989). Under other circumstances, with less intensive land preparation (overseeding) the development of desired plant communities depends upon the integration of artificial re-vegetation (establishment of seeded species) with natural re-vegetation (Valentine, 1980).

In addition to these perceived theories of re-vegetation of rangelands, seed bed preparation practices are also utilised to ameliorate harsh environmental conditions in the surface soil of arid and semi-arid rangelands. Preparation is done by ploughing and furrowing or other mechanical methods for the purpose of creating microsites/ microclimates suitable for seed germination, plant establishment and persistence. Harper, Williams and Sagar (1965), Grubb (1977) and Harper (1977) reported the need for suitable micro-environmental factors of the seedbed for successful seed germination, seedling establishment and subsequent plant growth. This is attributed to better water infiltration (Griffith *et al.*, 1984). Other researchers have also reported the importance of mulch, fertiliser and manure to create a favourable microenvironment in the seedbed for successful plant establishment.

In dry land areas, the high evaporation rate, due to the hot, dry climate under reduced rainfall and short rainy seasons, is the major cause of water deficits. This is a continuous process and a very high amount of water is lost through evaporation. One way of reducing evaporation is to use mulches (Rickert, 1973; Jordaan & Rautenbach, 1996). Soil temperatures are influenced by soil cover and especially by organic residues or other types of mulch placed on the soil surface. In warm regions, mulching may provide the double benefit of increased rooting in the more fertile topsoil plus decreased evaporation of water from the soil surface (Brady, 1990).

In the semi-arid tropics, surface mulching with crop residues has proven effective in conserving soil moisture, decreasing soil temperature and maintaining favourable soil structure through enhanced biological activity (Lal, 1979, as cited by Mitiku & Giorgis, 1991). Mulching also increases the soil OM and improves soil physical conditions as well as nutrient content and moisture retention capacity. It also has the distinct advantage of controlling weeds that compete with crop plants for water and nutrients. In the dry land farming research conducted at Katumani, Kenya, stover mulching was found to be effective in controlling run-off, reducing evaporation and increasing infiltration rates, and maize yield was increased by 100% during a low rainfall season (Nijiha, 1979, as cited by Mitiku & Giorgis, 1991).

Many researchers have reported on the importance of mulch. Dully and Kelly (1941), as reported by Hopkins (1954), stressed the importance of mulch in improving infiltration as compared with bare soil. The finding was confirmed by Rickert (1970) and Lavin, Johnson and Gomm (1981), who found that greater dry matter production of sown grasses in mulch treatments, resulted from increased plant populations. The increased plant populations resulted from a higher survival rate and better growth and establishment of the seedlings. This was the consequence of the modification of the surface soil microenvironments, such as moisture content and soil temperature (Hopkins, 1954; Leslie 1965; Rickert, 1973; Thompson, 1974; Watt, 1982; Jordaan & Rautenbach, 1996) and reduction in soil surface crusting (Rickert, 1973; Lavin *et al*., 1981) attributed to the application of mulch materials. Other studies by Lavin *et al*. (1981) emphasised the importance of straw mulch in protecting soil surfaces from puddling and erosion.

In the tropics, where herbage is used for livestock production, the chemical composition of the forage, especially with respect to N and P, is very important. However, low soil fertility, which is a major problem in the tropical rangeland of many parts of Africa, limits forage and livestock production. Nitrogen is the most deficient element in rangeland soils in terms of plant growth. Phosphorus deficiencies are also important in most rangeland soils. Hence the use of chemical fertilisers and organic manure as sources of plant nutrients for obtaining high yields has long been recognised. The application of organic material does not only potentially increases the C content of the soil, but could also help in the aeration and retention of water of the degraded soil. Addition of OM also increases the establishment and growth rate of over-sown seed plants (Van der Merwe, 1997; De Wet, 2001).

Range development programmes designed to attain higher productivity include, among other practices, fertilisation (Guevara *et al*., 1997). In natural grassland, N is recognised as the chief yield determinant (Rethman, 1980; Semmartin & Oesterheld, 2001). Phosphorus can have a dramatic positive effect on yield when these elements are deficient (Rethman, 1973 and Miles, 1988, as cited by Rethman & Beukes, 1989). Long-term fertiliser studies in Ethiopia showed that both chemical and organic fertiliser had significantly improved natural pasture in the highlands. Natural pasture could be improved significantly by applying 23 kg N ha^{-1}. The N fertiliser also considerably improved the crude protein content of the natural pasture. Phosphorus has little effect on dry matter yield (IAR, 1971).

Manure as organic fertiliser was also tested on dark brown clay in the Highland and Midland areas of the country. Application of 10 t manure ha^{-1} or more improved the dry matter yield of the pasture (Bekele, 1975). The manure also effected changes in both plant cover and species composition. Moreover, a report by McKenzie *et al*. (1998) and Guevara *et al.* (2000) indicated that N and P fertilisation played a determining role in the CP content of herbage.

Other reports indicated that P has little effect on forage yield, either alone or in combination with N (Hull, 1963; Leamer, 1963; Lavin, 1967). However, in contrast, Cosper and Thomas (1961) and Wight and Black (1979) confirmed that maximum production was obtained from N and P in combination. Smika, Haas and Rogler (1960) also indicated that the presence of P increased the uptake of N on dry ranges.

On the other hand, the use of fertilisers to increase seedling establishment and growth on extensive revegetated areas in arid and semi-arid regions is a questionable practice (Heady, 1975). However, for rapid restoration of degraded rangeland Edwards (1981) emphasised the need for fertilisers. Roundy and Call (1988) also showed the importance of fertilisation to promote plant establishment and growth on drastically disturbed areas. This was found to modify the fertility of the soil, thereby creating a favourable microenvironment for seeds to germinate.

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CHAPTER 3
STUDY AREA

The Allaidege rangeland is part of the district (wereda) of Amibara, in administrative zone 3 of the southern part of the Afar regional state. The district town Melka Werer is geographically located at 9°10'S; 40°9'E, 270 km northeast of Addis Ababa.

The research area (Allaidege rangeland) is on the eastern side of the Amibara district (wereda), bordered by the Asebot hills to the east and to the north and south by Gewane and Awash Fentale districts respectively. Geographically the rangeland is located between the coordinates of 9º 35' 17.170" N; 40º 11' 4.161" E, 9º 35' 12.996" N; 40º 29' 6.947" E, 9º 3' 16.271" N; 40º 10' 58.144" E and 9º 3' 12.33" N; 40º 28' 58.83" E east of the main highway that leads to the neighbouring countries of Eritrea and Djibouti.

The rangeland has an arid climate (Qolla) where the annual temperatures range between 32 ºC in June and 24 ºC in December and the mean annual rainfall during the experimental period of two years, 2003 and 2004, were 372.6 mm and 317.5 mm, respectively. The occurrence of limited rains in this area, according to Daniel (1977), is attributable to it being located in a low-pressure convergence zone known as the intertropical convergence zone. Another consequence of this geographic factor is that rainfall, humidity and temperature are highly variable throughout the zone, both in temporal and spatial terms. There are two rainfall patterns: the short rain (Belg), which occurs from February to April, and the main rainy season (Keremet) from July to September. Rainfall during the first wet season results from the convergence of moist southeast winds from the Indian Ocean with the dry northeast air stream, and is generally unreliable. It usually occurs as light rain (Daniel, 1977).

The Allaidege rangeland is the main grazing area of southern Afar. Before the intervention of agricultural enterprises in 1971, the rangeland was distinctively known to be a wet-season grazing area. The rangeland consists mainly of open grassland that sustains cattle and game animals (Halcrow, 1989; MCE, 2000). Camels and goats browse on the shrubs and bushy vegetation, mainly in the roadside portion of the rangeland. In the southern part of the plain camels browse on scattered, large shrubs and graze the palatable forbs during the growing season. After the dry-season grazing area became off limits, attempts were made in 1972 to carry out a range development programme to pacify the disgruntled nomadic population. The objective was to develop infrastructure and natural resources to support livestock production and marketing (Coppock, 1994). The main focus was to develop watering points at given distances so that the available pasture could be used properly. Simultaneously, the aim was to compensate the distant communities, to discourage them from reaching the plantation area, and to minimise dissatisfaction and interference in the dry-season grazing areas (Ayalew, 2001).

Currently the area is an all-season grazing area, despite the animals being moved to cotton fields from November to the end of January to utilise cotton residues (Personal communication with clan leaders & elders, 2003). The existing mode of life contributes to permanent settlement in portions of the rangeland. The establishment of schools and a mosque has strengthened permanent settlement and restricted the traditional mobility that was a way of life for so long. There is now a perception in the communities that significant vegetation changes have taken place, resulting in naturally irreversible stages of degradation in large portions of the rangeland.

3.1 Topography and soil

The Allaidege rangeland is estimated to comprise 200 000 hectares (Halcrow, 1989), at an altitude of about 820 - 840 m above sea level. A reconnaissance survey made by Halcrow (1989) indicates that the area is predominantly flat, with slopes encompassing probably less than 0.5%, except for slightly undulating areas associated with narrow, indistinct and often discontinuous drainage lines. The surface shows no microrelief and is free of stones.

The soils are predominantly fine-textured. At the western side of the plain silty loam to silty clay loam surface horizons pass to silty clay at depth. In some areas the soils are rather siltier and slightly lighter in colour, which appears to coincide with the presence of strongly calcareous subsoils. Approximately 5 km from the acacia bush at the edge of the hills the land appears to have a slight incline of about 1%. Soils, however, stay fairly uniformly dark and fine-textured. None of the soils examined showed impeded drainage, nor was there any detectable evidence of salinity (Halcrow, 1989).

3.2 Vegetation

According to the study made by MCE (2000), the vegetation cover of the zone is described as riparian, bushland/shrubland, grassland and wetland. The zone is said to have better rainfall than the others, with a much better plant species composition and range productivity. The Allaidege plain where the study is focused consists mainly of open grassland (Halcrow, 1989; MCE, 2000). However, closed shrub/bush vegetation also exists on the western side of the plain along the main highway (MCE, 2000) and scattered large shrubs are found towards the south (Halcrow, 1989). Currently, serious bush encroachment in the form of invasion by a noxious plant, *Prosopis juliflora*, is taking place in the northern region of the rangeland, and there is opposition against the plant by the pastoral community. Management and control of the plant should be promoted to prevent it from infesting the whole rangeland.

3.3 Climate

The long-term average annual rainfall registered over 34 years (1970-2004) at Werer Agricultural Research Centre (WARC), which is situated 20 km from the experimental site, amounts to 560 mm annum^{-1}, of which 42% occurred during July and August. Nevertheless, variation can be noticed in the amount of rainfall received during the year. The lowest monthly rainfall was 4 mm, occurring in December, and the highest was 122 mm, occurring in August (Fig. 3.1). The rainfall that occurred during the growing seasons of 2003 and 2004 was 372.6 mm and 317.5 mm respectively. But the actul rain received upto the sample harvest for 2004 was 223 mm.

According to the meteorological data of the grazing area recorded at the Research Centre over the last 34 years (1970-2004), the monthly temperatures vary from a mean minimum of 14.8 ºC and 23.7 ºC to a mean maximum of 30.5 ºC and 37.9 ºC. The highest maximum and least minimum temperatures recorded over the time period was 39.9 ºC and 9.6 ºC respectively. The temperature is generally high throughout the year, the coldest period occurring between September and January, and the hottest extending from March to June. In relative terms, December and June are respectively known to be the coldest and hottest months of the year (Fig. 3.2).

The monthly average number of sunshine hours fluctuates slightly between 7.2 hrs day^{-1} and 9.6 hrs day^{-1}, which means that the region is exposed to constant sunshine throughout the year. The cumulative effect of low and erratic rainfall, high temperatures and constant sunshine is responsible for the high rate of evaporation in the region. Rainfall and temperature data for the study period is given in Fig. 3.3.

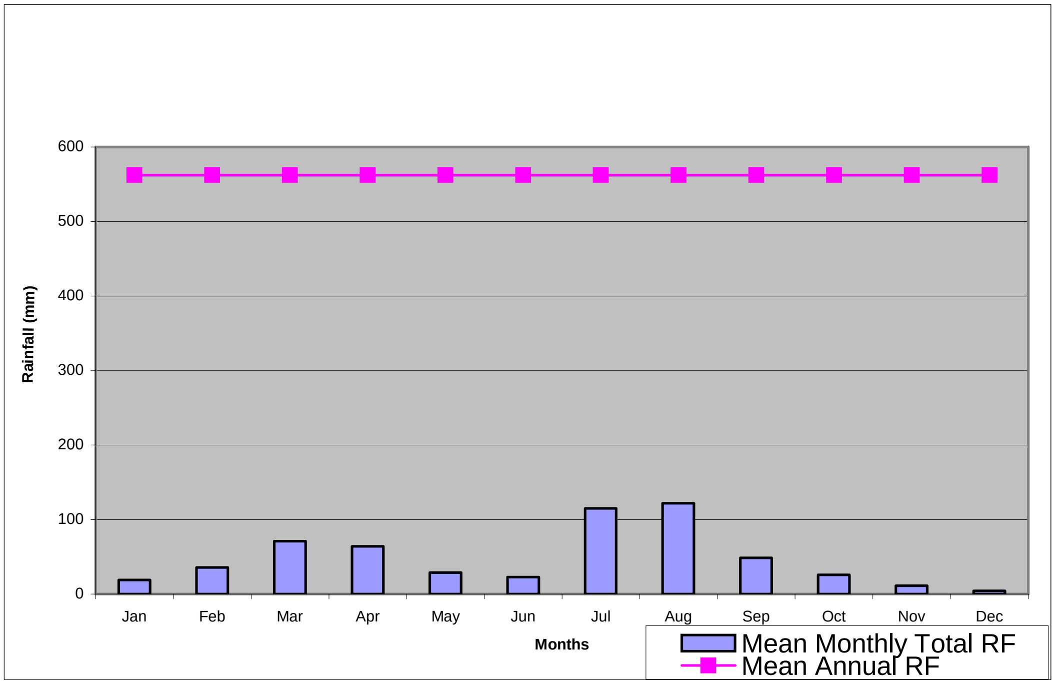

Figure 3.1 Mean annual rainfall and mean monthly total rainfall between 1970 and 2004 in Werer Agricultural Research Centre (WARC) (Source: WARC, Agrometeorology Research Section, 2004).

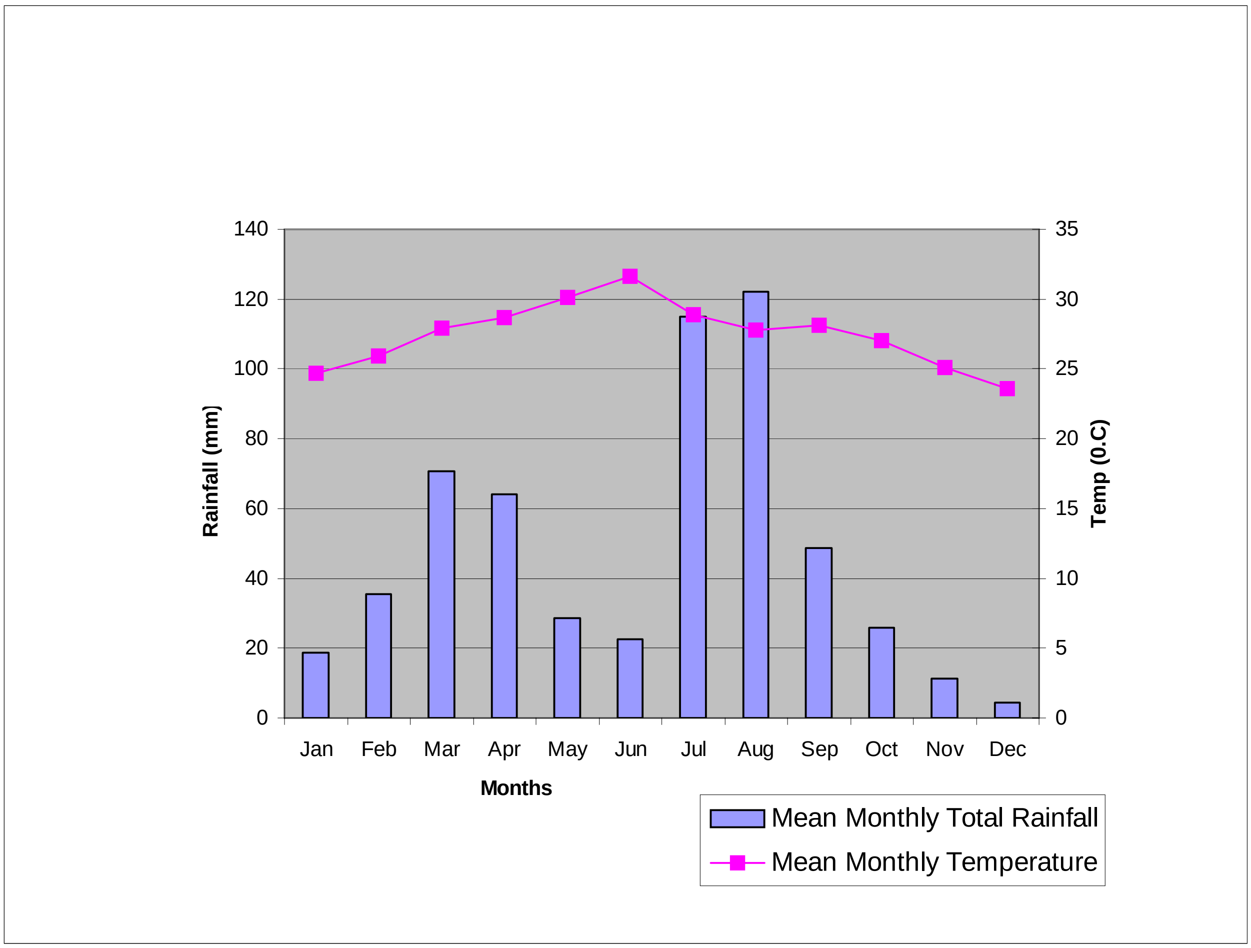

Figure 3.2 Mean monthly total rainfall and mean monthly temperature between 1970 and 2004 in Werer Agricultural Research Centre (WARC) (Source: WARC, Agrometeorology Research Section, 2004).

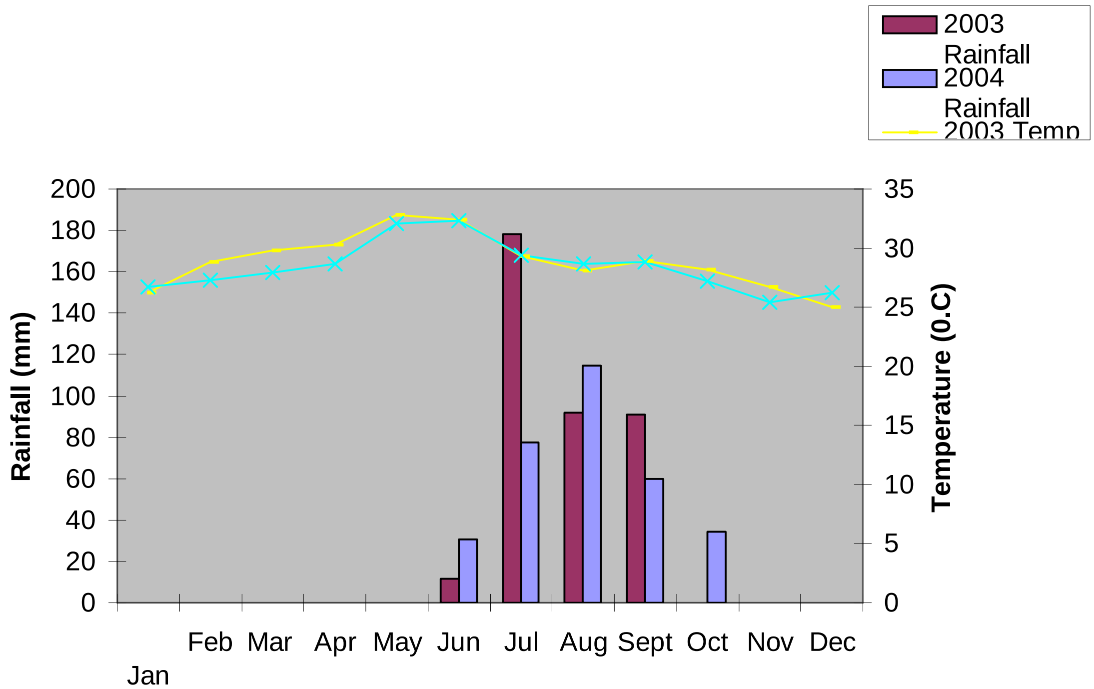

Figure 3.3 Monthly total rainfall and average temperature of the growing season in 2003 and 2004 in Werer Agricultural Research Centre (WARC) (Source: WARC, Agrometeorology Research Section, 2004).

3.4 Field experimental procedure

Before the commencement of the rainy season in 2003/2004, a research site with a watering facility was identified and the project proposal was informally discussed with community groups living in the area. The groups were suspicious of the fact that enclosure of areas in the rangeland by fence formed part of the project. This reaction stemmed from the fact that fencing would affect their grazing area and their livelihood in general. They were also concerned about the ultimate benefits arising from the project. These feelings were legitimate, because certain past activities had displaced pastoralists from their prime grazing area for the expansion of irrigated agriculture. On the other hand, it was also felt that many organisations (both government and non-government) that had conducted activities in the area had made no significant contribution towards recognising and alleviating the communities' problems (Personal communication with clan leaders & elders, 2003).

To address their concerns, meetings were called with the different groups in the community (clan leaders, elders, women, herders) and the contents of the project as a whole, as well as the advantages of running the experiment to alleviate the issue of degradation, were thoroughly discussed. This meeting alleviated the spirit of suspicion and reluctance and motivated the community as a whole to show interest and to take part in the execution of the experiment.

Eventually, individuals from the community group were involved in the field layout to stratify the grazing land into different degradation areas. In cognisance of the vegetation cover the grazing area was quantitatively stratified into four degradation areas: severely degraded (SD) (area = 48.97 ha) (Plate 1 and 2); moderately to severely degraded (MSD) (area = 52.99 ha) (Plate 3 and 4); moderately degraded (MD) (area = 24.98 ha) (Plate 5) and lightly degraded (LD) (area = 12.54 ha) (Plate 6). Coordinates were taken by GPS to map and calculate the area (Fig. 3.4).

A 1.2 km transect was laid out perpendicular to the direction of the grazing gradient, more or less in the middle of each of the degradation areas. Transects were laid out in the middle of each degradation area to avoid border effects on both sides of the area. On each transect, five 30 m x 30 m sample plots were laid out at 300 m intervals (Fig. 3.4), resulting in a total of 20 plots in the experimental field. The average distance of the plots in each degradation area from the watering point was recorded as 1 500 m, 3 600 m, 5 150 m and 6 250 m for the SD, MSD, MD and LD areas respectively. A 1500 distance was maintained for the SD area, which was not as such so close to watering point. This was for the reason that there was no vegetation cover to consider for data collection in between this distance from the watering point in the season the vegetation was stratified.

Plate 3.1 The severely degraded area of the Allaidege rangeland showing bare ground and encroachment by alien *Prosopis* species in the dry season.

Plate 3.2 The experimental site in the severely degraded area of the Allaidege rangeland in the rainy season, with palatable creeping *Ipomoea sinensis* and other unpalatable erect forbs.

Plate 3.3 The moderately to severely degraded area of the Allaidege rangeland in the dry season.

Plate 3.4 The moderately to severely degraded area of the Allaidege rangeland in the rainy season.

Plate 3.5 The moderately degraded area of the Allaidege rangeland in the rainy season.

Plate 3.6 The lightly degraded area of the Allaidege rangeland in the rainy season.

Figure 3.4 Map of the study site in the Allaidege rangeland (The numbered squares indicate the 30 m x 30 m plots in each degradation gradient – due to space constraints all the plots in the moderately degraded and lightly degraded areas are not shown).

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CHAPTER 4

IMPACT OF GRAZING AROUND A WATERING POINT ON BOTANICAL COMPOSITION IN THE ALLAIDEGE RANGELAND IN NORTH-EASTERN ETHIOPIA

4.1 Introduction

The Allaidege rangeland is one of the prominent grazing areas of the pastoral community of the Afar Regional State. In the past the rangeland was known to be the best traditional wet season grazing area before the intervention of commercial agriculture in the region. Degradation of the rangeland gradually took place with the development of a watering point causing grazing pressure in the area. This was also accompanied with the failure of exercising the developed grazing utilization scheme in the community (MCE, 2000). This failure and lack of knowledge in the community compelled the pastoral people to persevere with grazing systems practiced in the past. This mode of grazing effected complete extinction of the palatable perennial species, which is now widely acknowledged by the community (Personal communication with clan leaders and elders, 2004).

Up to now, there was no study to quantify the herbaceous compositional change of the range. Beruk (2000), in a survey assessment report of the Afar rangeland emphasized the very limited identification studies on the major indigenous grasses of the area and recommended a comprehensive study on species composition of the range.

Various researchers have reported grazing pressure, rainfall, edaphic condition and grazing history to influence botanical composition of a range (Milchunas & Lauenroth, 1993; O’Connor & Roux, 1995; Turner, 1999). Other researchers (Boudet, 1975; Stoddart, Smith & Box, 1975; Pratt & Gwynne, 1977) have explicitly indicated that livestock grazing pressure in semi-arid regions of Africa due to traditional range management caused changes in vegetation composition of the range. Amsalu and Baars (2002) have also reported that the communally grazed agro-pastoral range areas showed poor botanical composition due to grazing pressure. Thus livestock grazing can have a profound impact on vegetation composition. The general pattern of grazing-induced botanical composition change is well documented by Kirkman (1995), Owen-Smith and Danckwerts (1997) and Amsalu and Baars (2002). The heavy utilization by livestock of forage plants around watering points compared to areas further away is confirmed by

Friedel (1988) and Hart *et al*. (1993). To this effect it is known that less palatable or undesirable plants increase at the expense of desirable plants. The decrease of palatable plants was confirmed by Tainton (1972) and Noy-Meir, Gutman and Kaplan (1989) to be attributed to the impact of selective livestock grazing inducing a shift in botanical composition (Morris & Tainton, 1993). Hence this study evaluates the long-term effects of grazing impact around a watering point on vegetation dynamics of the range.

The objective of the study was to assess the long-term effect of grazing pressure on the botanical composition of the range around a watering point. The following hypothesis was tested: there is no difference in botanical composition at increasing distances from the watering point.

4.2 Materials and methods

The experiment was conducted from June 2003 to December 2004 in a communal grazing land around a watering point in the Allaidege rangeland in the southern Afar region of Ethiopia. See Chapter 3 for description of the study site. In each of the 30 m x 30 m sampling plots in each stratified degradation area, proportional species composition was determined by the nearest plant approach at 250 points (Bosch & Janse van Rensburg, 1987; Bosch & Kellner, 1991; Hardy & Walker, 1991) using the wheel point method of Tidmarsh and Havenga (1955). The survey was carried out in 2003 and 2004 when the majority of the pasture plants were at flowering stage. The abundance of species in the sample site is expressed as a proportion of the total number of observations made for the sample site. For some species not identified in the field a representative plant was pressed, labelled and transported to the National Herbarium of Addis Ababa University (AAU) for identification.

4.2.1 Statistical analysis

Descriptive statistics with frequency counts and percentages were calculated for each species and life form identified. Correspondence analysis was done to graphically show the occurrences of species and life forms within the degradation areas (severely (SD), moderately to severely (MSD), moderately (MD) and lightly (LD) degraded areas).

To compare all life forms with all degradation areas a Chi-square test was performed. Then, to determine more specifically where differences occurred, all combinations of 2 x 2 tables were analyzed with Chi-square tests, applying Bonferroni multiple testing. Compositional difference along the years was determined using classification tree analysis (see Appendix 4.1 and 4.2).

4.3 Results

4.3.1 Species frequency in 2003

The rangeland consisted of a matrix of perennial grasses, annual grasses and herbaceous forbs in 2003 (Table 4.1 and 4.2). In the SD grazing area, perennial grasses were not prominent in the composition and represented about 4% of the total herbage composition. The grazing area was dominated by annual grasses and unpalatable herbaceous forbs. Both groups comprised about 80% of the total composition of the grazing area (Table 4.1 and 4.2). Small numbers of the perennial grasses *Sporobolus ioclados, Paspalidium desertorum*, *Cynodon dactylon* and *Digitaria rivae* occurred (Table 4.1 and 4.2).

In the MSD area, perennial grasses, annual grasses and others (non grass species) comprised 16%, 63% and 21% of the botanical composition respectively. This grazing area is predominantely covered by the annual grass, *Setaria verticillata*, which was also abundant in the SD area (Table 4.1 and 4.2).

The botanical composition of the MD grazing area consisted of 40% perennial grasses. *Paspalidium desertorum*, *S. ioclados* and *Panicum coloratum* contributed 8%, 5% and 4% respectively to the total species composition. *Chrysopogon plumulosus* was more abundant, contributing 21% to the total species composition in the area. *Setaria verticillata* and other herbaceous forbs have however contributed almost 60% to the plant composition in the area (Table 4.1 and 4.2).

In the LD area perennial grassess contributed 47% to the composition. The perennial grasses *C. plumulosus*, *S. ioclados* and *P. coloratum* contributed 16%, 17%, and 10% to the composition respectively. Other perennial grasses that contributed less than 2% to the composition were also present.

Similar to the more degraded grazing areas, *S. verticillata* and other herbaceous forbs were present contributing 24% and 27% to the composition respectively, but were less prominent compared to the other degradation areas (Table 4.1 and 4.2).

4.3.2 Ordination of the species in 2003

Previous studies have highlighted the complexity of ordination if a variety of species are identified. To overcome this, reduction of variability was done by assigning species to functional groups (life forms) and considering the dynamics of groups, which possess common suites of vital attributes, rather than species (Friedel, Bastin & Griffin, 1988). The assumption for the dynamics of such groupings was that the between group variability far exceeds the within group variability (O'Connor & Roux, 1995). On this conceptual framework, correspondence analysis was done to ordinate the species and the life forms (perennial grasses, annual grasses, edible annual forbs, legume annual forbs, edible other forbs and others forbs) in each degradation area as shown in Figure 4.1 and 4.2.

In this study the species ordination was done by giving emphasis to species with frequency of occurrence above 1%, which also limits the number of species. It was evident that most unpalatable forb species (Other forbs) appear dominantly in the SD area. The annual grass *S. verticillata* was present in all areas but was relatively prominent in abundance in the MSD area. Similarly the analysis implicated that perennial grasses such as *P. desertorum* and *C. plumulosus* were present in MD and LD areas but more abundant in the MD area. *Panicum coloratum*, which is closely plotted to the LD area, is more abundant in this particular area than in the MD area (Fig. 4.1).

The MSD, MD and LD areas did share common species such as *S. verticillata, S. ioclados* and *Rhynchosia melacophylla* but a higher abundance was revealed in the MSD area for the first two species alone. *Rhynchosia melacophylla* maintained an equal frequency distribution in the three degradation areas (Table 4.1 and Fig. 4.1). The life form ordination also identified similar species ordination for *S. verticilata* (Annual grass) and *R. melacophylla* (Legume annual forb) (Fig. 4.2). *Blepharis edulis* is the only annual strictly limited to the MD and LD areas (Fig. 4.1 and 4.2) probably due to its localized nitche.

Table 4.1 Frequency count of each species in the different categorised degradation areas in the Allaidege rangeland in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Species name	Afar	Frequency count			
Perennial grasses	common name	*SD*	*MSD*	*MD*	*LD*
Chrysopogon plumulosus Hochst	Durfu	0	3	262	205
Sporobolus ioclados	Denekto	23	144	60	207
Panicum coloratum	Denekto (p)	0	45	45	120
Paspalidium desertorum	Bohale	11	4	99	27
Bothriochloa radicans (Lehm)	As ayso	0	0	36	0
Cynodon dactylon Pers	Rareta	13	0	0	0
Cenchrus ciliaris	Serdoyta	0	0	0	5
Lintonia nutans Stapf	Afara mole	0	0	0	2
Sporobolus pellucidus Hoehst	Sosokete	0	0	2	16
Digitaria rivae (choir) Stapf	Forele/Hamanto	2	0	1	0
Total count		**49**	**196**	**505**	**582**
Annual grasses					
Setaria verticillata (L.) P.Beauv	Delayta	500	783	416	295
Tetrapogon tenellus (Roxb) chior	Aytodyta	0	0	3	4
Sporobolus panicoides A. Ruch	Gewita / Bekelayso	0	3	9	27
Total count		**500**	**786**	**428**	**326**
Edible annual forbs					
Ipomoea sinensis & Momordica boivinii (Baill)	Halal	192	28	96	22
Other edible forbs					
Blepharis edulis	Yamarukta	0	0	61	102
Legume annual forbs					
Rhynchosia melacophylla (spreng,Boj)	Haro	7	33	43	31
Total count (forbs)		**199**	**61**	**200**	**155**
Other forbs					
Phyllanthus maderaspa tensis L.	Akelekelmi	184	78	10	108
Leucas nubica Benth	Ergufuma	177	0	0	0
Amaranthus spp.	Bunkete	10	0	0	1
Orthosiphon pallidus Royle	Hebeke	22	11	0	3
Unidentified	Alelus	7	0	0	0
Portulaca quadrifiola L.	Halihara	1	32	6	28
Unidentified	Ashara	25	0	0	0
Abutilon anglosomaliae Cufod	Hanbukto	60	10	8	8
Unidentified	Aburi	16	0	0	0
Koheutia caespitosa	Baroberbere	0	76	74	38
Unidentified	Mituki	0	0	19	1
Total count		**502**	**207**	**117**	**187**

Table 4.2 Average frequency (%) of the species composition in each degradation area in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

			Percent composition			
Species Name	**Afar common name**	**Lifeform**	***SD***	***MSD***	***MD***	***LD***
Perennial Grasses			%	%	%	%
Chrysopogon plumulosus Hochst	Durfu	Perennial	0	0.24	20.96	16.4
Sporobolus ioclados	Denekto	Perennial	1.84	11.52	4.8	16.6
Panicum coloratum	Denekto (p)	Perennial	0	3.6	3.6	9.6
Paspalidium desertorum	Bohale	Perennial	0.88	0.32	7.92	2.16
Bothriochloa radicans (Lehm)	As ayso	Perennial	0	0	2.88	
Cynodon dactylon Pers	Rareta	Perennial	1.04	0	0	0
Cenchrus ciliaris	Serdoyta	Perennial	0	0	0	0.4
Lintonia nutans Stapf	Afara mole	Perennial	0	0	0	0.16
Sporobolus pellucidus Hoehst	Sosokete	Perennial	0	0	0.16	1.28
Digitaria rivae (choir) stapf	Forele/ Hamanto	Perennial	0.16	0	0.08	0
Total percentage (%)			**3.92**	**15.46**	**40.42**	**46.6**
Annual Grasses						
Setaria verticillata (L.) P.Beauv	Delayta	Annual	40	62.64	33.28	23.6
Tetrapogon tenellus (Roxb) chior	Aytodyta	Annual	0	0	0.24	0.32
Sporobolus panicoides A. Ruch	Gewita/Bekelayso	Annual	0	0.24	0.72	2.16
Total percentage (%)			**40**	**62.88**	**34.24**	**26.1**
Edible annual forbs						
Ipomoea sinensis	Halal	Annual	15.4	2.24	7.68	1.76
Other edible forbs						
Blepharis edulis	Yamarukta	Annual	0	0	4.88	8.16
Legume annual forbs						
Rhynchosia melacophylla (spreng, Boj)	Haro	Annual	0.56	2.64	3.44	2.48
Total percentage (%)			**15.9**	**4.88**	**16**	**12.4**
Other forbs						
Phyllanthus maderaspa tensis L.	Akelekelmi	Annual	14.7	6.24	0.8	8.64
Leucas nubica Benth	Ergufuma	Annual	14.2	0	0	0
Amaranthus spp.	Bunkete	Annual	0.8	0	0	0.08
Orthosiphon pallidus Royle	Hebeke	Annual	1.76	0.88	0	0.24
Unidentified	Alelus	Annual	0.56	0	0	0
Portulaca quadrifiola L.	Halihara	Annual	0.08	2.56	0.48	2.24
Unidentified	Ashara	Annual	2	0	0	0
Abutilon anglosomaliae Cufod	Hanbukto	Annual	4.8	0.8	0.64	0.64
Unidentified	Aburi	Annual	1.28	0	0	0
Koheutia caespitosa	Baroberbere	Annual	0	6.08	5.92	3.04
Unidentified	Mituki	Annual	0	0	1.52	0.08
Total percentage (%)			**40.2**	**16.56**	**9.36**	**15**
Grand total percentage (%)			100%	100%	100%	100%

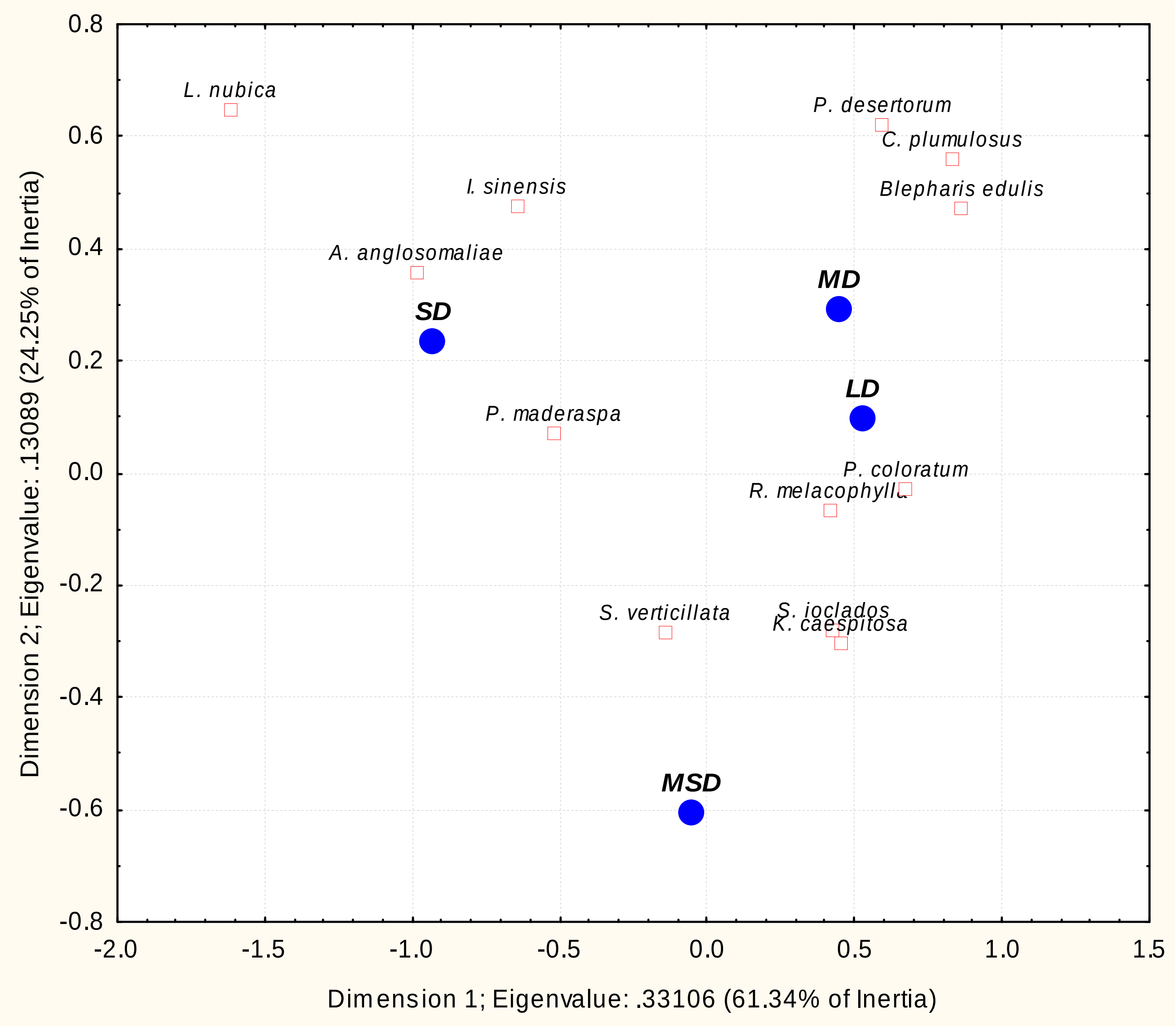

Figure 4.1 Ordination of the most abundant species in the Allaidege rangeland according to degradation areas in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

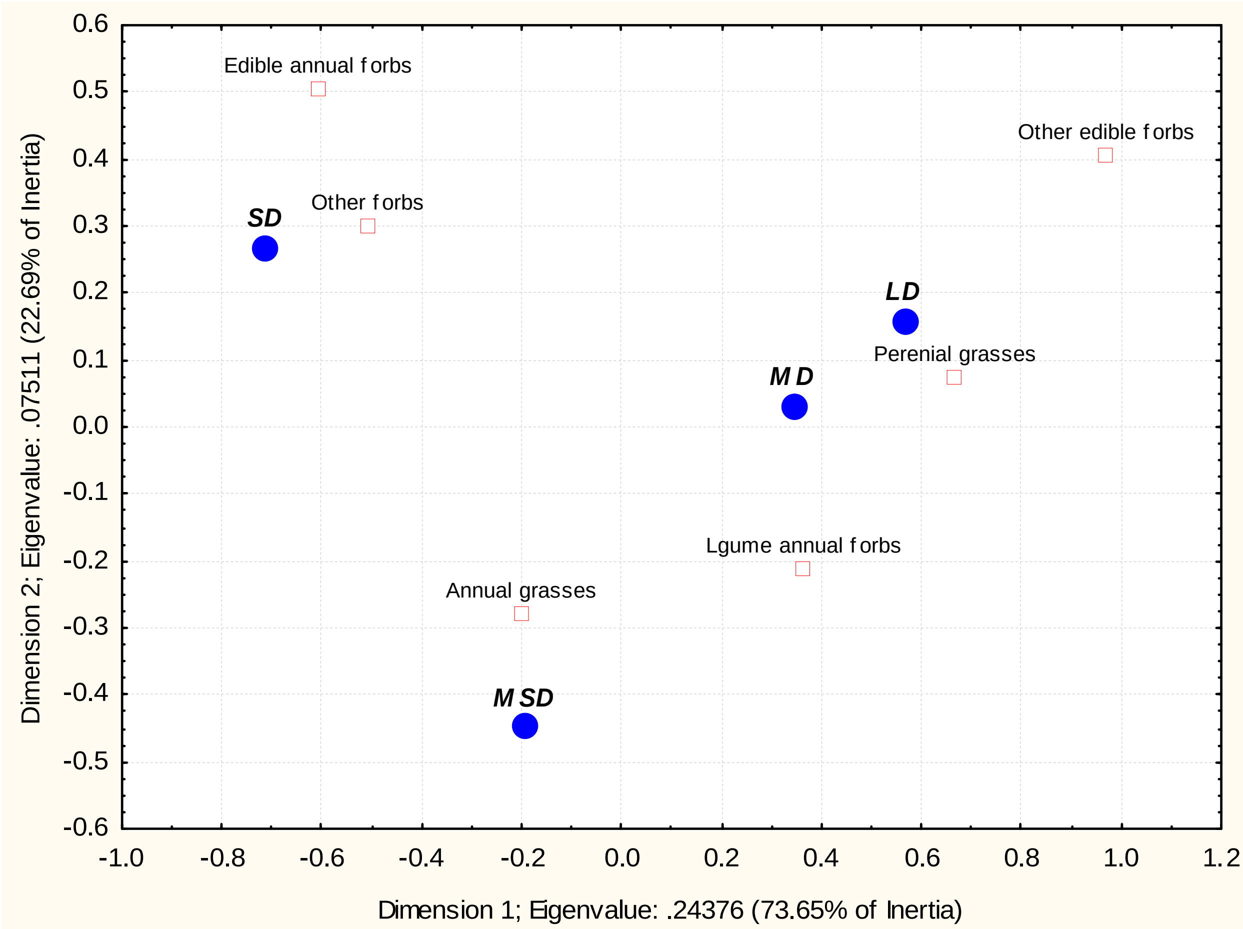

Figure 4.2 Ordination of life form groups in the Allaidege rangeland according to degradation areas in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

The species percentage distribution across the grazing gradient was identified using Classification Tree Analysis (CTA) for those species whose frequency of occurrence was 2 percent or more than 2. The perennial grass species, other edible and legume annual forbs (*B. edulis* and *R. melacophylla*) had a high frequency of occurrence in the MD and LD areas (37% and 42% respectively) compared to a low frequency of occurrence of 2% and 18% in the SD and MSD areas respectively (Fig. 4.3a). In contrast, the unpalatable species (*Phyllanthus maderaspa*, *Leucas nubica* and *Abutilon anglosomaliae*) relatively high in frequency and edible annual (*I. sinensis*) which are pioneers were found to have a total frequency of occurrence of 62% in the SD area and a consistent 12-14% frequency of occurrence in the other areas (Fig. 4.3b). A frequency of occurrence of 25% and 39% was recorded for the annual grass *S. verticillata* in the SD and MSD areas respectively. The percentages for *S. verticillata* in the MD and LD areas were 21% and 15% respectively (Fig. 4.3c).

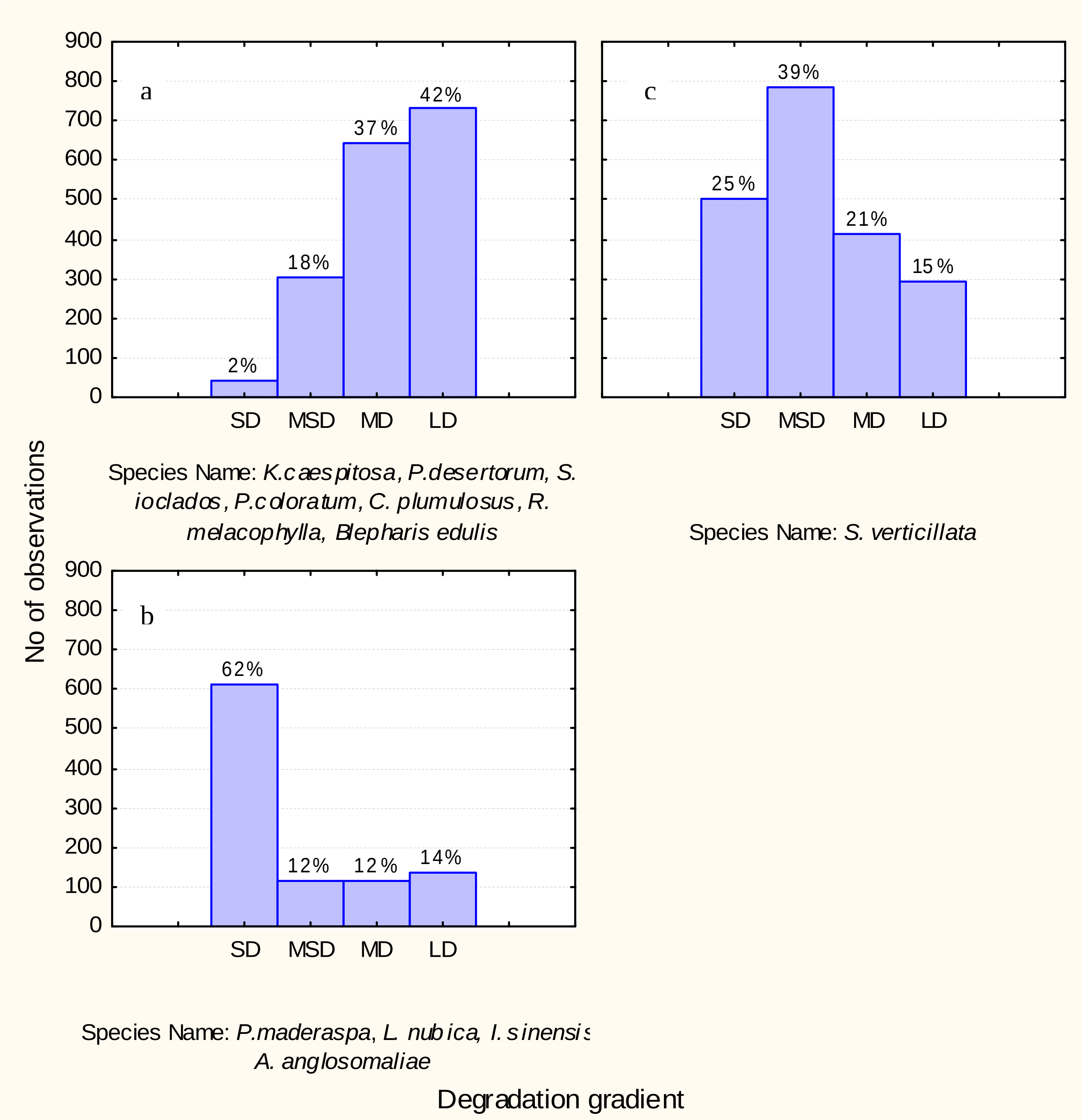

Figure 4.3 Frequency of occurrence of different species in the degradation areas (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

4.3.3 Species frequency in 2004

The botanical composition of the rangeland in 2004 was generally similar to that of the preceding year with only slight changes in species composition in some of the degradation areas. In the SD area, perennial species comprised 6% of the vegetation compared to 4% in 2003 (Table 4.3 and 4.4). The most abundant perennial species were *S. ioclados* and *P. desertorum*, which are characteristic inhabitants of degraded or disturbed areas. In contrast, annual grasses, predominantly *S. verticillata* comprised 50% of the total botanical composition and unpalatable herbaceous forbs 12%.

The MSD area consisted of 20%, 65% and 25% perennial grasses, annual grasses and other forbs respectively. Similar to the previous year, *S. verticillata* was the most abundant species comprising 65% composition of the total vegetation of this grazing area (Table 4.3 and 4.4).

In the MD area, similar to the previous year, perennials were more prominent (39% of the composition). The most frequently occurring species were *C. plumulosus*, *P. desertorum* and *P. coloratum* contributing 20%, 8% and 4% to the composition respectively. *Bothriochloa radicans*, *Sporobolus pellucidus* and *Digitaria rivae* were present in small numbers (less than 1%). The annual grass *S. verticillata* and other herbaceous forbs comprised 35% and 26% of the composition respectively (Table 4.3 and 4.4).

In the LD area, perennial grasses, annual grasses and other forbs comprised 38%, 36% and 25% of the total composition respectively, which was similar to the MD area. In contrast with the composition of the LD area in 2003, a low frequency of occurrence of perennials (38% compared to 46% in 2003) was recorded while abundance of the annual grass species increased (Table 4.3 and 4.4).

4.3.4 Ordination of the species in 2004

Ordination of the species and the life forms using correspondence analysis was done for each degradation area (Fig. 4.4 and 4.5). From the figures certain trends could be observed in the botanical composition of the herbaceous species over the study period. Certain species were more abundant in the plots of degradation areas close to the watering point relative to the plots of degradation areas further away from the watering point. On the other hand, the decrease in abundance of other species was a common phenomena observed. The species that increased in abundance relative to plots further from the watering point were the unpalatable species and *Ipomoea sinensis*, which is palatable. Although lower in abundance, the unpalatable species were also detected in the degradation areas further away from the watering point. The annual grass, *S. verticillata* existed in all grazing gradients but was more frequent in MSD and SD areas, similar to the trend observed for the same species in 2003 (Fig. 4.4).

The perennial species were ordinated in accordance to their preference/palatability for animals and it was sometimes impossible to detect patterns of change of botanical composition for some of the species. For example, *P. desertorum*, which is less palatable, was more abundant in the MSD area relative to the MD and SD areas (Fig. 4.4). The lower abundance of this species in the SD area indicates that availability of preferred species is scarce and animals are persuaded to graze the less palatable species available.

Chrysopogon plumulosus, which is known to be a palatable species, has a very low abundance in the MSD area closer to the watering point relative to the higher abundance observed in MD and LD areas further away from the watering point. *Chrysopogon plumulosus* did not occur in the SD area. Similarly *P. coloratum* was more abundant in the LD area relative to the abundance in the MD area. The abundance of the species varied from nil to very low in the SD and MSD areas respectively. *Sporobolus ioclados*, despite its low abundance in the SD area, existed at a consistent frequency in both MSD and MD areas (Fig. 4.4).

In terms of life forms the same trends as in 2003 were evident. The only deviation was the case of the "Other forbs" group that was more evenly distributed over the four degradation areas (Fig. 4.5) than in 2003, when it occurred mainly in the SD area (Fig. 4.2).

Table 4.3 Frequency count of each species in the different categorized degradation areas in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

			Frequency count			
Species	**Afar common name**	**Lifeform**	**SD**	**MSD**	**MD**	**LD**
Perennial grasses						
Chrysopogon plumulosus Hochst	Durfu	Perennial	0	59	252	251
Sporobolus ioclados	Denekto	Perennial	25	38	42	5
Panicum coloratum	Denekto (p)	Perennial	0	13	59	155
Paspalidium desertorum	Bohale	Perennial	32	138	99	11
Bothriochloa radicans (Lehm)	As ayso	Perennial	0	0	35	12
Cenchrus ciliaris	Serdoyta	Perennial	0	0	0	3
Lintonia nutans Stapf	Afara mole	Perennial	0	0	0	32
Sporobolus pellucidus Hoehst	Sosokete	Perennial	0	2	2	8
Digitaria rivae (choir) stapf	Forele/Hamanto	Perennial	12	0	1	2
Total count			**69**	**250**	**490**	**479**
Annual grasses						
Setaria verticillata (L.) P.Beauv	Delayta	Annual	627	810	427	318
Tetrapogon tenellus (Roxb) chior	Aytodyta	Annual	0	3	3	1
Sporobolus panicoides A. Ruch	Gewita	Annual	0	0	9	133
Total count			**627**	**813**	**439**	**452**
Edible annual forbs						
Ipomoea sinensis	Halal	Annual	396	55	92	15
Other edible forbs						
Blepharis edulis	Yamarukta	Annual	0	83	69	260
Legume annual forbs						
Rhynchosia melacophylla (spreng, Boj)	Haro	Annual	3	9	43	2
Total count (forbs)			**399**	**147**	**204**	**277**
Other forbs						
Phyllanthus maderaspa tensis L.	Akelekelmi	Annual	56	6	10	7
Leucas nubica Benth	Ergufuma	Annual	0	0	0	0
Amaranthus spp.	Bunkete	Annual	2	0	0	0
Orthosiphon pallidus Royle	Hebeke	Annual	4	0	0	0
Unidentified	Alelus	Annual	12	0	0	0
Portulaca quadrifiola L.	Halihara	Annual	11	1	6	4
Unidentified	Ashara	Annual	1	0	0	0
Abutilon anglosomaliae Cufod	Hanbukto	Annual	11	2	8	2
Koheutia caespitosa	Baroberbere	Annual	58	20	74	2
Unidentified	Mituki	Annual	0	11	19	24
Total count			**155**	**40**	**117**	**39**
Grand Total			**1250**	**1250**	**1250**	**1247**

Table 4.4 Average frequency (%) of the species composition in the degradation areas in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

			Percent composition			
Species Name	**Afar common name**	**Lifeform**	**SD**	**MSD**	**MD**	**LD**
Perennial grasses			%	(%)	%	%
Chrysopogon plumulosus Hochst	Durfu	Perennial	0	4.72	20.16	20.08
Sporobolus ioclados	Denekto	Perennial	2	3.04	3.36	0.4
Panicum coloratum	Denekto (p)	Perennial	0	1.04	4.72	12.4
Paspalidium desertorum	Bohale	Perennial	2.56	11.04	7.92	0.88
Bothriochloa radicans (Lehm)	As ayso	Perennial	0	0	2.8	0.96
Cenchrus ciliaris	Serdoyta	Perennial	0	0	0	0.24
Lintonia nutans Stapf	Afara mole	Perennial	0	0	0	2.56
Sporobolus pellucidus Hoehst	Sosokete	Perennial	0	0.16	0.16	0.64
Digitaria rivae (choir) stapf	Forele or	Perennial	0	0	0.08	0.16
	Hamanto	Perennial	0.96	0	0	0
Total percentage (%)			**5.52**	**20**	**39.2**	**38.32**
Annual Grasses						
Setaria verticillata (L.) P.Beauv	Delayta	Annual	50.2	64.8	34.16	25.44
Tetrapogon tenellus (Roxb)chior	Aytodyta	Annual	0	0.24	0.24	0.08
Sporobolus panicoides A. Ruch	Gewita	Annual	0	0	0.72	10.64
Total percentage (%)			**50.2**	**65.04**	**35.12**	**36.16**
Edible annual forbs						
Ipomoea sinensis	Halal	Annual	31.7	4.4	7.36	1.2
Other edible forbs						
Blepharis edulis	Yamarukta	Annual	0	6.64	5.52	20.8
Legume annual forbs						
Rhynchosia melacophylla (spreng, Boj)	Haro	Annual	0.24	0.72	3.44	0.16
Total percentage (%)			**31.9**	**11.76**	**16.32**	**22.16**
Other forbs						
Phyllanthus maderaspa tensis L.	Akelekelmi	Annual	4.48	0.48	0.8	0.56
Leucas nubica Benth	Ergufuma	Annual	0	0	0	0
Amaranthus spp.	Bunkete	Annual	0.16	0	0	0
Orthosiphon pallidus Royle	Hebeke	Annual	0.32	0	0	0
Unidentified	Alelus	Annual	0.96	0	0	0
Portulaca quadrifiola L.	Halihara	Annual	0.88	0.08	0.48	0.32
Unidentified	Ashara	Annual	0.08	0	0	0
Abutilon anglosomaliae Cufod	Hanbukto	Annual	0.88	0.16	0.64	0.16
Koheutia caespitosa	Baroberbere	Annual	4.64	1.6	5.92	0.16
Unidentified	Mituki	Annual	0	0.88	1.52	1.92
Total percentage (%)			**12.4**	**3.2**	**9.36**	**3.12**
Grand total percentage (%)			100%	100%	100%	100%

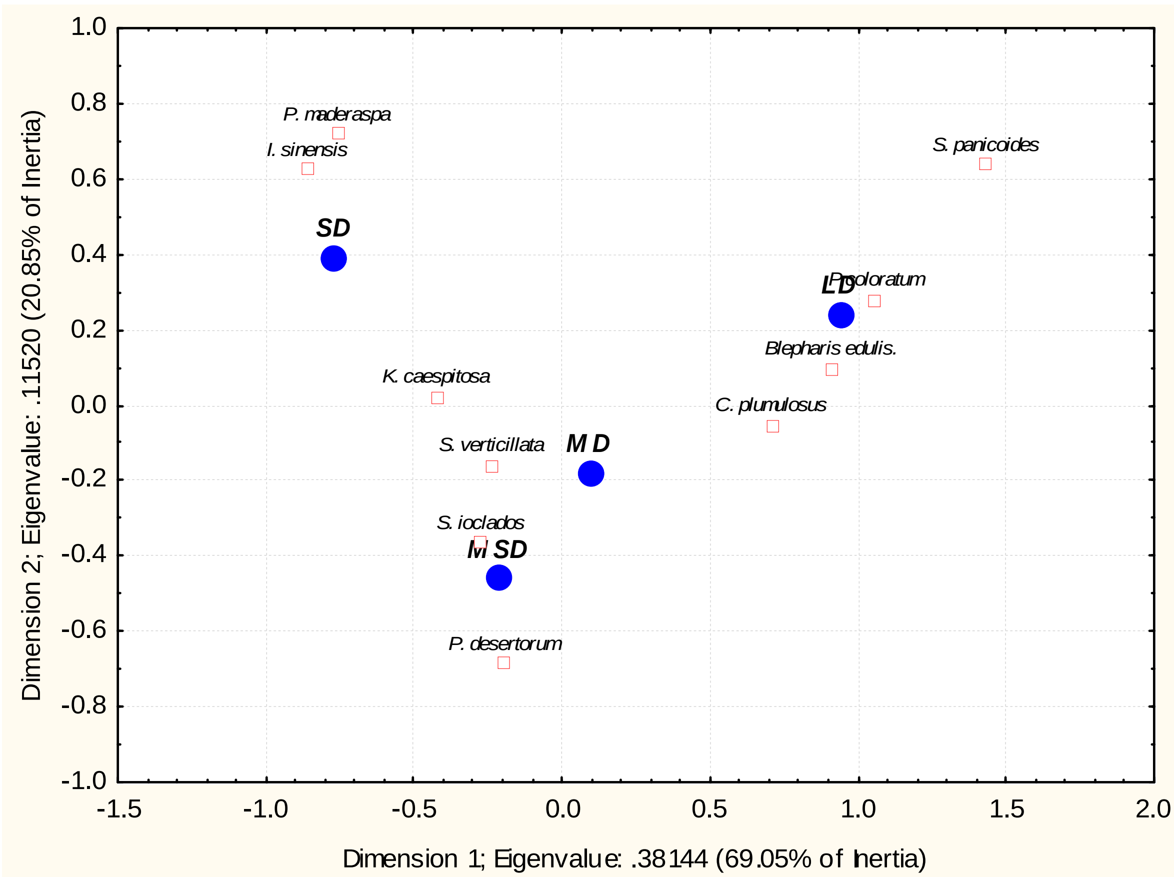

Figure 4.4 Ordination of the most abundant species in the Allaidege rangeland according to degradation areas in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

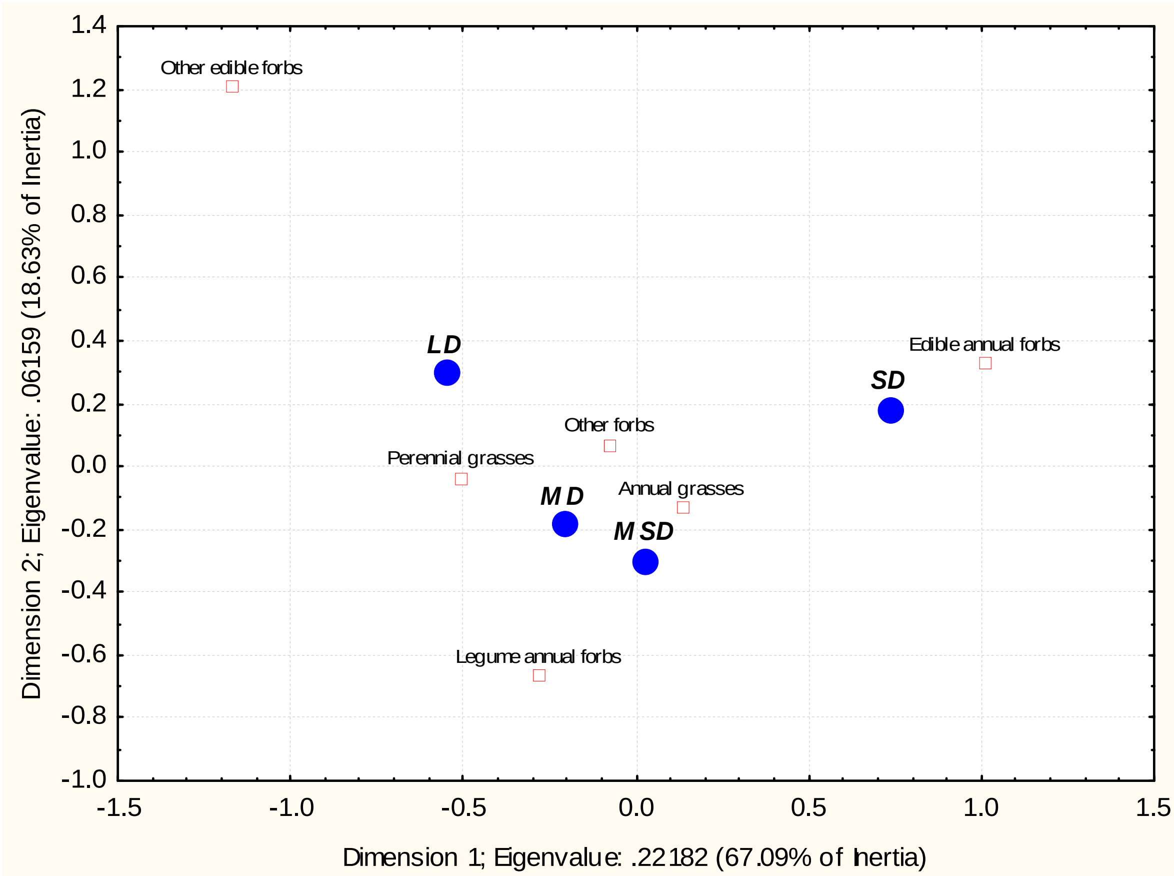

Figure 4.5 Ordination of life form groups in the Allaidege rangeland according to degradation areas in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

4.3.5 Frequency of life forms in the grazing gradient in 2003 and 2004

Species compositional difference in each degradation area was examined based on the frequency of occurrence of different life forms (perennial grass, annual grass and other forbss) observed in the field including all those species found to be very low in frequency of occurrence (Table 4.5 and 4.6). This is because the life forms concisely categorized the species distribution in each degradation area. The perennial species distribution in the grazing gradient was emphasized for the important role they play in both animal production and soil erosion control. Before running a test comparison of each grazing gradient for the different life forms that occurred, a chi square test of the degradation levels (SD, MSD, MD and LD areas) and life forms of the species was carried out to evaluate if life forms are dependent on degradation or not. Accordingly, a highly significant difference ($P < 0.05$) was recorded in both years for the different degradation areas and the three life forms considered (Fig. 4.6 and 4.7).

In 2003, annual grasses and other forbs were most abundant in the SD area with 48% and 49% frequency of occurrence respectively compared to the 3% occurrence of perennial grasses. In the MSD area, annual grass species were dominant with a frequency of occurrence of 66%, whereas perennial grasses and other forbs were at equal proportions of 17%. In MD and LD areas a three-fold increase of frequency was recorded for perennial grasses compared to the MSD area. On the other hand, annual grasses decreased to 41% and 30% and the other forbs to 11% and 18% in the MD and LD areas respectively. This in general was evidence that the grazing gradient had an impact on the herbaceous composition (Fig. 4.6).

In 2004, the occurrence of annuals was high in the SD and MSD areas with frequency of occurrence of 74% and 66% respectively. The others and perennials were 18% and 8%, 11% and 21% for SD and MSD areas respectively. In MD and LD areas the annual grasses were more or less similar in frequency in both areas in both years. The others and perennials were almost similar in both MD and LD areas. From these general findings, a Bonferroni comparison test was carried out to observe the compositional difference in each degradation area for the different life forms (Tables 4.7 and 4.8).

4.3.6 Statistical compositional difference of life forms in 2003

A Bonferroni multiple comparison test were made to observe the compositional difference in each degradation area for the different life forms (Table 4.7). The comparison made for almost all the combined tests implicated that the different life forms were significantly different ($P < 0.05$) for each comparison test of the life form versus degradation showing the impact of degradation on life form. One exception is combination test entry No. 10 made for the MSD and MD areas versus the life forms of annuals and others, in which the case was not significant ($P > 0.05$). This means that the frequency of occurrence of the annuals and others was similar in both areas (Fig.4.6). The same applies for entry No. 18, made for MD and LD areas vs others and perennials. Regarding perennial species, the relative proportion was compared to annuals and others in relation to each degradation area. The figure shows that the frequency of abundance of perennials increased along the grazing gradient away from the watering point for each comparison made (Fig 4.6).

Table 4.5 Observed frequencies of the life forms of the species in each degradation area for 2003 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Marked cells have counts > 10. Chi-square test: p=0.0000				
	Annual grasses	Other forbs	Perennial grasses	Total
SD	500	517	35	1052
Row %	47.53%	49.14%	3.33%	
MSD	783	207	199	1189
Row %	65.85%	17.41%	16.74%	
MD	429	117	505	1051
Row %	40.82%	11.13%	48.05%	
LD	329	194	579	1102
Row %	29.85%	17.60%	52.54%	
Totals	2041	1035	1318	4394

Table 4.6 Observed frequency of the life form of the species in each degradation area for 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Marked cells have counts > 10. Chi-square test: p=0.0000				
	Annual grasses	Other forbs	Perennial grasses	Total
SD	630	156	67	853
Row %	73.86%	18.29%	7.85%	
MSD	814	129	249	1192
Row %	68.29%	10.82%	20.89%	
MD	439	187	490	1116
Row %	39.34%	16.76%	43.91%	
LD	451	186	468	1105
Row %	40.81%	16.83%	42.35%	
Totals	2334	658	1274	4266

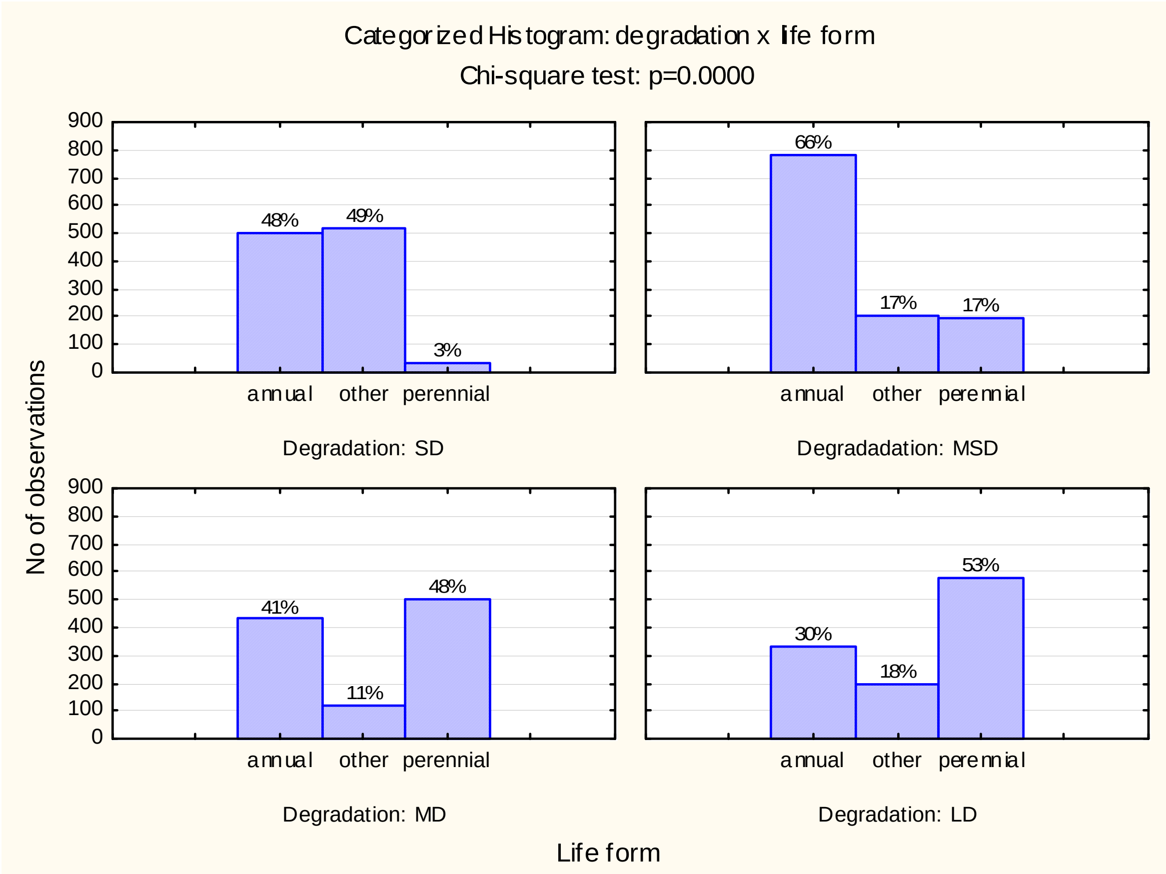

Figure 4.6 Frequency of occurrence of life forms in the degradation gradient in 2003 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses).

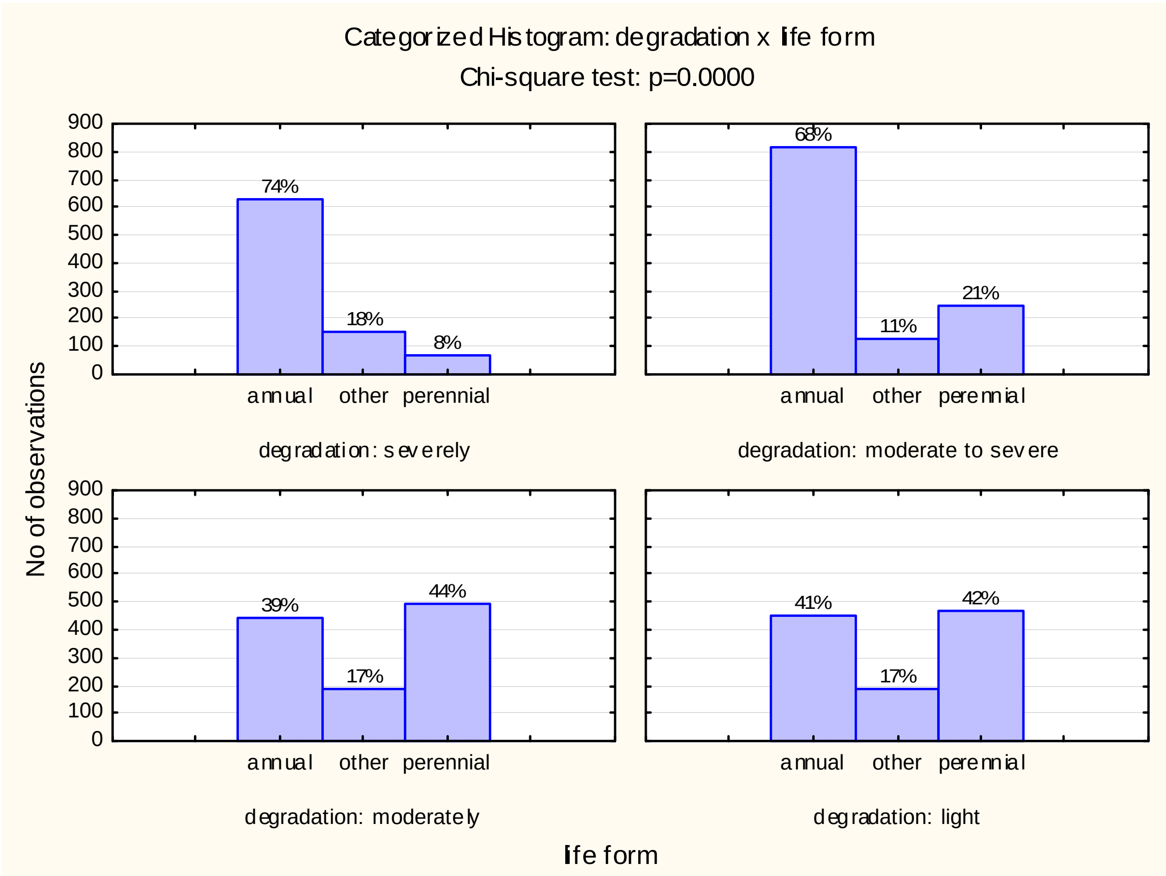

Figure 4.7 Frequency of occurrence of life forms in the degradation gradient in 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses).

Table 4.7 Bonferroni comparison test for life form compositional difference in each degradation area in 2003 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses)

	Combination	Bonferroni adapted P-value
1	(SD, MSD) vs (annual, other)	< 0.01
2	(SD, MSD) vs (annual, perennial)	< 0.01
3	(SD, MSD) vs (other, perennial)	< 0.01
4	(SD, MD) vs (annual, other)	< 0.01
5	(SD, MD) vs (annual, perennial)	< 0.01
6	(SD, MD) vs (other, perennial)	< 0.01
7	SD, LD) vs (annual, other)	< 0.01
8	(SD, LD) vs (annual, perennial)	< 0.01
9	(SD, LD) vs (other, perennial)	< 0.01
10	(MSD, MD) vs (annual, other)	1
11	(MSD, MD) vs (annual, perennial)	< 0.01
12	(MSD, MD) vs (other, perennial)	< 0.01
13	(MSD, LD) vs (annual, other)	< 0.01
14	(MSD, LD) vs (annual, perennial)	< 0.01
15	(MSD, LD) vs (other, perennial)	< 0.01
16	MD, LD) vs (annual, other)	< 0.01
17	(MD, LD) vs (annual, perennial)	< 0.01
18	(MD, LD) vs (other, perennial)	0.09

4.3.7 Statistical compositional difference of life forms in 2004

The Chi-square test in general denoted that the life forms differ significantly ($P < 0.05$) along the degradation gradient (Fig. 4.7). Perennial grasses, which are the major fodder source for animals are low in abundance in both SD and MSD areas where the relative abundance of annual grasses was high.

On the other hand, quite satisfactory frequency of abundance for perennial grasses was observed in MD and LD areas with a decline in abundance of the annual species. The MD and LD areas had more or less similar frequency of occurrence of annual grasses, other forbs and perennial grasses. The frequency of occurrence of the perennial grasses in both gradients was two-fold that of perennial grasses in the MSD area (Fig. 4.7).

The Bonferroni test carried out to compare the compositional difference of each degradation area vs life form was significant for most combinations (Table 4.8). The MSD combination test for both MSD and LD areas implicated that the proportion of abundance of other forbs and perennial grass species was more or less the same making the test insignificant ($P > 0.05$). Similarly, the MD and LD areas were also insignificant ($P > 0.05$) for the life form comparison of other forbs vs annual grasses, other forbs vs perennial grasses and annual grasses vs perennial grasses. It could be assumed from Figure 4.6 and 4.7 that there was a decrease of perennial grasses and an increase of other forbs in the MD area and an increase of annual grasses and a decrease of perennial grasses in the LD area in 2004 compared to the preceding year.

4.3.8 Species compositional differences in 2003 and 2004

To compare changes in botanical composition of each degradation area over the two years, Classification Tree Analysis was carried out where it revealed that there were species differences in the two seasons (Fig. 4.8). The differences were restricted only to the severely degraded area where frequency of occurrence of annual grasses was 73% in 2004 compared to 48% in 2003. On the other hand, 50% frequency of occurrence was recorded for other forbs in 2003 and 20% in 2004. The species composition of other areas was more or less similar over the two years (Fig 4.9).

Table 4.8 Bonferroni comparison test of life form compositional difference of each degradation area in 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses)

	Combination	Bonferroni adapted p-value
1	(SD, MSD) vs (annual, other)	< 0.01
2	(SD, MSD) vs (annual, perennial)	< 0.01
3	(SD, MSD) vs (other, perennial)	< 0.01
4	(SD, MD) vs (annual, other)	< 0.01
5	(SD, MD) vs (annual, perennial)	< 0.01
6	(SD, MD) vs (other, perennial)	< 0.01
7	SD, LD) vs (annual, other)	< 0.01
8	(SD, LD) vs (annual, perennial)	< 0.01
9	(SD, LD) vs (other, perennial)	< 0.01
10	(MSD, MD) vs (annual, other)	< 0.01
11	(MSD, MD) vs (other, perennial)	0.5
12	(MSD, MD) vs (annual, perennial)	< 0.01
13	(MSD, LD) vs (annual, other)	< 0.01
14	(MSD, LD) vs (other, perennial)	1
15	(MSD, LD) vs (annual, perennial)	< 0.01
16	MD, LD) vs (annual, other)	1
17	(MD, LD) vs (annual, perennial)	1
18	(MD, LD) vs (other, perennial)	1

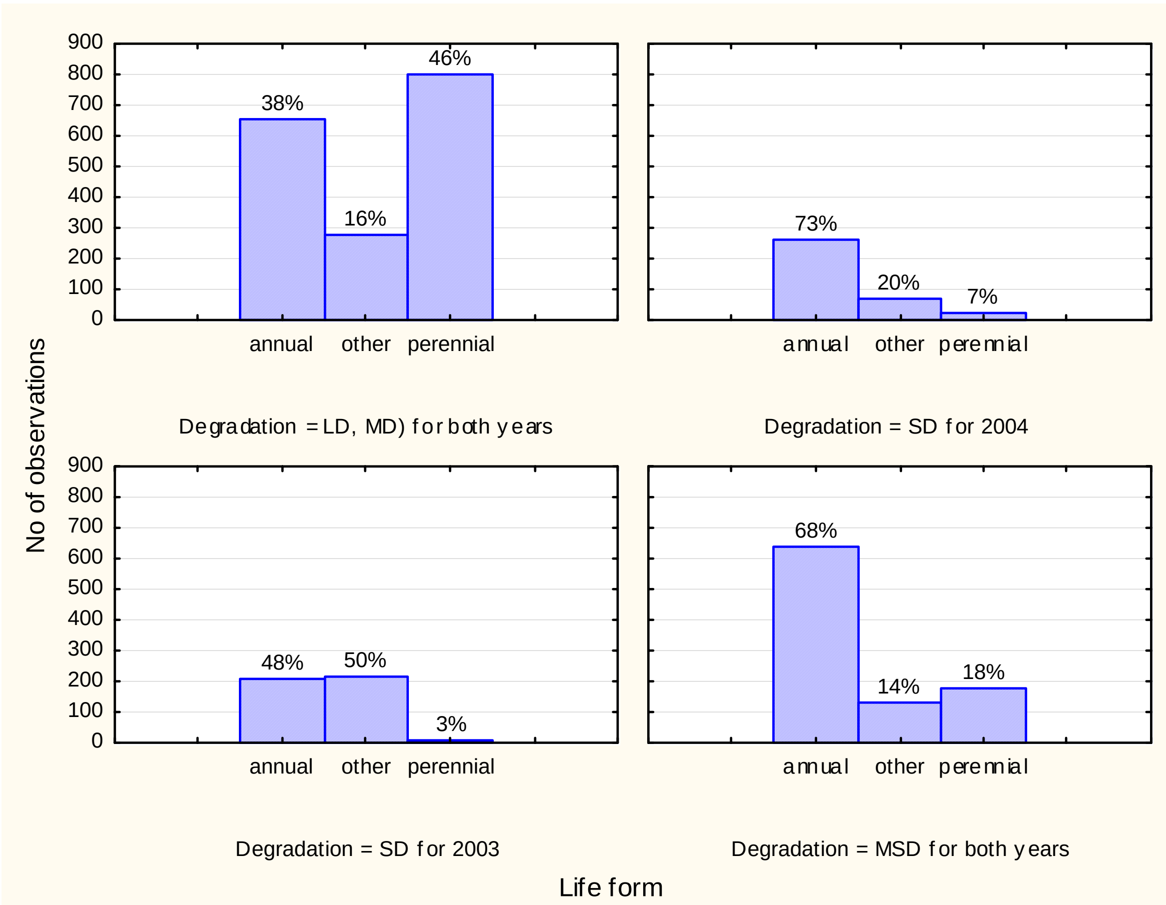

Figure 4.8 Life form compositional difference comparison of the degradation areas for 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses).

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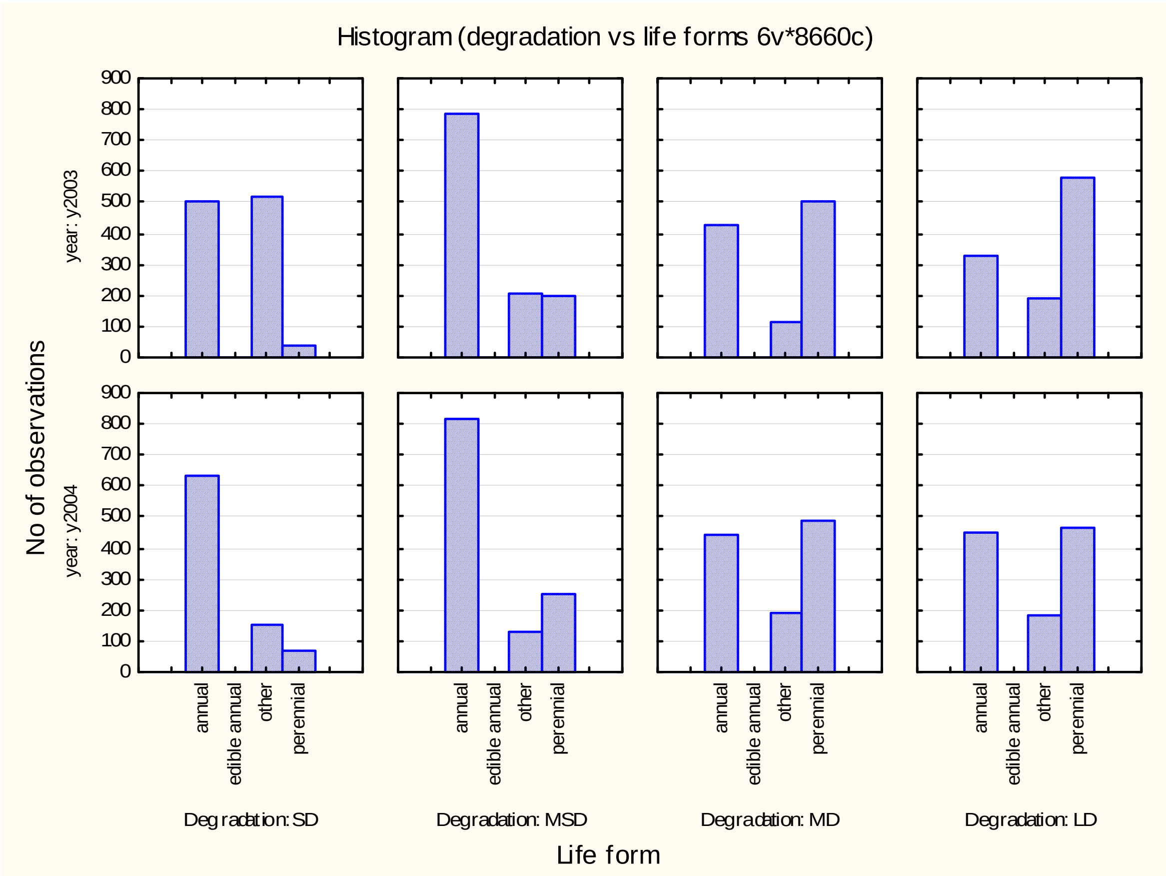

Figure 4.9 Life form compositional difference comparison of each grazing gradient for 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (annual = Annual grasses, other = Other forbs and perennial = Perennial grasses).

4.4 Discussion

The classification of the species in each degradation area in general was a reflection of the pasture species response to grazing intensity of the rangeland. Dyksterhuis (1949) and Foran, Tainton and Booysen (1978) stated that the most realistic and ecologically sound method of classification is to classify the species according to their reaction to injudicious veld management practices and other disturbances such as drought and fire. Similarly, Bosch and Janse van Rensburg (1987) grouped the species of the western grassland biome into five categories on the basis of their abundance curves on the grazing gradient.

The plant species that characterize the severely degraded area close to the watering point were annual grasses and unpalatable herbaceous forbs in both seasons. These are in general defined as pioneer species or short-lived plants, which increase under high levels of continuous selective grazing. This definition and characterization agrees with reports made by Andrew and Lange (1986), Friedel and Blackmore (1988) and Beukes and Ellis (2003). The pioneer annual grass species was *S. verticillata* with abundance percentages of 40% and 50% in 2003 and 2004 respectively in the severely overgrazed vegetation close to the watering point (Table 4.2 and 4.4). The dominance of this species in overgrazed areas was also reported by Van Oudtshoorn (1999).

In this study, most of the forbs found are unpalatable except for the annual herb *I. sinensis* that comprised 15% of the composition of the total herbage of the severely degraded area grazed by cattle (Table 4.2). This study has recognized high percentage abundance of forbs in the SD area close to the watering point. However, some forbs were recorded in the degradation areas far from the watering point. This agrees with the finding of Friedel and Blackmore (1988) that some forb species were closely associated with the watering point where others occurred throughout the gradient. The 4% occurrence of perennial grass species in the SD area in 2003 (Table 4.2) consisted mainly of *S. ioclados* and *C. dactylon* while the 6% perennial grass species in 2004 consisted of *P. desertorum* and *S. ioclados* (Table 4.4). These are known to be less palatable species and usually dominant in heavily grazed areas (Van Oudtshoorn, 1999; Amsalu & Baars, 2002). Studies carried out around artificial water sources have indicated a decrease in palatable perennial plants (Pinchak *et al.* 1991; Hart *et al.* 1991, 1993). This study also highlighted the absence of palatable perennial species in the SD area that confirms results of previous studies.

The observed development of this less palatable, species poor and sparse community in the inner 1500 m zone around the watering point (SD area) is in agreement with other workers who found that grazing impacts are greatly diminished beyond 1-2 km from a watering point (Foran, 1980; Pinchak *et al*, 1991; Perkins & Thomas, 1993; Fusco *et al.* 1995).

In the MSD area a small increase in palatable perennial species was depicted in both seasons relative to the nil occurrences in the severely degraded area.

The frequency of occurrence was less than 1% in 2003 and almost 5% in 2004 for *Chrysopogon plumulosus*. *Panicum coloratum* exhibited 4% occurrence in 2003 and 1% occurrence in 2004. *Chrysopogon plumulosus* and *P. coloratum* are the most preferred and palatable species but *C. plumulosus* is known as a more preferred species compared to *P. coloratum* (Personal communication: Afar elders and herdsmen, Allaidege rangeland, 2004). The finding was in agreement with Ayana and Baars (2000) who assessed the condition of the Borana rangelands in six communal grazing areas and on a Government owned ranch. In that study, *C. plumulosus* and *P. coloratum* were classified as desirable/preferred species, likely to decrease with heavy grazing pressure. The scientifically determined preferableness of the species substantiated the preferableness of the species as perceived by the community. Bogdan (1977) also concluded that these species are readily grazed by all kinds of stock and are much valued by pastoralists. Moreover, in the MSD area, an increase of the less palatable perennial species *S. ioclados* and *P. desertorum* was observed in both growing seasons. (In 2003 *S. ioclados* was found to be dominant in the area with 12% frequency of occurrence. On the contrary in 2004, *P. desertorum* was more abundant than in the 2003-growing season).

The annual grass *S. verticillata* has shown abundances as high as 63% and 65% in 2003 and 2004 respectively in the MSD areas (Table 4.2 and 4.4). The grass was evaluated as the sole crop in some of the plots and in the space between the tussocks of the perennial grasses. In 2004, the frequency abundance of annuals was high in the SD and MSD areas at 74% and 66% respectively. This could be due to inter-annual variation of rainfall in 2003 and 2004 and agrees with many researchers who found that inter-annual variation in rainfall influence species composition of range vegetation (Ellis & Swift, 1988; Westoby, Walker & Noy-Meir, 1989). Others have critically stated that short-term rainfall events (Van Rooyen *et al.* 1990) and certain rainfall conditions of semi-arid areas (Figueroa & Davy, 1991) influence the dominance of annual species. The frequency of occurrence of the unpalatable forbs has declined to 3% in this area.

In the MD and LD areas, which are far from the watering point, a drastic increase in abundance of the palatable perennial species was observed. In both areas, less than 10% frequency of abundance was recorded for the less palatable perennial species.

In conclusion, this study confirmed what other researchers found in other semi-arid parts of the world. Unpalatable forbs and annual grass dominate the vegetation in heavily overgrazed areas (such as near a watering point). As the grazing pressure decrease further away from the watering point, some of the forbs are replaced by unpalatable perennial grass species and in areas that have low grazing pressure, palatable perennial grass species dominate the vegetation. Thus, the hypothesis that was tested is therefore rejected.

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CHAPTER 5

IMPACT OF GRAZING AROUND A WATERING POINT ON FORAGE PRODUCTION AND BASAL COVER IN THE ALLAIDEGE RANGELAND IN NORTH-EASTERN ETHIOPIA

5.1 Introduction

The measurement of the available biomass yield is to the advantage of a livestock owner involved in a range based livestock production system. The total amount of herbage most commonly measured is the above ground level expressed in dry matter per unit area. The total herbage yield measurement is required to calculate other attributes that are important, such as amount of green material, amount of individual species, growth, pasture utilization, deterioration and amount of nutrients. Total dry matter is also an important element to calculate grazing capacity (Barnes *et al*., 1987) where this is defined as amount of dry matter available per animal.

The measurement of basal cover represents the proportion of the ground occupied by the bases (where they are rooted to the ground) of the individual species. Basal cover is a more stable property of vegetation than canopy cover. Basal cover is also considered a relatively stable quantitative attribute of grassland vegetation (Morris & Muller, 1970). Basal cover is commonly used in South Africa to evaluate the long term effect of treatments applied to natural pasture (Edwards, 1968) on the assumption that changes in cover reflect the effect of the treatment. Until recently, botanical composition derived to assess rangeland condition was supplemented with basal cover estimates (Tainton, 1981). This stems from the fact that basal cover was found to strongly influence the amount of runoff and soil loss (Snyman & Van Rensburg, 1986) and gives an indication of potential herbage production. Du Toit and Aucamp (1985) have also pointed to the sensitivity of basal cover while Vogel and Van Dyne (1966) implicated its significance over total productivity as a parameter of determining vegetation changes over a short period of time when overutilization occurs.

Earlier, the Allaidege rangeland was characterized as a wet season grazing retreat. The animals were allowed to graze only during the rainy season for limited periods of time watering the animals from available surface water sources such as ponds, drain canals and intermittent streams created by runoff.

These water sources that existed over the entire area only in the rainy season resulted in the protection of large areas of range from grazing and from conglomeration of animals around specific watering points. On the other hand the need to secure dry season grazing areas also resulted in the herdsmen moving without causing much pressure on the area. This trend was disrupted about three decades ago when large tracts of land were capitalized for agricultural projects.

To make up for the losses and displacements sustained by the nomadic groups, settlement schemes and provision of irrigated pasture have been adopted as compensatory measures. In conjunction with this 10 boreholes were constructed over the plain and more people started to settle around the boreholes and exploited the grazing area throughout the year. The use of the boreholes was not satisfactory. Currently, only one borehole in the area is functional. This limitation has increased the over utilization of the grazing area around the water source to the extent of completely wiping out some of the more palatable species in the area.

The changes observed in forage production and basal cover around water sources were revealed by many authors (Valentine, 1947; Lange, 1969; Martin & Ward, 1970; Pinchak *et al.*, 1991; Hart *et al*., 1991, 1993; Thrash, 1998). Complementary to this finding various researchers have empirically shown how the total forage production and basal cover was related to distance from water (Martin & Ward, 1970; Soltero, Bryant & Melgoza, 1989; Bosch & Gauch, 1991; Pinchak *et al*., 1991; Perkins & Thomas, 1993; Thrash, Theron & Bothma, 1993; Fusco *et al.*, 1995; Thrash, 1998).

This study is therefore proposed to obtain a better understanding of the primary production and basal cover of the range along the grazing gradients from the water source, for more judicious management of the range in the future. The objective of the study was to investigate the difference in plant biomass production and basal cover along a grazing gradient from a watering point in the Allaidege rangeland in the southern Afar region of Ethiopia. The hypothesis tested was: there is no difference in plant biomass production and basal cover at increasing distances from a watering point.

5.2 Materials and methods

5.2.1 Biomass yield

In 2003/2004, biomass yield was recorded from 60 sites of the grazing gradient by placing in each plot a 2 m x 2 m cage randomly on three collection sites of each degradation area (See Chapter 3 for layout of experimental site). Forage samples were collected at seed setting stage from a 1 m x 1 m quadrat inside the cage. The samples were clipped at ground level by using a sickle. Each forage sample taken from each plot was weighed using a scale balance to determine the total green weight of the sample. A sub-sample of 300-400 g was taken from each harvested sample to determine dry matter (DM) yield after drying in an oven at 65ºC for 72 hrs (Van Soest, 1988). The dried samples were stored for chemical analyses.

In the year 2004/2005, three cages were randomly placed in each plot in each degradation area. The forage samples were harvested from a 1 m x 1 m quadrat inside the cage at seed setting stage and were identified and sorted into groups (palatable, intermediate and others). The samples were oven dried for determination of dry matter yield. The percent contribution of each species in each grazing gradient was computed from the total sample collected.

5.2.2 Basal cover

The percentage basal cover of the species in each grazing gradient was determined from the number of basal strikes recorded at 1000 points in each plot using the wheel point method (Tidmarsh & Havenga, 1955). The plants were recorded when the striker with the marker hit on rooted living basal plant material. The proportion basal cover of each species recorded was determined from the total number of observation points made (Tidmarsh & Havenga, 1955; Tainton, Edwards & Mentis, 1980).

5.2.3 Statistical analysis

The different degradation areas were compared using ANOVA and the Bonferroni post-hoc tests. In some cases where the data was not suitable for ANOVA analysis non-parametric Bootstrap techniques (using Bonferroni multiple testing) were used.

5.3 Results

5.3.1 Dry matter yields in 2003

The DM yield recorded in 2003 was 0.89 t DM ha^{-1} yr^{-1}, 1.76 t DM ha^{-1} yr^{-1}, 3.31 t DM ha^{-1} yr^{-1} and 2.3 t DM ha^{-1} yr^{-1} for the SD, MSD, MD and LD areas respectively (Fig. 5.1). The average yearly dry matter yield over the grazing gradient was 2.07 t Dm ha^{-1} yr^{-1}. There was an increasing trend in dry matter yield from the SD to MD areas, but an unexpected decrease in yield from the MD to LD area (Fig. 5.1).

Dry matter yield comparison of the different degradation areas was insignificant for the season. Statistical significance ($P < 0.05$) was however observed when one outlier in the data was removed from the analysis. This difference was exhibited for the MD, SD and LD areas in which the MD area yielded 2.4 t ha^{-1} and 1.95 t ha^{-1} more than the SD and LD areas respectively (Table. 5.1).

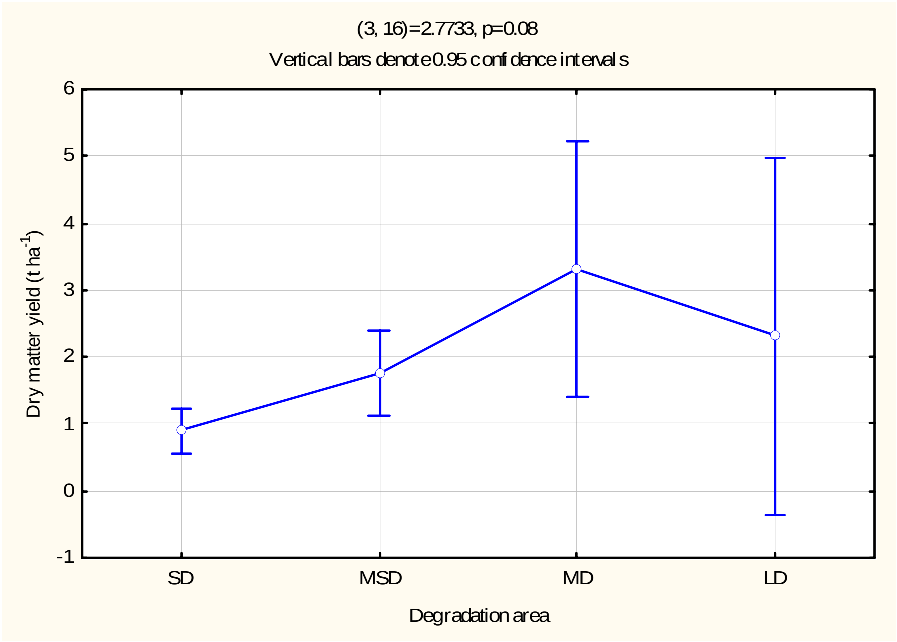


Figure 5.1 The mean dry matter yield in the different degradation areas in the Allaidege rangeland in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 5.1 Bonferroni test to compare the dry matter yield of the different degradation areas in the Allaidege rangeland in 2003 with one outlier excluded (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable Biomass Yield/2003 (Spreadsheet1) Probabilities for Post Hoc Tests
Error: Between MS = .77075,
df = 15.000 Exclude cases: 16

	Grazing gradient	{1}	{2}	{3}	{4}
1	SD		0.84322	0.003395	1
2	MSD	0.84322		0.080962	1
3	MD	0.003395	0.080962		0.028103
4	LD	1	1	0.028103	

5.3.2 Dry matter yields in 2004

In 2004 the mean annual dry matter yield over the whole grazing gradient was 0.9 t ha^{-1} yr^{-1}. The yields in the grazing gradient were 0.61 t ha^{-1} yr^{-1}, 0.93 t ha^{-1} yr^{-1}, 0.97 t ha^{-1} yr^{-1} and 0.90 t ha^{-1} yr^{-1} for the SD, MSD, MD and LD areas respectively (Fig. 5.4). A steady increase in yield was recorded along the grazing gradients but it did decline slightly in the LD area. The low yield recorded in 2004, was a drastic yield decline compared to 2003. Due to the low yield in 2004, there were no significant ($P > 0.05$) yield differences between degradation areas in 2004 although the trend suggested that less dry matter was produced in the SD area.

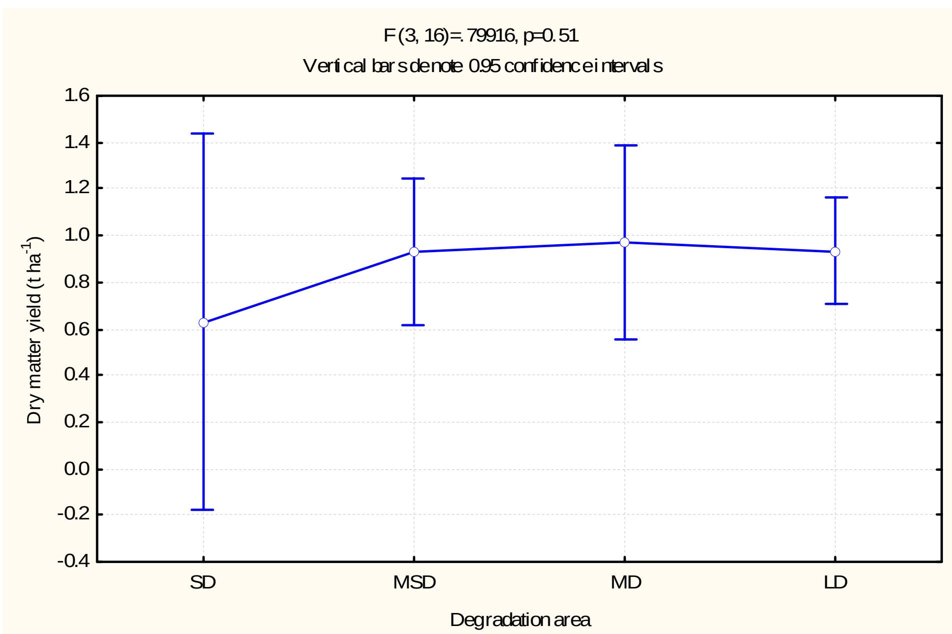


Figure 5.2 The mean dry matter yield in the different degradation areas along a grazing gradient in the Allaidege rangeland in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

In 2004 the herbage yield contribution of each species was calculated for each degradation area. *Setaria verticillata*, *Sporobolus ioclados* and *Paspalidium desertorum* were major contributors in the SD area producing 0.26, 0.23 and 0.12 t DM ha^{-1} yr^{-1} respectively (Table 5.2).

In the MSD area again S. *verticillata* and *P. desertorum* were dominant, producing 0.34 and 0.27 t DM ha^{-1} yr^{-1} respectively. The more palatable species *Chrysopogon plumulosus* and *Panicum coloratum* produced realtively small amounts of dry mass of 0.16 and 0.12 ton DM ha^{-1} respectively (Table 5.2).

In the MD area *C. plumulosus* and *P. desertorum* dominated with productions of 0.55 and 0.18 t DM ha^{-1} yr^{-1} respectively whereas the LD area was dominated by *C. plumulosus* (0.60 t DM ha^{-1} yr^{-1}) and *P. coloratum* (0.10 t DM ha^{-1} yr^{-1}). Some of the perennial species and annuals that were very low in abundance together contributed 0.18 t DM ha^{-1} yr^{-1} to the total herbage yield. Among the perennial species were *Cenchrus ciliaris*, *Bothriochloa radicans, S. ioclados* and *P. desertorum* and the most common annual species was *Sporobolus panicoides* (Table 5.2).

5.3.3 Dry matter yield comparison between 2003 and 2004

The annual average dry matter yield of 2003 was significantly higher than the annual average dry matter yield recorded in 2004 ($P < 0.05$) (Table 5.3). An average annual dry matter yield of 2 t DM ha^{-1} yr^{-1} was exhibited in 2003 and less than 1 t DM ha^{-1} yr^{-1} in 2004 (Fig. 5.5). The low yield recorded in 2004 was probably due to the low amount of annual rainfall (see Chapter 3), in particular during the growing seasons of July and August, resulting in lower vegetative production of the herbage.

Table 5.2 Yield contribution by different species in the different degradation areas in a grazing gradient in the Allaidege rangeland in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

	Yield					Mean[1]
	Plot 1 (t DM ha^{-1})	Plot 2 (t DM ha^{-1})	plot 3 (t DM ha^{-1})	Plot 4 (t DM ha^{-1})	Plot 5 (t DM ha^{-1})	total contribution
Species			**SD**			
Setaria verticillata	0	0.7	0	2.2	1	0.26
Sporobolus ioclados	0.6	0.05	0.6	1.3	0.95	0.23
Paspalidium desertorum	0	0	0	1.65	0.2	0.12
Ipomoea sinensis	0.1		0.35	0	0	0.03
			MSD			
Sporobolus ioclados	0.3	0	0	0	0.2	0.03
Ipomoea sinensis	0.1	0	0	0	0	
Setaria verticillata	1.55	0	1.1	0.6	1.8	0.34
Chrysopogon plumulosus	1.05	1.41	0	0	0	0.16
Paspalidium desertorum	0	0.8	1.57	1.75	0	0.27
Panicum coloratum	0	1.78	0	0	0	0.12
			MD			
Ipomoea sinensis	0.1	0	0	0.1	0	
Setaria verticillata	1.15	0	0	1.1	0	
Chrysopogon plumulosus	1.3	1.2	1.45	0	4.27	0.53
Paspalidium desertorum	0	2.1	0.6	0	0	0.18
Sporobolus ioclados	0	0	0.7	0.3	0	
Panicum coloratum	0	0	0.2	0	0	
			LD			
Chrysopogon plumulosus	1.45	1.67	1.2	1.84	2.8	0.6
Panicum coloratum	0.7	0	0.25	0.6	0	0.1
Cenchrus cilliaris	0.3	0.45	0	0	0	0.05
Bothriochloa radicans	0	0.7	0	0	0	0.05
Sporobolus ioclados	0.45	0	0	0	0	0.03
Paspalidium desertorum	0	0	0.6	0	0	0.04
Sporobolus panicoides	0.2	0	0	0	0	0.01
Digitaria rivae	0.2	0.3	0	0	0	0.03
Lintonia nutans	0	0.2	0	0	0	0.01
Setaria verticillata	0	0	0	0	0.1	0.01

[1] The mean is calculated by adding up the totals in the plots and dividing it by number of total quadrats which is 15 (3 quadrats in each plot)

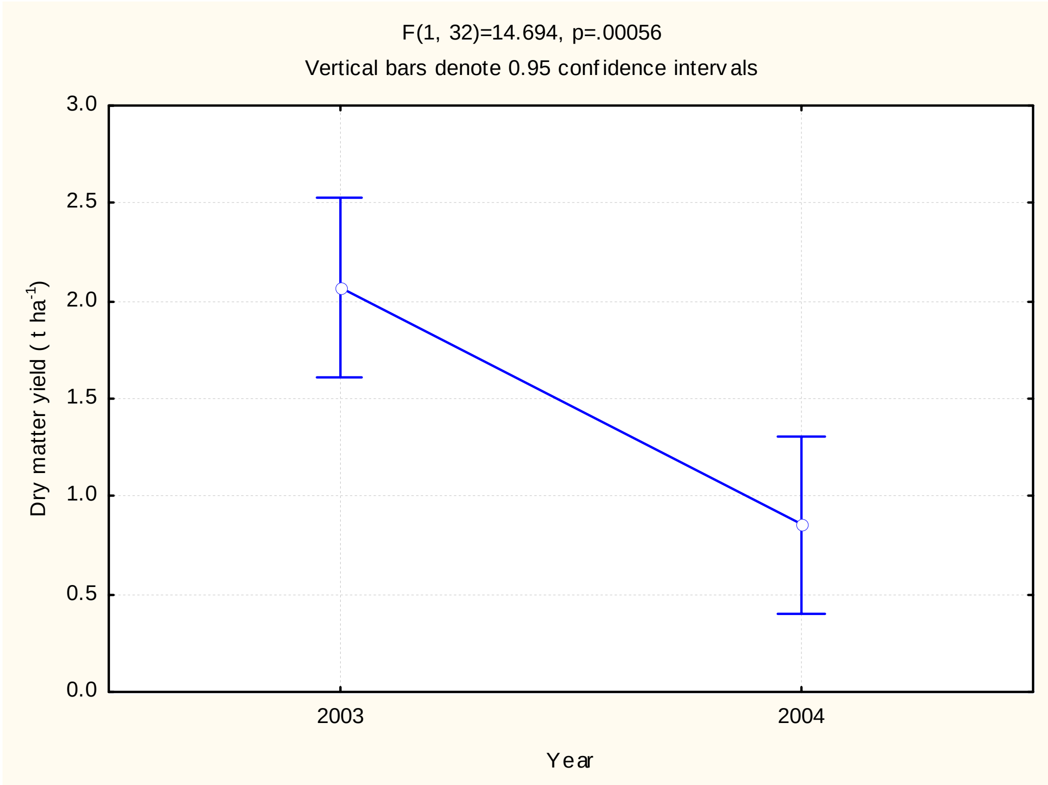


Figure 5.3 The average annual dry matter yields (pooled over degradation areas) in the Allaidege rangeland in 2003 and 2004.

The interaction between the degradation areas and different years was also assessed but no statistically significant interaction ($P > 0.05$) was observed (Table 5.3). The trends for 2003 and 2004 were similar apart from the fact that there was a bigger increase in dry mass production from the MD area compared to the other areas in 2003 (Fig. 5.6) This indicates that the impact of degradation was not different in the two years of the experimental period. There were no significant trends seen between any of the treatment combinations (Table 5.4). But, when two outliers were removed, this same trend became significant for degradation, year and the interaction (Table 5.5). The yield of the MD area of 2003 was significantly higher than the yield in all the other areas (Fig. 5.7). In general, when the yield is high as in 2003 the degradation had a big effect, but the same effect could not be seen in 2004 due to the low yield.

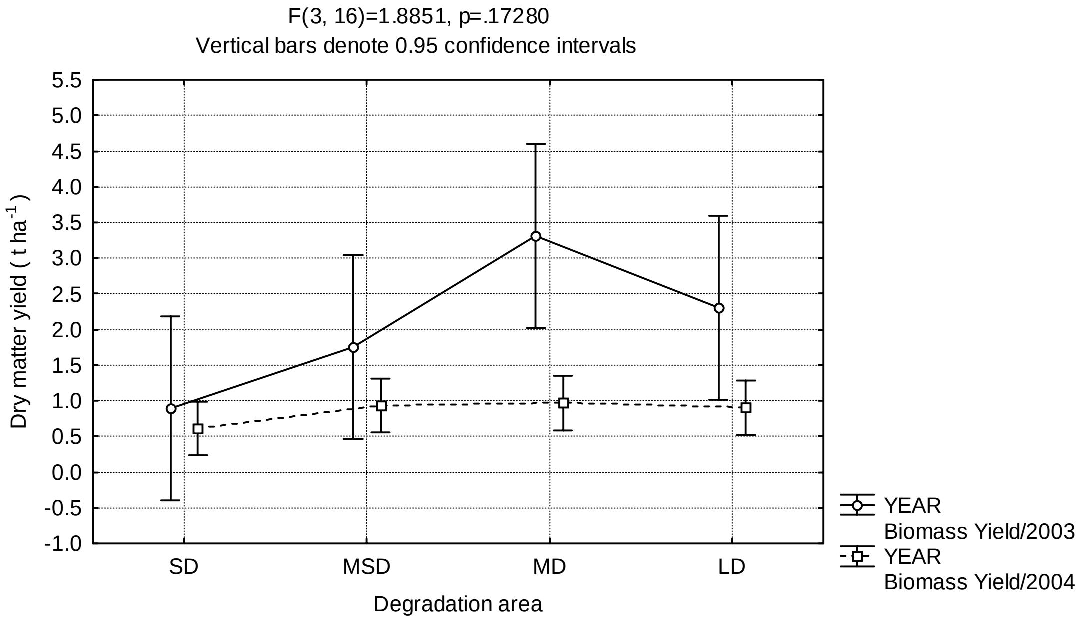


Figure 5.4 The dry matter yield pattern in different degradation areas along a grazing gradient in the Allaidege rangeland in 2003 and 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 5.3 Analysis of variance of the effect of degradation and year on dry matter yield along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance
(Spreadsheet22) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	85.52700	1	85.52700	87.09637	0.000000
Degradation	9.98145	3	3.32715	3.38820	0.044014
Error	15.71170	16	0.98198		
YEAR	14.77440	1	14.77440	14.35870	0.001609
YEAR*Degradation	5.81913	3	1.93971	1.88513	0.172798
Error	16.46322	16	1.02895		

Table 5.4 Scheffe test to compare dry matter yields in the different degradation areas in a grazing gradient in the Allaidege rangeland in 2003 and 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Scheffe test; variable Biomass Yield/2003 (Thesis Data.sta)
Probabilities for Post Hoc Tests Error: Between MS = 1.0055, df = 32.000

	Year	Degradation	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}
1	2003	SD		0.963008	0.075305	0.663647	0.999968	1.000000	1.000000	1.000000
2	2003	MSD	0.963008		0.549430	0.997443	0.850219	0.970677	0.977439	0.964824
3	2003	MD	0.075305	0.549430		0.919676	0.030802	0.083770	0.093566	0.077120
4	2003	LD	0.663647	0.997443	0.919676		0.433633	0.692073	0.721290	0.670017
5	2004	SD	0.999968	0.850219	0.030802	0.433633		0.999927	0.999845	0.999961
6	2004	MSD	1.000000	0.970677	0.083770	0.692073	0.999927		1.000000	1.000000
7	2004	MD	1.000000	0.977439	0.093566	0.721290	0.999845	1.000000		1.000000
8	2004	LD	1.000000	0.964824	0.077120	0.670017	0.999961	1.000000	1.000000	

Table 5.5 Analysis of variance (with two outliers excluded) of the effect of degradation and year on dry matter yield along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (Spreadsheet22)
Sigma-restricted parameterization Effective hypothesis decomposition Exclude cases: 4,16

	SS	Degr. of	MS	F	p
Intercept	59.58152	1	59.58152	166.1942	0.000000
Degradation	11.61771	3	3.87257	10.8020	0.000613
Error	5.01908	14	0.35851		
YEAR	9.32523	1	9.32523	17.7518	0.000868
YEAR*Degradation	5.67793	3	1.89264	3.6029	0.040672
Error	7.35437	14	0.52531		

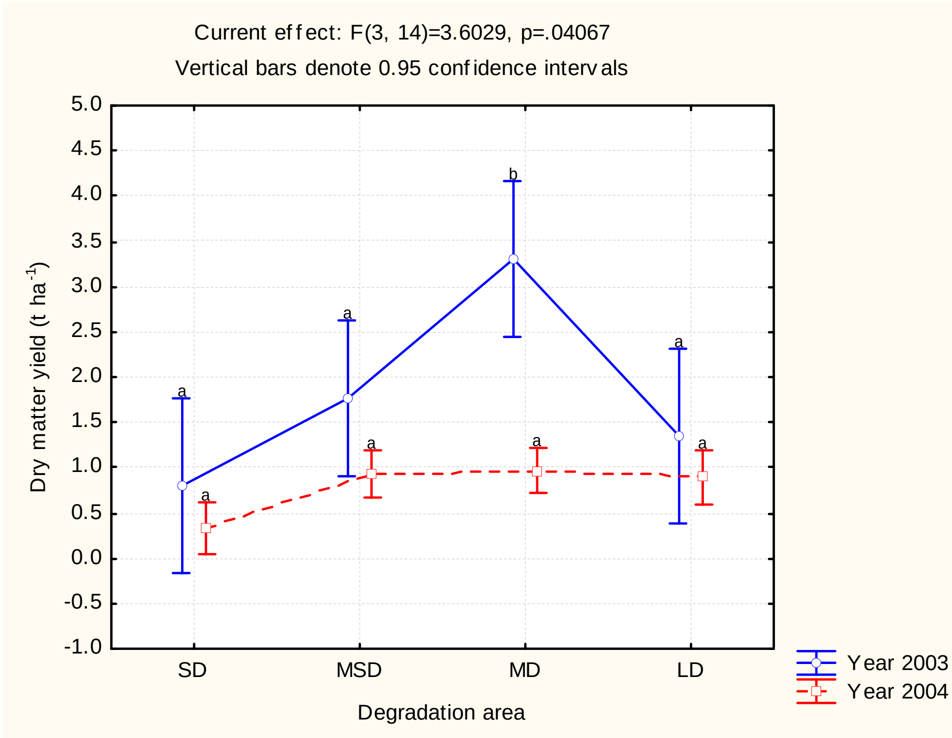


Figure 5.5 The dry matter yield pattern in different degradation areas in a grazing gradient in the Allaidege rangeland in 2003 and 2004 when two outliers were excluded (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (Data points with different superscripts differ at P = 0.05).

5.3.4 Basal cover of species

The total basal cover of the herbaceous stratum was not consistent along the grazing gradient in 2003. An increasing trend was observed from the SD to MSD areas and from there a steady decline to the MD and LD areas (Fig. 5.8a). The total basal cover recorded was 8%, 14.76%, 11.5% and 9% for the SD, MSD, MD and LD areas respectively (Table 5.6). The same trend was observed in 2004 (Fig. 5.8b) with total basal cover of 7%, 15.8%, 11.88% and 8.76% for the SD, MSD, MD and LD areas respectively (Table 5.7). In both seasons the total basal cover did not significantly change along the grazing gradient (Fig. 5.8a and 5.8b), but the relative contribution of each species to total basal cover responded differently along the grazing gradient.

Certain trends were observed in the basal cover of the herbaceous species stratum along the grazing gradient. It was found that percentage basal cover of certain species decreased in the vicinity of the watering point, where other species increased.

In 2003, the most frequent perennial species with higher basal cover around the watering point were *S. ioclados, P. desertorum, S. pellucidus* and *Digitaria rivae* (Table 5.6). In 2004 *S. ioclados* and *P. desertorum* showed increased basal cover around the watering point Table 5.7). No statistical difference (between degradation areas) was evident for the basal cover of the specific species in both years despite an increasing basal cover trend towards the watering point.

Species with decreased basal cover around the watering point were *Chrysopogon plumulosus, Panicum coloratum, Cenchrus ciliaris* and *Lintonia nutans* in 2003 (Table 5.6). The two main perennial grass components of the rangeland, *C. plumulosus* and *P. coloratum* showed the same trend. Both species showed a steady increase in percentage basal cover along the gradient with increasing distance from the watering point (Fig 5.9a and 5.10a). The increase was significant ($P < 0.05$) for *C. plumulosus* but not for *P. coloratum* (Only the Bootstrap analysis showing the increasing trend is showed because the data was not suitable for an ANOVA analysis). The remaining perennial species were very rare and totally absent in most of the areas and percentage basal cover did not change significantly between degradation areas.

Similar to 2003, *C. plumulosus, P. coloratum* and *C. ciliaris* showed a decreasing trend in basal cover towards the watering point in 2004 (Table 5.7). Both *C. plumulosus* and *P. coloratum* exhibited an increase in basal cover percentage along the gradient away from the watering point (Fig. 5.9b and 5.10b). The increase was statistically significant in the case of *C. plumulosus* ($P < 0.05$) but not in the case of *P. coloratum.*

The percentage basal cover of the annual grass, *S. verticilata*, the most abundant in some of the gradients showed an increasing trend towards the watering point, but sharply decreased in the SD area in both seasons (Table 5.6 and 5.7). *Momordica boivinii* and *Ipomoea sinensis* known by a single common local name were recorded together and showed an increased percentage basal cover in the SD area near the watering point in both seasons (Table 5.6 and 5.7).

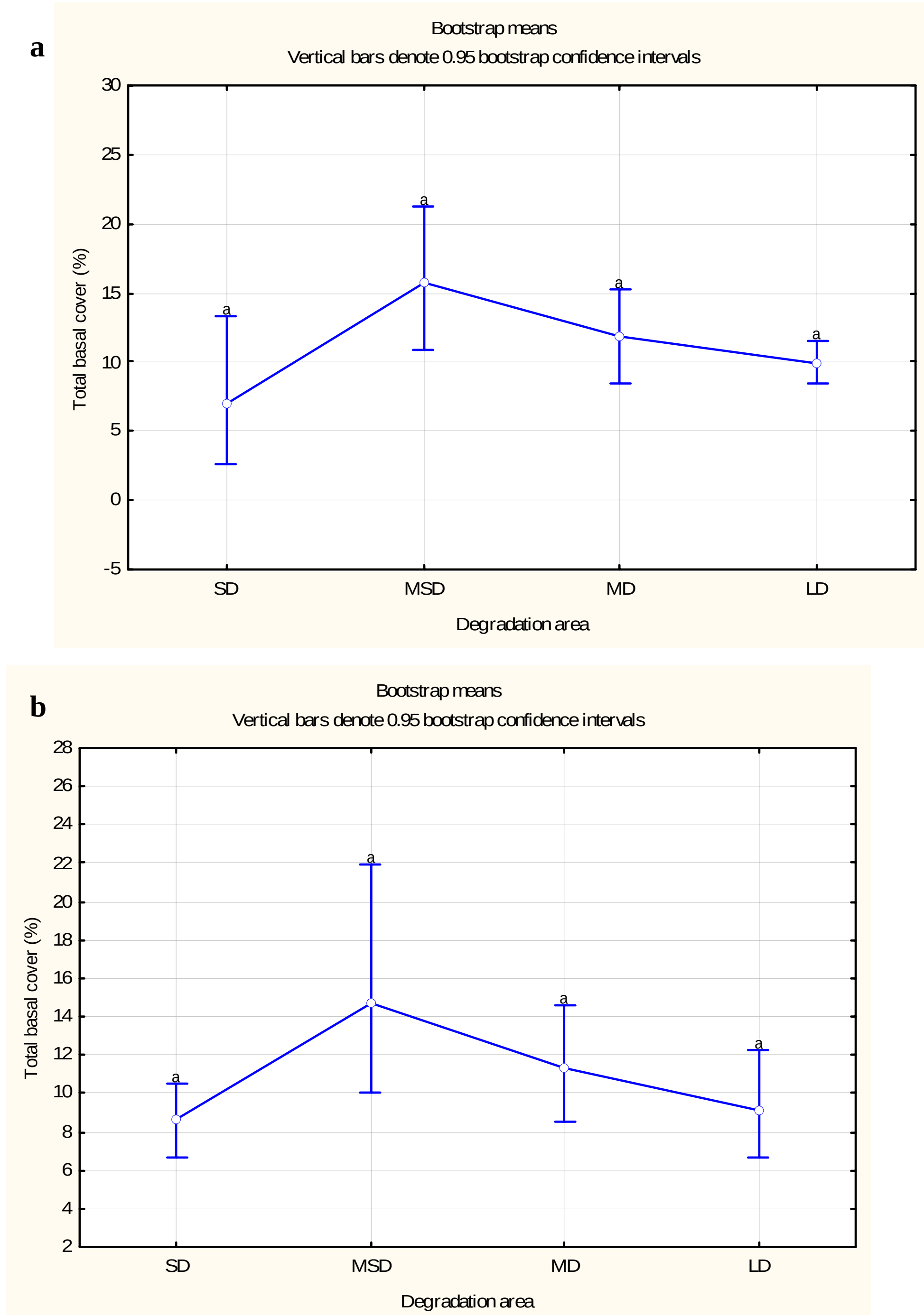


Figure 5.6 Total basal cover trends in different degradation areas along a grazing gradient in the Allaidege rangeland in a) 2003 and b) 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (Data points with different superscripts differ at P = 0.05).

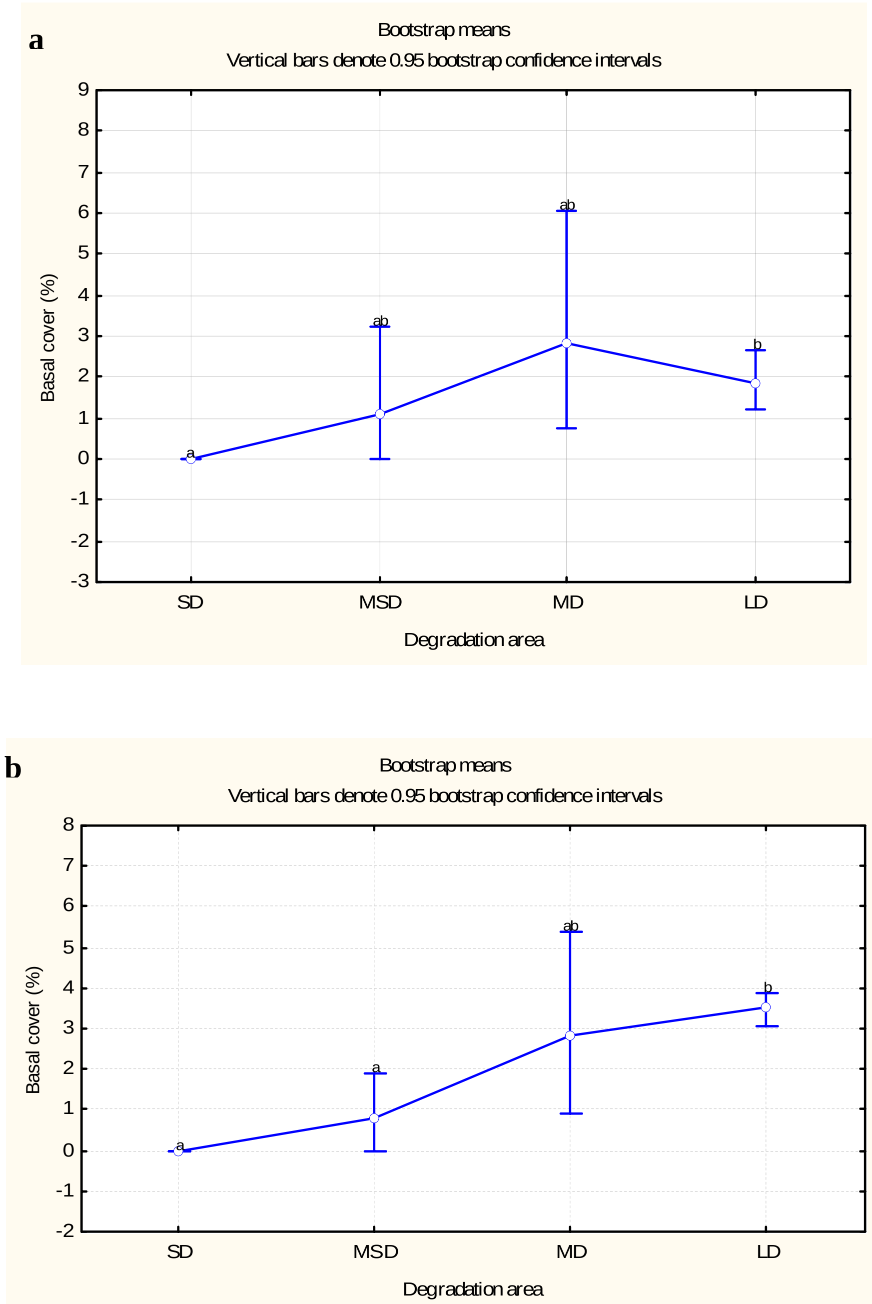
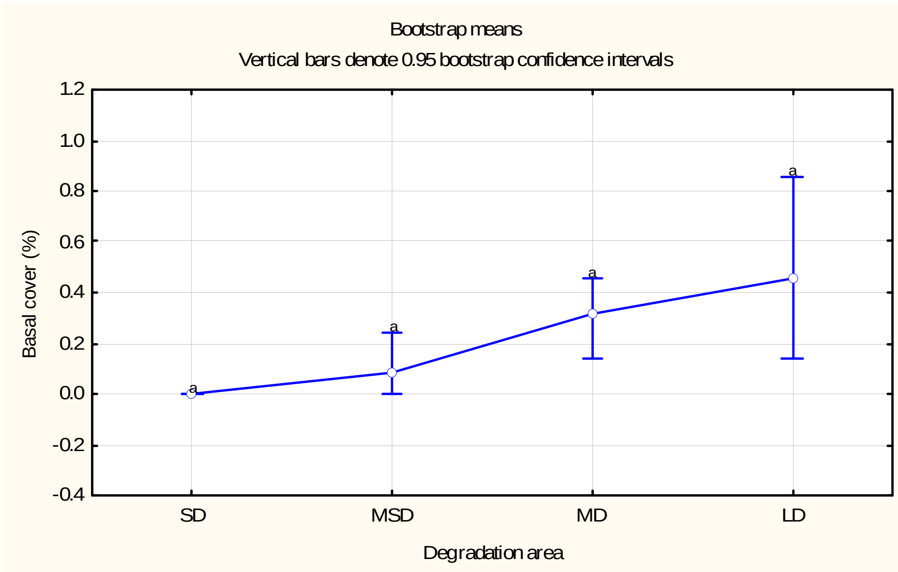


Figure 5.7 Basal cover trend of *Chrysopogon plumulosus* in the degradation areas along a grazing gradient in the Allaidege rangeland in a) 2003 and b) 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (Data points with different superscripts differ at P = 0.05).

a



b

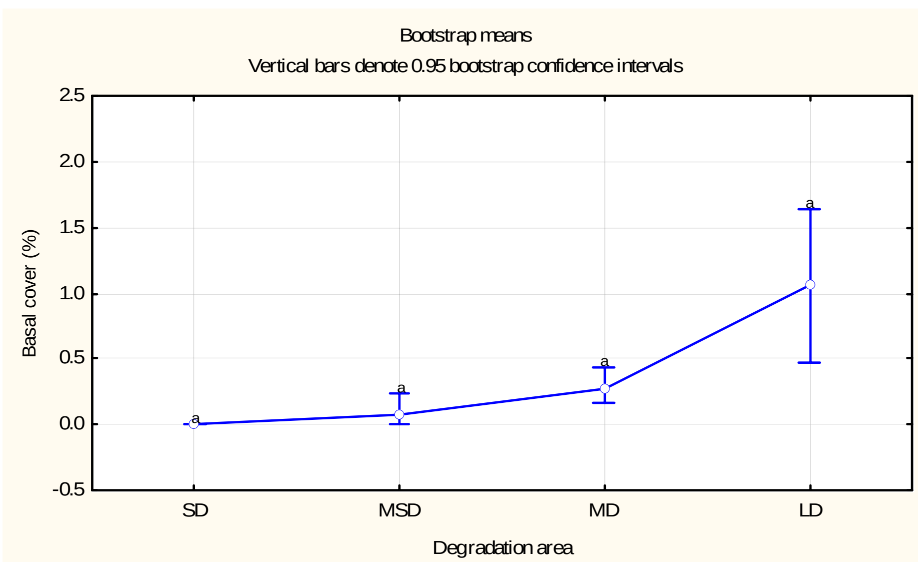


Figure 5.8 Basal cover trend of *Panicum coloratum* in the degradation areas along a grazing gradient in the Allaidege rangeland in a) 2003 and b) 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area) (Data points with different superscripts differ at P = 0.05).

Table 5.6 Basal cover percentage of species in different degradation areas along a grazing gradient in the Allaidege rangeland in 2003 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

			Percent basal cover			
Species name	**Afar common name**	**Lifeform**	**SD**	**MSD**	**MD**	**LD**
Perennial grasses			%	%	%	%
Chrysopogon plumulosus Hochst	Durfu	Perennial	0	1.12	2.8	1.82
Sporobolus ioclados	Denekto	Perennial	0.74	0.78	0.24	0.42
Panicum coloratum	Denekto (p)	Perennial	0	0.08	0.32	0.48
Paspalidium desertorum (Aurich) Stapf	Bohale	Perennial	0.02	1.76	1.52	0.08
Bothriochloa radicans (Lehm)	As ayso	Perennial	0	0	0.06	0.02
Cenchrus ciliaris	Serdoyta	Perennial	0	0	0.04	0.02
Lintonia nutans Stapf	Afara mole tat	Perennial	0	0	0	0.34
Coelachyrum poiflorum (choir)	Afara mole	Perennial	0.02	0	0	0.02
Sporobolus pellucidus Hoehst	Sosokete	Perennial	0.04	0	0	0
Digitaria rivae (choir) Stapf	Hamanto	Perennial	0.22	0	0.04	0.06
Total %			**1.04**	**3.74**	**5.02**	**3.26**
Annual grasses						
Setaria verticillata (L.) P. Beauv	Delayta	Annual	3.86	9.74	4.46	2.96
Tetrapogon tenellus (Roxb) chior	Aytodyta	Annual	0	0	0.04	0
Sporobolus panicoides A. Ruch	Bekelayso	Annual	0	0	0.2	2.1
Total %			**3.86**	**9.74**	**4.66**	**5.06**
Other forbs (edible)						
Momordica boivinii Baill & *Ipomoea sinensis*	Halal	Annual	0.84	0.16	0.1	0
Blepharis edulis	Yamarukta	Annual	0	0.1	0	0.28
Rhynchosia melacophylla (Spreng, Boj)	Haro	Annual	0.02	0.14	0.1	0.02
Total %			**0.86**	**0.4**	**0.2**	**0.3**
Other forbs (unpalatable)						
Un identified	Mutuki	Annual	0	0	0.1	0.02
Un identified	Ashara	Annual	0.02	0	0	0
Portulaca quadrifiola L.	Halihara	Annual	0.3	0.04	0.08	0
Unidentified	Baroberbere	Annual	0.22	0.38	0.42	0
Orthosiphon pallidus Royle	Hebeke	Annual	0.12	0	0	0
Abatalion anglosomaliae Cufod	Hambukto	Annual	0.22	0	0.04	0.06
Amaranthus spp	Bunkete	Annual	0.06	0	0	0
Un identified	Mercehal	Annual	0.56	0	0.02	0
Leucas nubica Benth	Ergufuma	Annual	0.52	0.04	0	0
Phyllanthus recticulatus	Akelekelmi	Annual	1.04	0.42	0.96	0.46
Total %			**3.06**	**0.88**	**1.62**	**0.54**
Total basal cover %			**8.82**	**14.76**	**11.5**	**9**

Table 5.7 Basal cover percentage of species in different degradation areas along a grazing gradient in the Allaidege rangeland in 2004 (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

			Percent basal cover			
Species name	**Afar common name**	**Lifeform**	**SD**	**MSD**	**MD**	**LD**
Perennial grasses			%	%	%	%
Chrysopogon plumulosus Hochst	Durfu	Perennial	0	0.8	2.92	3.52
Sporobolus ioclados	Denekto	Perennial	0.32	0.18	0.04	0.26
Panicum coloratum	Denekto (p)	Perennial	0	0.08	0.28	1.06
Paspalidium desertorum (Aurich) Stapf	Bohale	Perennial	0.42	1.28	0.84	0.2
Bothriochloa radicans (Lehm)	As ayso	Perennial	0	0	0.2	0
Cenchrus ciliaris	Serdoyta	Perennial	0	0	0	0.12
Lintonia nutans Stapf	Afara mole tat	Perennial	0	0	0.02	0
Coelachyrum poiflorum (choir)	Afara mole	Perennial	0	0.08	0	0.18
Digitaria rivae (choir) Stapf	Hamanto	Perennial	0	0	0.08	0.54
Total %			**0.74**	**2.42**	**4.38**	**5.88**
Annual grasses						
Setaria verticillata (L.) P. Beauv	Delayta	Annual	6.02	12.96	5.66	1.36
Tetrapogon tenellus (Roxb) chior	Aytodyta	Annual	0	0	0.14	0
Sporobolus panicoides A. Ruch	Bekelayso	Annual	0	0	0.2	1.2
Total %			**6.02**	**12.96**	**6**	**2.56**
Other forbs (edible)						
Momordica boivinii Baill & *Ipomoea sinensis*	Halal	Annual	0.34	0.08	0.04	0.02
Blepharis edulis	Yamarukta	Annual	0	0.14	0.12	0.12
Rhynchosia melacophylla (Spreng, Boj)	Haro	Annual	0	0.02	0.28	0.02
Total %			**0.34**	**0.24**	**0.8**	**0.16**
Other forbs (unpalatable)						
Unidentified	Mutuki	Annual	0	,02	0.12	0.04
Unidentified	Baroberbere	Annual	0.02	0.06	0.48	0
Abatalion anglosomaliae Cufod	Hambukto	Annual	0	0.02	0.06	0.04
Phyllanthus recticulatus	Akelekelmi	Annual	0.04	0.06	0.04	0.08
Total %			**0.06**	**0.16**	**0.7**	**0.16**
Total basal cover %			**7.16**	**15.78**	**11.88**	**8.76**

5.4 Discussion

The dry matter yield drastically declined to 0.97 t ha^{-1} in 2004 - a yield difference of 1.2 t ha^{-1} compared to 2003. This yield reduction was attributed to low annual rainfall received in 2004, especially during the growing seasons of July and August. Even though rainfall as a driving force has not been investigated in this study, non-equilibrium views of range ecology emphasize the role played by rainfall in influencing inter-annual variations in the productivity of range vegetation (Ellis & Swift, 1988; Westoby, Walker & Noy-Meir, 1989)

The average dry matter yield for the two seasons was 1.52 t ha^{-1}. This yield was lower than a study survey estimate of 1.7 t ha^{-1} (MCE, 2000). The estimated yield was higher because only ungrazed and lightly grazed areas were considered, ignoring more degraded areas. The results of this study was comparable to the yield estimate of 1.3 t ha^{-1} in seasonally grazed areas of the Mid Rift valley of Ethiopia, where very low yields were recorded for all the communally grazed zones (Amsalu & Baars, 2002).

In this study, dry matter yield of the different degradation areas was evaluated at varying distances from a watering point. The decline in yield observed in the LD area could be due to the allocation of some of the experimental plots on patchy overgrazed areas that was relatively well drained and was more preferred by livestock.

In 2004, the dry matter yield detected in each degradation area was very low and masked the apparent existence of the gradient. However, other notable features such as dry matter yields of each species in different degradation areas were evidence for grazing gradient differences. This was in agreement to a study by Friedel (1988) where he tried to trace the apparent features of grazing gradients from characteristics of plant species growing in each zone**.** Similarly, in the SD area the annual grass *S. verticillata* was abundant, producing 42.62% of the total dry matter yield. The presence of the species was recognized as a disturbance indicator caused by overgrazing or drought (Tolsma, Ernst & Verwey, 1987). The perennial species *S. ioclados* and *P. desertorum* were also associated with this area producing 37.70% and 19.67% respectively of the total herbage yield. These species were found dominating near watering points in the SD area, because cattle do not prefer the species and they are species adapted to the habitat of disturbed areas (Bogdan, 1977; Tolsma *et al.*, 1987). In general, *S. verticillata*, *S. ioclados* and *P. desertorum* are species commonly occurring in overgrazed areas of rangelands.

In the MSD areas, *S. verticillata* and *P. desertorum* were consistent in growth and more abundant in case of *P.desertorum* than observed in the SD area, due to animals selectively overutilizing the palatable perennial forages available in the area. The contribution of each species to total dry matter yield was recorded as 36.56% and 29.03% respectively. The preferred perennial species that occurred in the area were *C. plumulosus* and *P. coloratum* with herbage contributions of 17.20% and 12.90% respectively to the total herbage yield. Friedel (1988), Amsalu and Baars (2000) and Van Oudtshoorn (1999) classified these species as preferred species that could be categorized as decreasers from the decreasing trend observed with increasing grazing pressure on the range.

In the MD and LD areas, the preferred *C. plumulosus* and *P. coloratum* increased in abundance. A total dry matter yield contribution of 56.70%, 18.56%, 15.46% and 7.22% was recorded for *C. plumulosus*, *P. desertorum*, *S. verticillata* and *S. ioclados* respectively in the MD area. In the LD area 66.67%, 11.11%, 5.56%, 5.56%, 4.44% and 3.33% of the total herbage yield was recorded for *C. plumulosus*, *P. coloratum*, *C. ciliaris*, *Botriochloa radicans*, *P. desertorum* and *S. ioclados* respectively. *Sporobolus panicoides*, *Coelachyrum poiflorum* and *S. verticilata* were low in abundance with a dry matter contribution of 2.89% of the total herbage yield. The increased cover of the preferred species was related to a further distance from the watering point. This agrees with the finding of Perkins and Thomas (1993), Fusco *et al*. (1995) and Beukes and Ellis (2003), who confirmed that grazing effects on preferred species was reduced beyond 1500 m from a watering point.

In 2004, even though there was a slight dry matter yield increase along the gradient, the increase was very low. The other aspect to consider in terms of dry matter yield is the composition of the dominant plant species in the range. Cowling *et al.* (1994) has emphasized the importance of perennial plant species composition for herbage productivity. In this study, preferred perennial species are not growing densely, but are scattered over the area and the chance of encountering perennial species is rare when the number of sample quadrats are small. This might have contributed to the slow increase of dry matter yield along the gradients.

In general, the data did not reveal statistically significant yield differences between all degradation areas. The main reason was assumed to be due to large variations in the data and small number of plots (five) allocated per field. Nevertheless, the yield showed an increasing trend (Fig. 5.4) with distance from the watering point.

This is in agreement with reports from different researchers on the increase of herbage yield along gradients from watering points (Martin & Ward, 1970; Fusco *et al.*, 1995).

The dry matter yield recorded in 2003 from the SD area, which is 1500 m from the watering point was reduced by about 50 percent compared to the adjacent MSD area at 3600 m. This was different from the finding of Soltero *et al.* (1989), who found a 50% reduction of biomass of grass in the zone less than 600 m from water. In 2004, the yield reduction escalated to 66% in the SD area. This information showed that the dry matter yield was affected negatively closer to the watering point.

Total basal cover showed interesting trends (Fig. 5.8). The low basal cover in the SD area could be attributed to the continuous grazing and trampling of the annual grass species and forbs due to the communal camp around the watering point. However, in the MSD area the highest basal cover was recorded. This agrees with the observations of Stoddart, Smith and Box (1975) and Amsalu and Baars (2002) who pointed out the increase in basal cover when range condition declines due to the replacement of tall, erect species with low growing, spreading species. Vogel and Van Dyne (1966) also found that total basal cover of grasses, sedges and forbs were the same in both grazed and protected areas. However, basal cover of individual species varied considerably. This was observed in this study where short-lived low growing annual species (grass or forbs) covered the space in between the tufted erect growing grass species. No significant difference in total basal cover along the grazing gradients was observed in both seasons.

The contribution of each species to total basal cover of the grazing gradient was assessed and contributions of species increased or decreased around watering points, depending on their life form and palatability. Barker, Herlocker and Young (1989) and Van Rooyen *et al*. (1990) also found changes in basal cover of species relative to distance from the watering point. The increase and decrease of basal cover of species is related to the preference (palatability) of the species by animals. Those species showing a decreasing trend around water points were livestock preferred species. Many studies have reported the decrease of preferred species around watering points (Martin & Ward, 1970; Van Rooyen, *et al.* 1990; Thrash, 1998; Beukes & Ellis, 2003).

Taking into account the average biomass yield production of the two growing seasons, the study has tried to estimate the grazing capacity of the entire Allaidege rangeland. Grazing capacity was calculated with the following formula (Holecheck, Pieper & Herbel, 1989):

$$Y = d / (DM \times f)/r$$

Where, Y = Grazing capacity (ha/TLU)

d = no of days in a year (365)

DM = Total grass DM yield (kg ha^{-1}) (1520 kg ha^{-1}, 2 years average)

f = Utilization factor (0.5)

r = Daily grass DM required per TLU (2% of body mass)

In accordance to this, the computed grazing capacity of the range was estimated to be 2.4 ha TLU^{-1} or 83 333 TLU per year. Then this grazing capacity of the rangeland was related to the livestock (cattle and sheep) population of the Administrative Zone estimated as 1 201 814 cattle and 381 285 sheep population (MCE, 2000). In doing so, the livestock numbers were first converted to standardized tropical livestock units (TLU) (MCE, 2000), where TLU is equivalent to an animal weighing 250 kg. Therefore cattle = 0.72 TLU and sheep = 0.1 TLU. The livestock population of the zone seems to be exaggerated. However, the study adhered to these figures because of the intensity of degradation observed in the range. Consequently, the approach to stocking rate was made considering the total TLU of cattle and sheep of the zone, mainly on account that they are the primary grazers. From this population 50% of the total TLU of cattle and sheep were assumed to graze in the rangeland. This large group of grazing animals inhabiting the range was assumed because of the dependency of the local people on the rangeland. Hence, 451 717 TLU of cattle and sheep were expected to forage, which were 368 384 TLU more than the capacity of the rangeland. From this perspective overstocking is assumed to be major cause of range degradation, affecting the biomass yield and cover of the Allaidege rangeland.

In conclusion, the limited number of sampling plots used in this study which tended to cause large variations in the data presented problems. This leads to a lack of statistical significance for the differences in many cases. However, the trend in yield increase further away from the watering point was clear. Similarly a general increase in total basal cover and decline in perennial species composition towards the watering point was revealed in the study. These facts justify the general observation that that there are differences in plant biomass production and basal cover at increasing distances from the watering point, thereby refuting the posed hypothesis.

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CHAPTER 6

IMPACT OF GRAZING AROUND A WATERING POINT ON FORAGE QUALITY IN THE ALLAIDEGE RANGELAND IN NORTH-EASTERN ETHIOPIA

6.1 Introduction

Rangeland is the primary source of livestock feed in the Afar Regional State of Ethiopia, but livestock production is constrained by both quantity and quality of forage produced and consumed. Knowledge of the nutrient quality trends of range forage together with the seasonal fluctuations will assist to indicate the optimal time of utilization of the range, as well as help to predict the animal nutritional status and to indicate supplementation requirements.

It is universally accepted that the highest quality of forage is available in the early stage of forage development prior to the reproductive stage. Utilization of rangeland by moderate to heavy grazing at an early stage of growth was found to be effective in removing low quality senesced forage, improving forage quality and prolonging the period of high nutritive value by stimulating subsequent re-growth (Vallentine, 2001). McNaughton (1984) has also observed higher concentrations of nutrients in grazed areas compared to similar ungrazed areas. However, Hart *et al.* (1993) have reported that grazing, as a preconditioning treatment to improve forage quality for later grazing was unreliable in arid and semi-arid regions.

Forage quality measurements are those that provide the animal with the requirement of protein, energy and minerals (Vallentine, 2001). It is, however an established fact that clipped pasture samples may not fully represent what animals actually graze. To overcome this ambiguity, both clipped and samples collected from esophageal fistula are considered to quantify the nutritional relationships.

Crude protein (CP) as the primary measurement of quality in arid and semi-arid areas was reported by Norton (1982). In general, however, forage quality is constrained by soil fertility, animal management, plant species, plant parts, stage of maturity and seasonal conditions (Tainton, 1981; Wilson, 1982; Milchunas & Lauenroth, 1993; O’Connor & Roux, 1995; Turner, 1999; Vallentine, 2001).

Apart from the natural characteristics of the soil and plant species contributing to low quality forage, overgrazing is becoming instrumental in causing a decline in the forage quality of the Afar rangeland. The impact of grazing causes changes in botanical composition (Hardy & Hurt, 1989; Morris, Tainton & Hardy, 1992; Holecheck *et al*., 2003) due to the fact that animals selectively graze palatable perennial plants repeatedly and impair the vigour of the plant causing a lower production of herbage (Van Niekerk *et al*., 1984; Chapman & Lamaire, 1993). This ultimately favours the emergence of poor quality forages, which are less palatable or unpalatable species (Westoby, 1980; O' Connor, 1991; Thrash, Theron & Bothma, 1993). In areas where watering points are available, overstocking creates sacrifice areas. As a consequence, survival of palatable perennial herbaceous plants of good quality decline to the extent of extinction (Westoby, 1980; O'Connor, 1991; Thrash *et al*., 1993), being replaced by forages of poor quality or unpalatable species, (O'Connor, 1991; Thrash *et al*., 1993), which is usually associated with a decline in forage quality of the available forage (Boudet, 1975).

Thus this study was initiated to quantify the change in forage quality caused by the effect of grazing around watering points in the southern Afar region of Ethiopia. The objective was to evaluate the difference in rangeland forage quality at increasing distances from a watering point in the southern Afar region of Ethiopia. The hypothesis tested was: there is no difference in rangeland forage quality at increasing distances from a watering point.

6.2 Materials and methods

6.2.1 Chemical analysis of forage samples

The nutrient content of the rangeland forage was estimated from the samples harvested for yield determination as described in Chapter 5. In 2003, forage samples were collected at seed setting stage (October 3/2003) from a 1 m x 1 m quadrat. The samples were cut at ground level by means of a sickle. A total of 60 sub samples of 300-400 g was taken from the 20 sampling plots (five in each degradation area) and dried in an oven at 65 ºC for 72 hrs (Van Soest, 1988). In 2004 samples were collected in a similar manner but earlier on September 3/2004 due to the interference of herdsmen coming from a distant area who attempted to dismantle the fence to graze the plot. The forage samples were harvested from a 1 m x 1 m quadrat at initiation of seed setting using a sickle and were sorted into groups (palatable, intermediate and others species). The samples were oven dried as described above to calculate the dry matter yield contribution of each species. After that sample groups of the same plot were mixed in order to get 60 sub samples to prepare for chemical analysis. All the collected samples were ground through a 1 mm sieve using a Wily mill to obtain a 300 g sample from each sample plot and stored in labeled airtight bottles until chemical analyses were performed. The samples were analysed for nitrogen (N) by means of the Kjeldahl method, according to the AOAC (1990). Crude protein was calculated by multiplying the N content with 6.25.

Fibre analysis (acid detergent fibre (ADF) and neutral detergent fibre (NDF)) and lignin was done according to Van Soest (1988) and *in-vitro* digestibility according to Tilley and Terry (1963). The mineral Ca was analysed by means of an Atomic Absorption Spectrophotometer (AAS) and P was analysed by means of the Auto-analyser method of the AOAC (1990).

6.2.2 Chemical analysis of clipped and esophageal collected forage samples

In this experiment 2 esophageal fistulated young steers were allocated to collect the esophageal samples. The experimental animals were allowed to graze communally with the community herds at regular fixed times every morning at 08h00 with the objective of securing enough material in the collection bag. The grazing scheme was scheduled to begin in September 2003 and 2004 after the rainy season ended. The animals were herded to graze in the moderately to severely degraded (MSD) and moderately degraded (MD) areas. The esophageal samples were collected at the end of each month in plastic bags for four consecutive days per period at a fixed collection time to obtain enough material. The collected esophageal samples were taken to the Werer Agricultural Research Centre (WARC) and kept frozen to avoid unnecessary loss of nutrients. At the same time hand clipped forage samples were collected for chemical comparison with esophageal samples. The months September, October and November, were designated as periods I, II and III, respectively. Clipped forage samples and fistula samples were oven dried at 50°C (Van Soest, 1988) and ground through a 1 mm sieve using a Wily mill and stored in labeled air tight bottles until chemical analyses were performed. The samples were analysed for N by means of the Kjeldahl method (AOAC, 1990). Crude protein was calculated by multiplying the N content with 6.25. Fibre analysis of ADF, NDF and lignin was analysed according to Van Soest (1988) and *in vitro* digestibility according to Tilley and Terry (1963). The mineral Ca was analysed by means of an Atomic Absorption Spectrophotometer (AAS) and P was analysed by means of the Auto-analyser method of the AOAC (1990).

6.2.3 Statistical analysis

Repeated measures of ANOVA (using the Statistica 7 package) were used to compare forage quality between different degradation areas over two years (2003 and 2004). The Proc. GLM command of SAS for Windows version 8.2 was used to compare the clipped samples with the esophageal collected samples (SAS Inst., 2000).

6.3 Results

6.3.1 Chemical analysis of forage samples

6.3.1.1 Crude protein (CP)

Although Figure 6.1 indicate that there is an interaction between year and degradation gradient, it was not statistically significant at P = 0.05 (Table 6.1). In 2003, significant variation ($P < 0.05$) in CP levels was recorded among forage plants found in the degradation areas away from the watering point (Table 6.2). Crude protein levels of more than 7% were recorded in the severely degraded (SD) area close to the watering point. Beyond the SD area, CP content was more or less constant in the other degradation areas. The CP levels recorded were 4.59% 3.89% and 4.36% for the MSD, MD and lightly degraded (LD) areas respectively (Fig. 6.1). Crude protein level of forage species found in the SD area was significantly ($P < 0.05$) higher than in the other areas. Similarly, in 2004 CP levels differed significantly ($P < 0.05$) along the grazing gradient (Table 6.3). The highest CP level of more than 8% was recorded in the SD area. This decreased to 7% in the MSD and MD areas and to 5% in the LD area (Fig. 6.1). The only significant ($P < 0.05$) difference between CP levels in 2004 occurred between the SD and LD areas (Table 6.3). The CP content was generally higher in 2004 (Fig. 6.1).

The pooled (average of 2 years) CP level was considered to analyse the effect of the degradation gradient. Significant variation in CP levels was noted along the gazing gradient (Table 6.4). Crude protein levels were high close to the watering point and tended to decrease with increased distance from the watering point. The CP levels recorded were 5.8%, 5.4% and 4.68% for the MSD, MD and lightly degraded (LD) areas respectively (Fig. 6.2). Crude protein levels differed significantly between years (Table 6.1) and were significantly higher in 2004 compared to 2003 (Fig. 6.3).

Table 6.1 Analysis of variance of the effect of degradation and year on crude protein (CP) content of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (data) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	1416.695	1	1416.695	1182.853	0.000000
Degradation	53.864	3	17.955	14.991	0.000066
Error	19.163	16	1.198		
YEAR	35.213	1	35.213	29.596	0.000054
YEAR*Degradation	10.019	3	3.340	2.807	0.073050
Error	19.036	16	1.190		

Table 6.2 Bonferoni test to compare mean crude protein (CP) content between degradation areas in 2003 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test, Probabilities for Post Hoc Tests

Error, Between, within, pooled MS= 1.1937, df= 32.00

			Crude protein content (%)			
Cell No.	**Degradation**	**Year**	**1**	**2**	**3**	**4**
			7.21	**4.59**	**3.89**	**4.36**
1	SD	2003		0.044602	0.005438	0.02244
2	MSD	2003	0.044602		1	1
3	MD	2003	0.005438	1		1
4	LD	2003	0.02244	1	1	

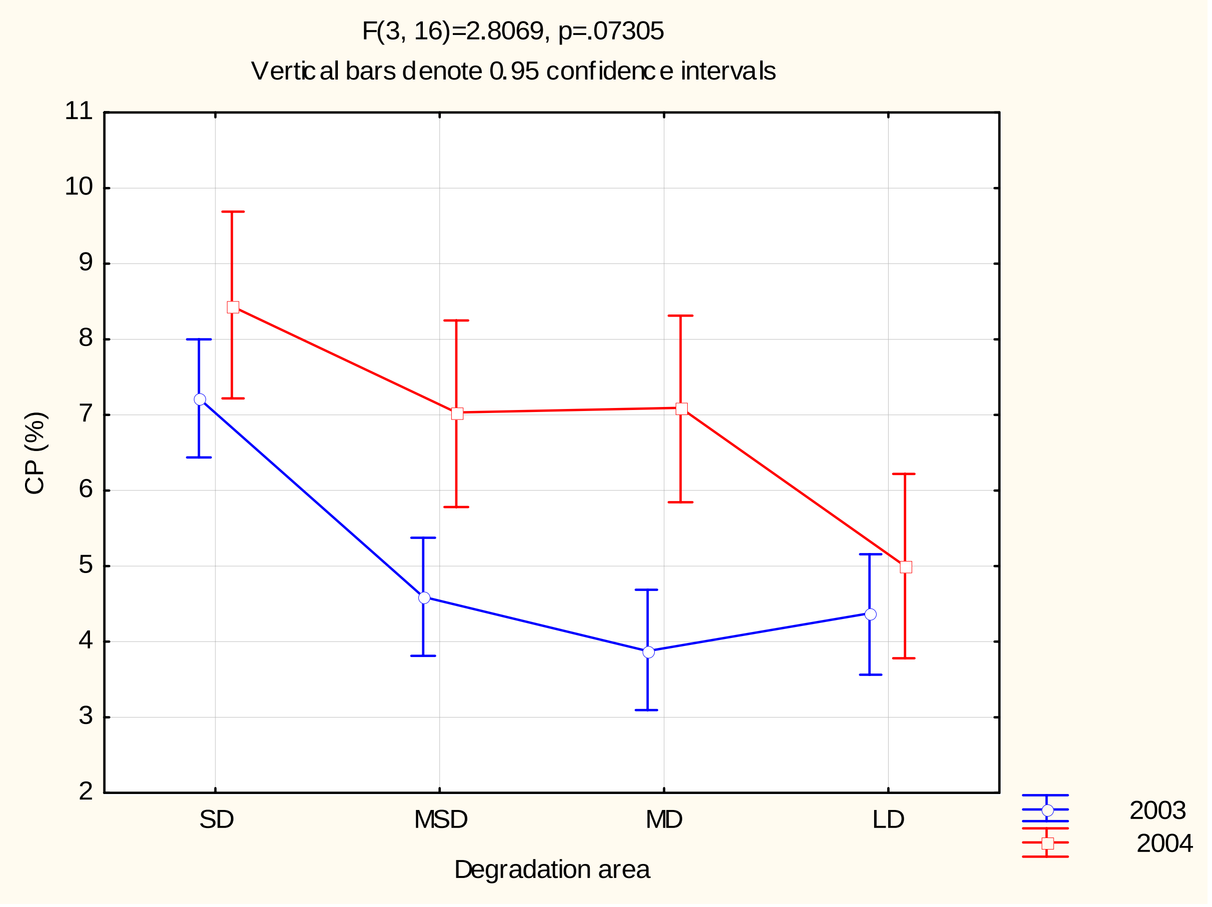

Figure 6.1 Mean crude protein (CP) content of forage samples collected from a degradation gradient in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 6.3 Bonferoni test to compare mean crude protein (CP) content between degradation areas in 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test, Probabilities for Post Hoc Tests

Error, Between, within, pooled MS= 1.1937, df= 32.00

			Crude protein content (%)			
Cell No.	**Degradation**	**Year**	**1** **8.45**	**2** **7.02**	**3** **7.09**	**4** **5**
1	SD	2004		1	1	0.003781
2	MSD	2004	1		1	0.283069
3	MD	2004	1	1		0.22793
4	LD	2004	0.003781	0.283069	0.22793	

Table 6.4 Bonferroni test to compare mean crude protein (CP) content between degradation areas (pooled for 2003 and 2004) in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable DV_1 (data) Probabilities for Post Hoc Tests
Error: Between MS = 1.1977, df = 16.000

		Crude protein content (%)			
Cell no	**Degradation**	**SD** **7.83**	**MSD** **5.80**	**MD** **5.49**	**LD** **4.68**
1	SD		0.004561	0.001209	0.000049
2	MSD	0.004561		1.000000	0.214622
3	MD	0.001209	1.000000		0.709472
4	LD	0.000049	0.214622	0.709472	

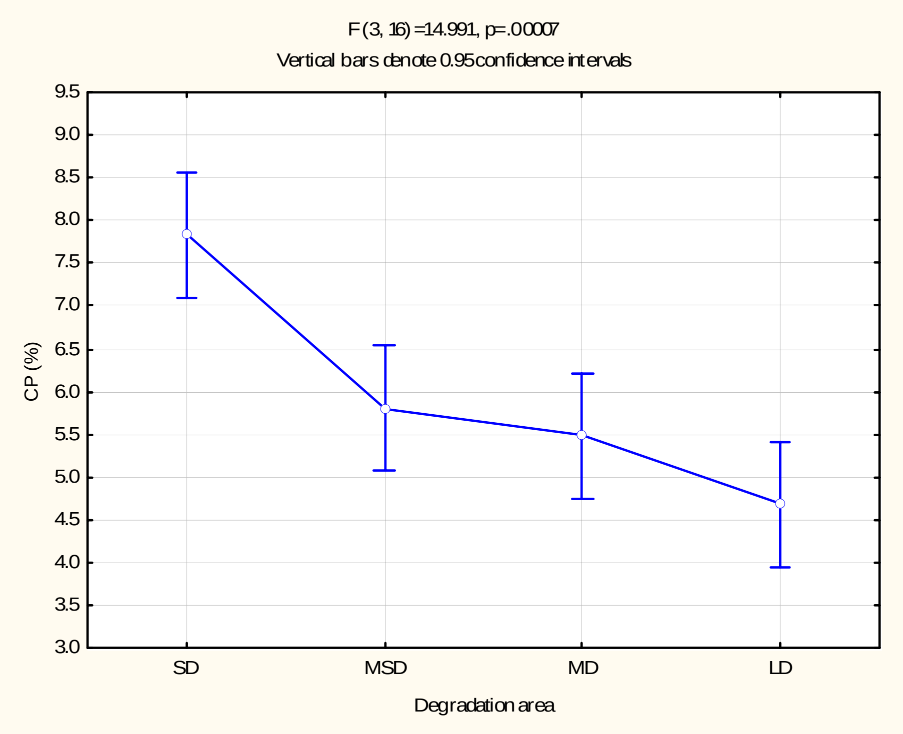

Figure 6.2 Mean pooled (2003 and 2004) crude protein (CP) content of forage samples collected from a degradation gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degradedarea).

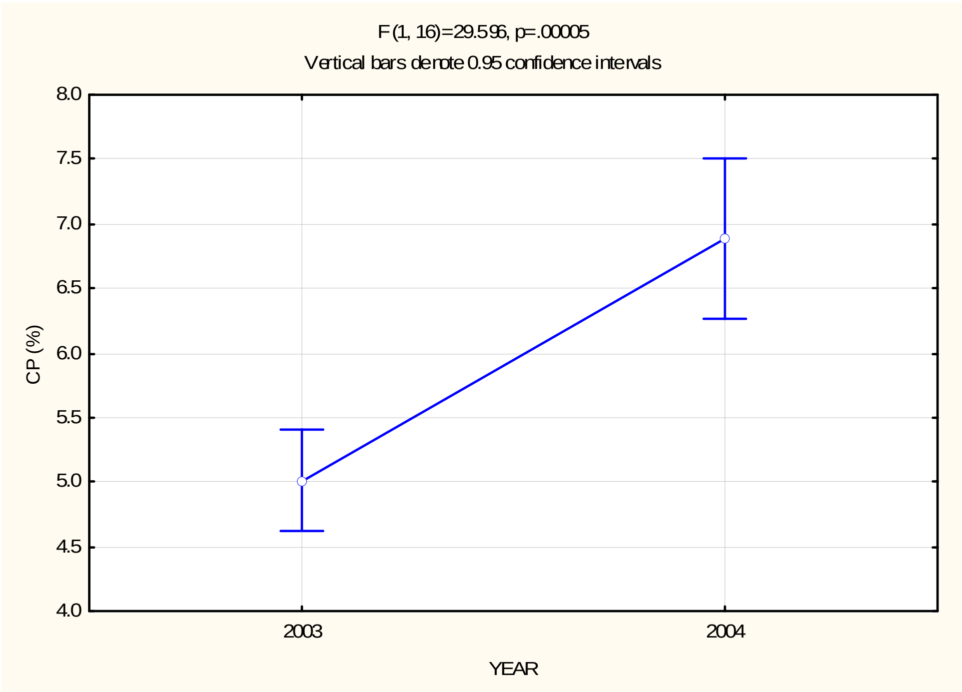

Figure 6.3 Mean pooled (degradation areas) crude protein (CP) content of forage samples collected in 2003 and 2004 in the Allaidege rangeland.

6.3.1.2 Neutral detergent fibre (NDF)

There was a significant (P = 0.02) interaction between year and gradient in terms of NDF (Table 6.5). Figure 6.4 shows that the main cause of the interaction was due to the contrasting NDF levels in the MSD area in 2003 and 2004. The 2003 NDF levels in the MSD area were significantly (P < 0.05) (Table 6.6) higher than in 2004 in the same area. Significant differences were also observed between the two years in some of the degradation gradients, but the 2004 NDF levels were generally lower than the 2003 values, indicating a better quality fodder in 2004 in terms of digestibility.

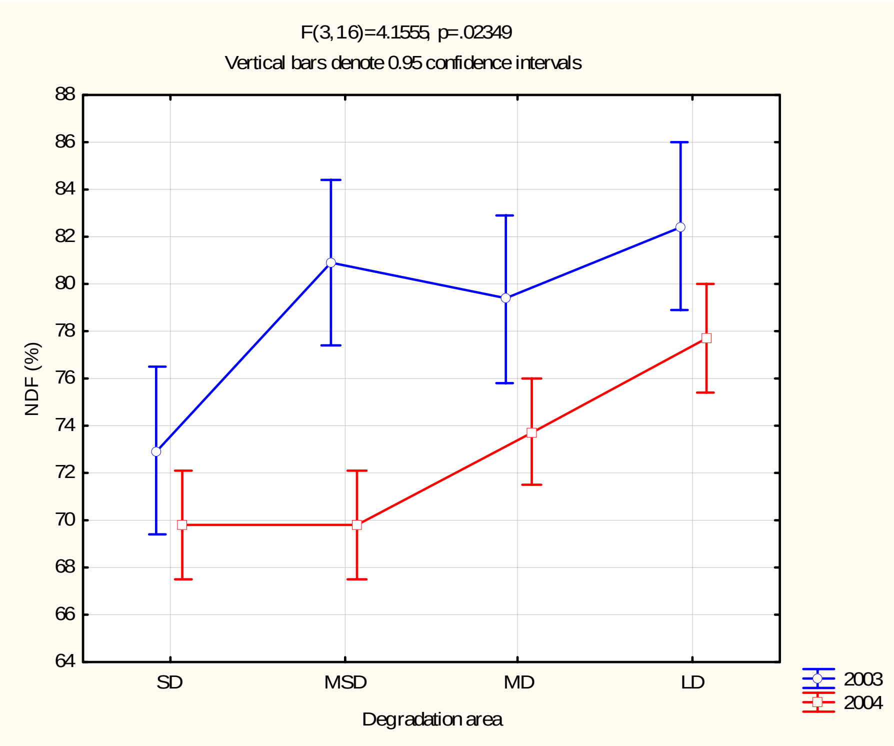

Figure 6.4 Mean neutral detergent fibre (NDF) content of forage samples collected from a degradation gradient in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 6.5 Analysis of variance of the effect of degradation and year on neutral detergent fibre (NDF) content of forages in the Allaidege rangeland

Repeated Measures Analysis of Variance (Spreadsheet13) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	230027.3	1	230027.3	18478.74	0.000000
Degradation	387.4	3	129.1	10.37	0.000492
Error	199.2	16	12.4		
YEAR	377.3	1	377.3	52.05	0.000002
YEAR*Degradation	90.4	3	30.1	4.16	0.023488
Error	116.0	16	7.2		

Table 6.6 Bonferroni test to compare mean neutral detergent fibre (NDF) contents between degradation areas in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable DV_1 (Spreadsheet13) Probabilities for Post Hoc Tests Error: Between; Within; Pooled MS = 9.8483, df = 29.915										
	Degra dation	**YEAR**	**{1}**	**{2}**	**{3}**	**{4}**	**{5}**	**{6}**	**{7}**	**{8}**
1	SD	2003		1.000000	0.071588	1.000000	0.303184	1.000000	0.016479	0.619902
2	SD	2004	1.000000		0.000128	1.000000	0.001127	1.000000	0.000014	0.076059
3	MSD	2003	0.071588	0.000128		0.000196	1.000000	0.031728	1.000000	1.000000
4	MSD	2004	1.000000	1.000000	0.000196		0.001073	1.000000	0.000014	0.073650
5	MD	2003	0.303184	0.001127	1.000000	0.001073		0.127653	1.000000	1.000000
6	MD	2004	1.000000	1.000000	0.031728	1.000000	0.127653		0.003691	1.000000
7	LD	2003	0.016479	0.000014	1.000000	0.000014	1.000000	0.003691		0.374531
8	LD	2004	0.619902	0.076059	1.000000	0.073650	1.000000	1.000000	0.374531	

6.3.1.3 Acid detergent fibre (ADF)

The ADF results were similar to the NDF results. There was again significant (P = 0.02) interaction between year and degradation gradient (Table 6.7). Figure 6.5 shows the same trend as for NDF, which is to be expected. The main cause of the interaction is again the varying response in the MSD area in the two years (Fig. 6.5). The ADF in the MSD area in 2003 was significantly (P = 0.007) higher in 2003 than in the same area in 2004 (Table 6.8 and Fig. 6.5).

Table 6.7 Analysis of variance of the effect of degradation and year on acid detergent fibre (ADF) content of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (Spreadsheet13) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	85517.18	1	85517.18	9010.908	0.000000
Degradation	290.89	3	96.96	10.217	0.000533
Error	151.85	16	9.49		
YEAR	119.68	1	119.68	11.202	0.004094
YEAR*Degradation	130.33	3	43.44	4.066	0.025209
Error	170.94	16	10.68		

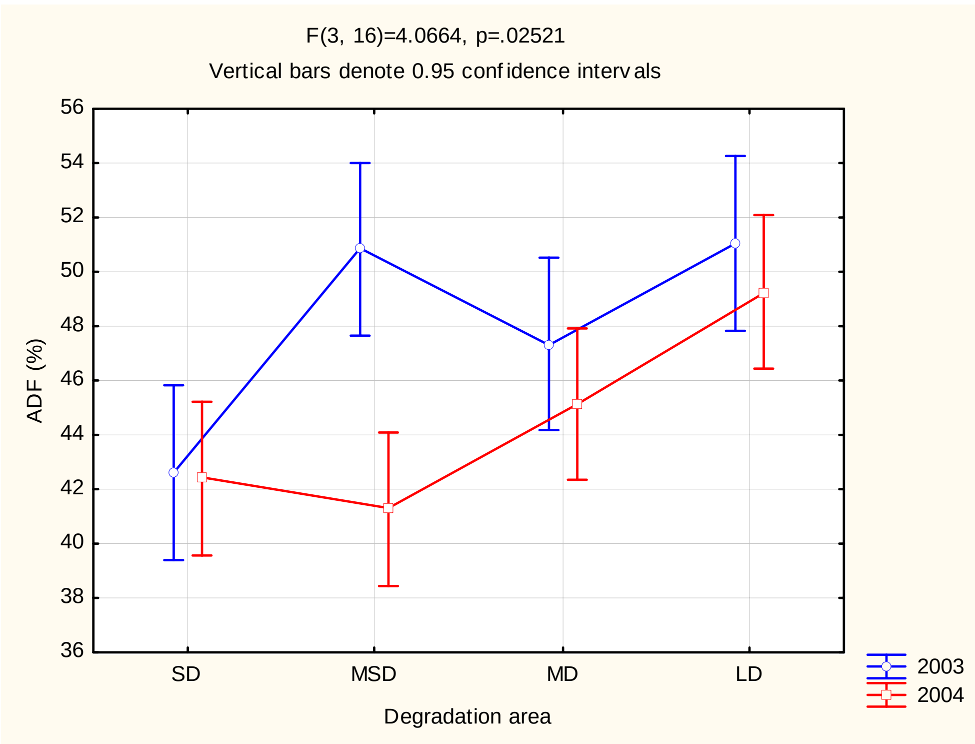

Figure 6.5 Mean acid deteregent fibre (ADF) content of forage samples collected from a degradation gradient in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 6.8 Bonferroni test to compare mean acid detergent fibre (ADF) contents between degradation areas in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable DV_1 (Spreadsheet13) Probabilities for Post Hoc Tests Error: Between; Within; Pooled MS = 10.087, df = 31.888										
	Degradation	**YEAR**	**{1}**	**{2}**	**{3}**	**{4}**	**{5}**	**{6}**	**{7}**	**{8}**
1	SD	2003		1.000000	0.018380	1.000000	0.780553	1.000000	0.014805	0.069368
2	SD	2004	1.000000		0.005575	1.000000	0.548158	1.000000	0.004189	0.082380
3	MSD	2003	0.018380	0.005575		0.007735	1.000000	0.214072	1.000000	1.000000
4	MSD	2004	1.000000	1.000000	0.007735		0.136773	1.000000	0.000821	0.024045
5	MD	2003	0.780553	0.548158	1.000000	0.136773		1.000000	1.000000	1.000000
6	MD	2004	1.000000	1.000000	0.214072	1.000000	1.000000		0.166254	1.000000
7	LD	2003	0.014805	0.004189	1.000000	0.000821	1.000000	0.166254		1.000000
8	LD	2004	0.069368	0.082380	1.000000	0.024045	1.000000	1.000000	1.000000	

6.3.1.4 *In vitro* dry matter digestibility (IVDMD)

In terms of IVDMD, there was no significant (P = 0.46) interaction between year and degradation gradient (Table 6.9). When the data of the two years was pooled, there were also no significant (P = 0.07) difference between the IVDMD values in the different grazing gradients (Table 6.9, Fig. 6.6). As was expected, considering the ADF and NDF values, there was a rather clear decreasing trend in IVDMD with increasing distance from the water point. Figure 6.7 shows that there was no significant (P = 0.13) differences between years although the IVDMD appeared a little bit lower in 2003.

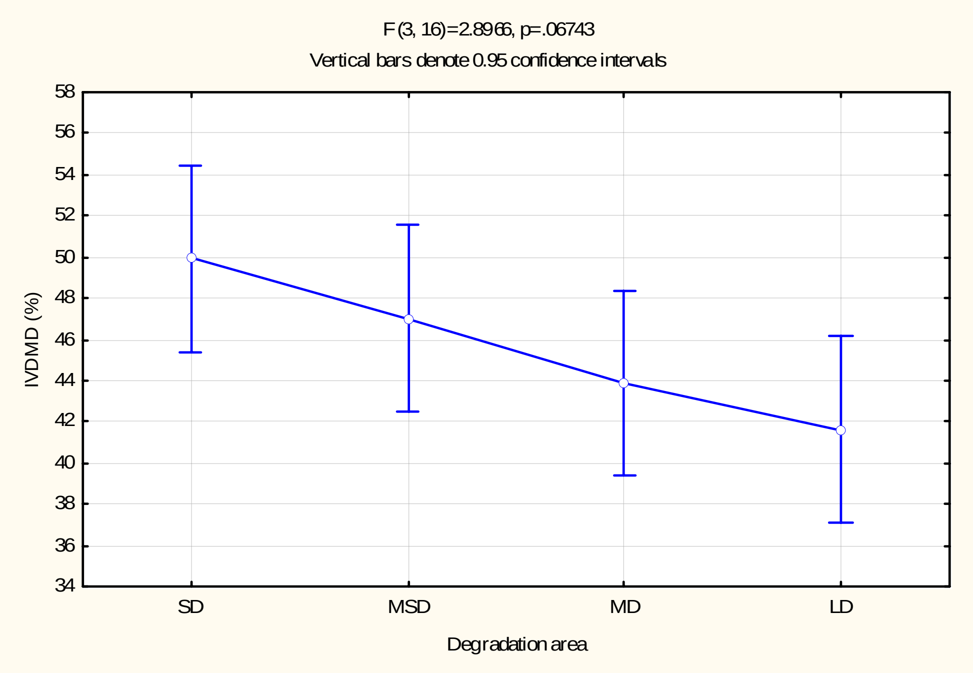

Figure 6.6 Mean pooled (2003 and 2004) *in vitro* dry matter digestibility (IVDMD) level of forage samples collected from different degradation areas in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 6.9 Analysis of variance of the effect of degradation and year on *in vitro* dry matter digestibility (IVDMD) level of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (Spreadsheet13) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Degradation	396.36	3	132.12	2.897	0.067435
Error	729.80	16	45.61		
YEAR	164.67	1	164.67	2.573	0.128227
YEAR*Degradation	173.69	3	57.90	0.905	0.460559
Error	1023.84	16	63.99		

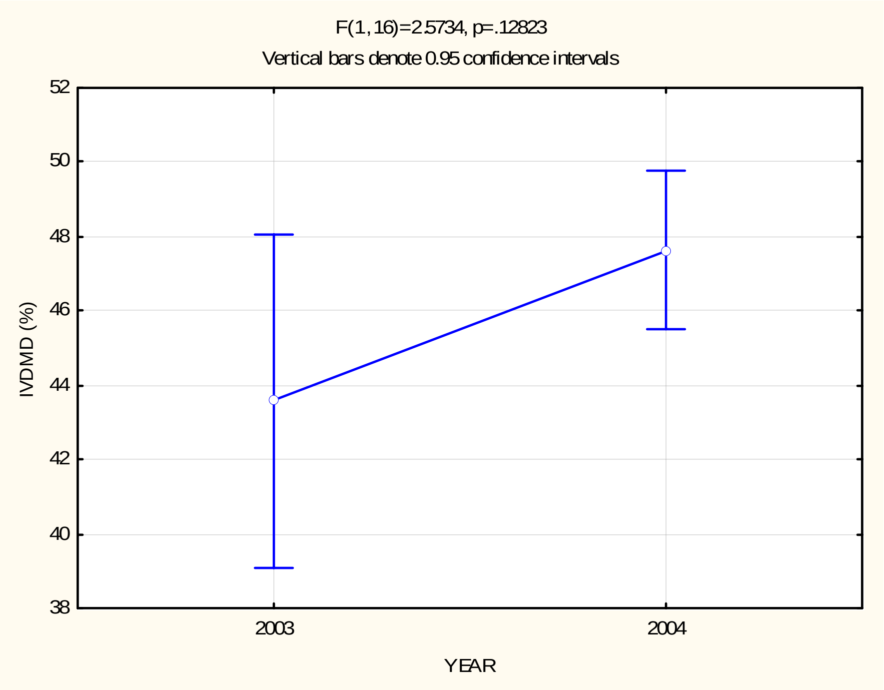

Figure 6.7 Mean pooled (degradation area) *in vitro* dry matter digestibility (IVDMD) level of forage samples collected in 2003 and 2004 in the Allaidege rangeland.

6.3.1.5 Macro elements - phosphorus (P) and calcium (Ca)

There was no significant interaction (P = 0.21) between year and degradation gradient in terms of P content (Table 6.10). The 2 years pooled average P content of the forages indicated insignificant (P = 0.10) variation along the grazing gradient (Table 6.10). However, a slight increase of P concentration of the forages was displayed along the gradient away from the watering point, where it peaked in the MD area and dropped sharply in the LD area (Fig. 6.8). The mean P concentration of the range forages ranged between 0.07% in the LD area to 0.14% in the MD area. The seasonal effect caused significant (P = 0.000) variation of P concentration in the forages (Table 6.10). The P levels varied from 0.07% P in 2003 to 0.15% P in 2004 (Fig. 6.9).

Table 6.10 Analysis of variance of the effect of degradation and year on phosphorus (P) content of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (Spreadsheet13) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	0.525097	1	0.525097	453.7751	0.000000
Degradation	0.008438	3	0.002813	2.4308	0.102916
Error	0.018515	16	0.001157		
YEAR	0.070308	1	0.070308	74.2882	0.000000
YEAR*Degradation	0.004779	3	0.001593	1.6833	0.210550
Error	0.015143	16	0.000946		

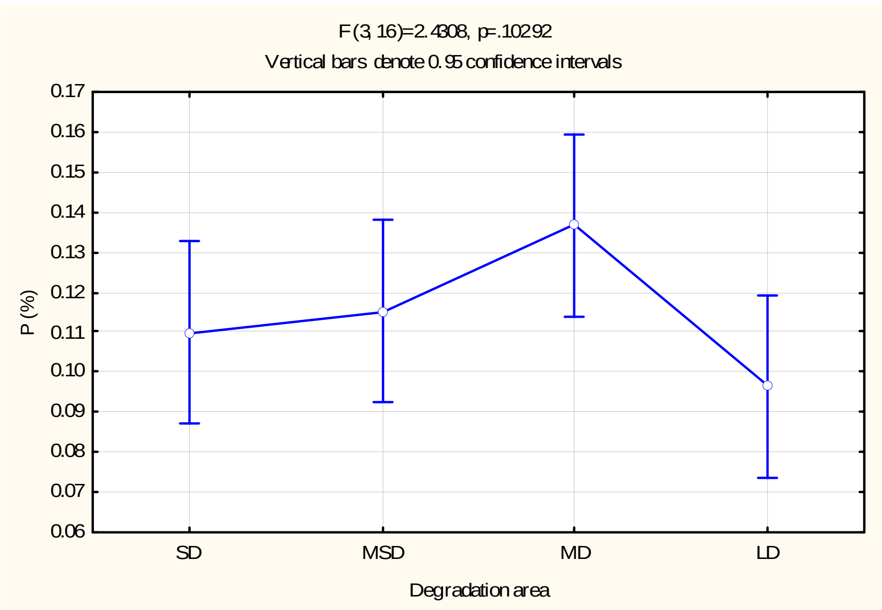

Figure 6.8 Mean pooled (2003 and 2004) phosphorus (P) content of forage samples collected from different degradation areas in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

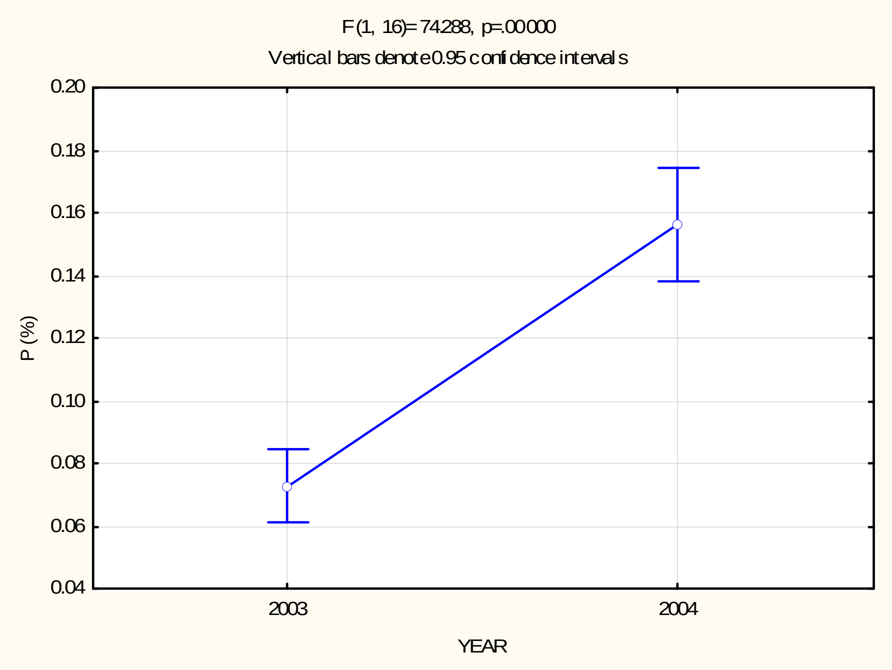

Figure 6.9 Mean pooled (degradation areas) phosphorus (P) content of forage samples collected in 2003 and 2004 in the Allaidege rangeland.

There was no significant (P = 0.45) interaction between year and degradation gradient (Table 6.11) in terms of Ca content of the fodder. Ca however displayed significant within-treatment differences for gradient (P < 0.05) and season (P = 0.019) (Table 6.11). The Ca concentration was significantly (P < 0.05) (Table 6.12) higher in the SD area compared to areas further away from the watering point (Fig. 6.10). The Ca concentration was 1.4%, 0.92%, 0.74% and 0.66% for the SD, MSD, MD and LD areas respectively (Fig. 6.10). The differences between the MSD, MD and LD areas were not statistically significant (Table 6.12). The Ca concentration in 2003 (1%) was significantly higher than in 2004 (0.85%) (Fig. 6.11).

Table 6.11 Analysis of variance of the effect of degradation and year on calcium (Ca) content of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (data) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	34.52164	1	34.52164	678.6748	0.000000
Degradation	3.16150	3	1.05383	20.7177	0.000009
Error	0.81386	16	0.05087		
YEAR	0.25921	1	0.25921	6.8233	0.018869
YEAR*Degradation	0.10477	3	0.03492	0.9193	0.453838
Error	0.60782	16	0.03799		

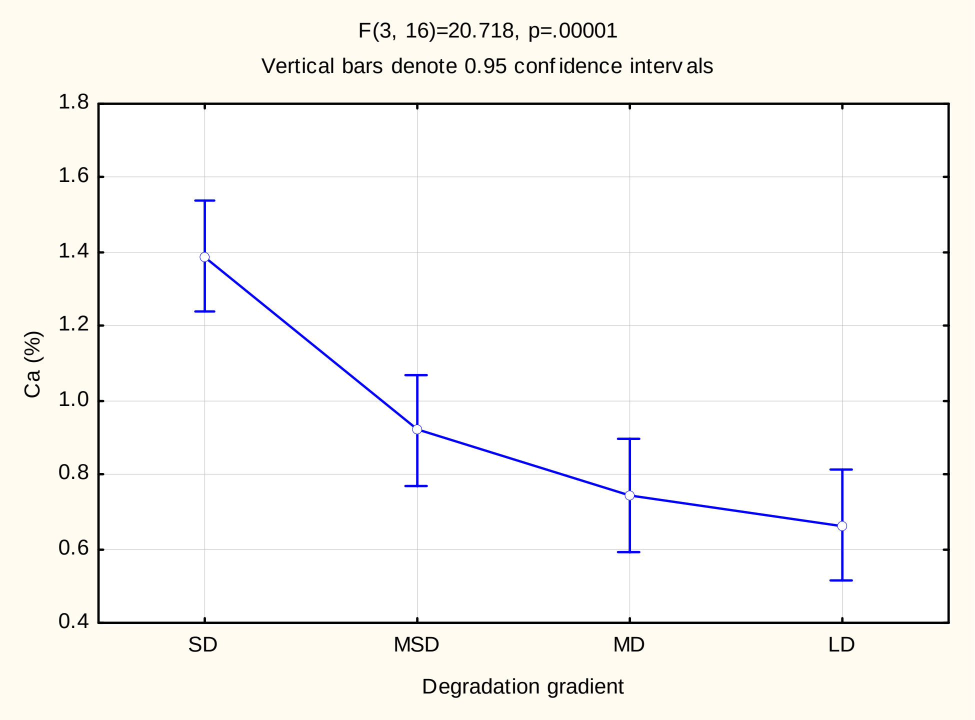

Figure 6.10 Mean pooled (2003 and 2004) calcium (Ca) content of forage samples collected from different degradation areas in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 6.12 Bonferroni test to compare mean calcium (Ca) content (pooled for 2003 and 2004) between degradation areas in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable DV_1 (data) Probabilities for Post Hoc Tests
Error: Between MS = .05087, df = 16.000

	Degradation	**SD 1.39**	**MSD .92**	**MD .74**	**LD .66**
1	SD		0.001569	0.000053	0.000013
2	MSD	0.001569		0.611712	0.134202
3	MD	0.000053	0.611712		1.000000
4	LD	0.000013	0.134202	1.000000	

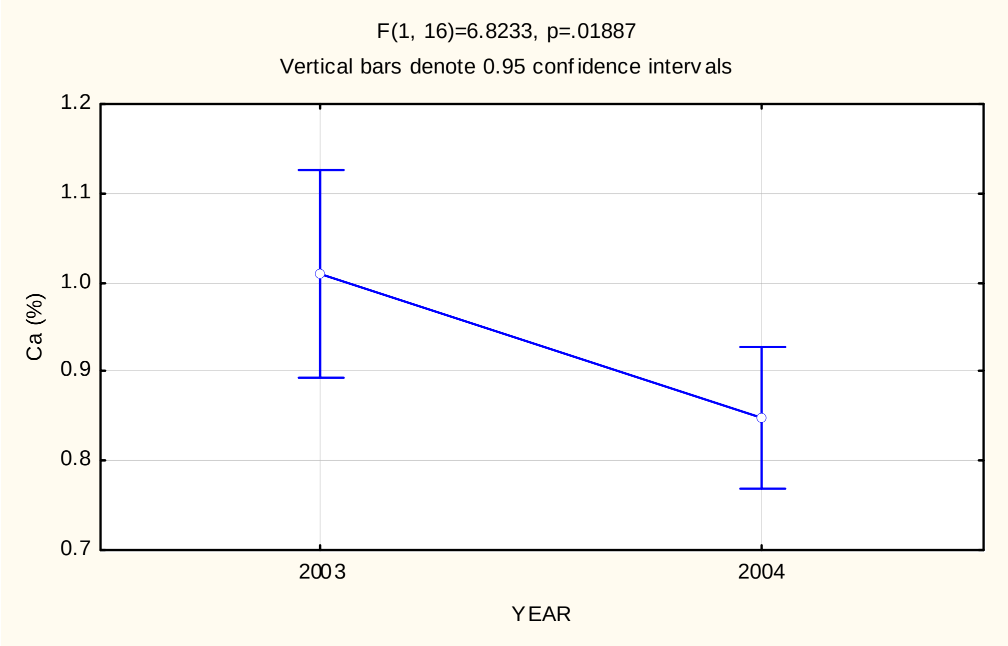

Figure 6.11 Mean pooled (degradation areas) calcium (Ca) content of forage samples collected in 2003 and 2004 in the Allaidege rangeland.

6.3.1.6 Lignin

A significant interaction (P = 0.045) occurred between year and degradation gradient in terms of lignin (Table 6.13). A high lignin level content occurred throughout the gradient in 2003 characterized by a lignin level of 6.7% in the SD area and an almost constant level along the gradient beyond the SD area (Fig. 6.12). In 2004 an inconsistent pattern occurred as portrayed in Figure 6.12. The inconsistency was noted in the pattern of decline from a lignin level of 6.3% in the SD area to a 5% level in the MSD area and then a steady increase till it peaked in the LD area (Fig. 6.12).

Table 6.13 Analysis of variance of the effect of degradation and year on lignin content of forages along a grazing gradient in the Allaidege rangeland in 2003 and 2004

Repeated Measures Analysis of Variance (Spreadsheet13) Sigma-restricted parameterization
Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	1860.223	1	1860.223	1860.549	0.000000
Degradation	8.821	3	2.940	2.941	0.064839
Error	15.997	16	1.000		
YEAR	29.860	1	29.860	29.254	0.000058
YEAR*Degradation	10.273	3	3.424	3.355	0.045275
Error	16.331	16	1.021		

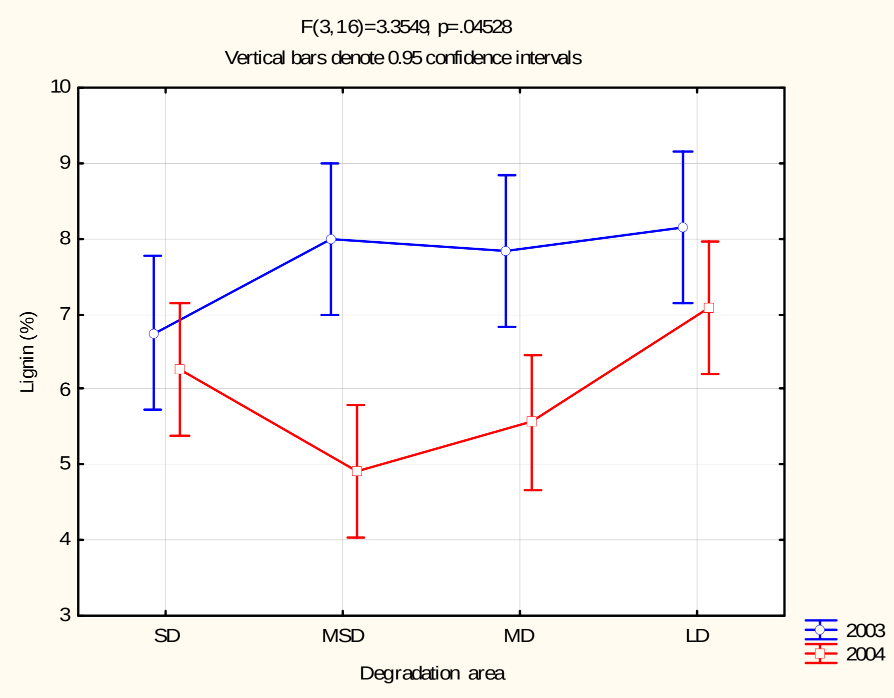

Figure 6.12 Mean lignin content of forage samples collected from a degradation gradient in 2003 and 2004 in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

6.3.2 Chemical analysis of clipped and esophageal collected forage samples

Dry matter (DM) content of the esophageal collected and hand clipped samples were significantly different (P = 0.03) (Table 6.14). Dry matter content varied from 92.9% to 92.3% for clipped and esophageal collected samples respectively (Fig. 6.13). No significant difference was observed for organic matter (OM) between the esophageal collected sample and hand clipped sample (P = 0.07) (Table 6.14). The OM content varied from 90.2% to 86.1% in the clipped and esophageal collected samples respectively (Fig. 6.13).

The ash content of the esophageal collected sample and hand clipped samples showed a difference but it was not statistically significant (P = 0.06) (Table 6.14). Ash content varied from 9.7% to 14.04% for clipped and esophageal collected samples respectively (Fig. 6.14).

Table 6.14 Summary of Anova tables for all variables when comparing the esophageal collected samples with the clipped samples of fodder in the Allaidege rangeland in 2003 and 2004

	DF	Type I SS	Mean square	F value	pr > F
DM	1	2.93446	2.93446	5.71	0.0304
Ash	1	70.75139	70.75139	4.06	0.0622
OM	1	64.85299	64.85299	3.8	0.0701
P	1	0.05464	0.05464	3.53	0.08
Ca	1	0.44401	0.44401	3.92	0.0663
ADF	1	34.68752	34.68752	3.47	0.0823
Lignin	1	5.63869	5.63869	7.35	0.0161
IVDMD	1	168.0068	168.006763	7.63	0.0145
CP	1	23.74937	23.74937	3.32	0.087
NDF	1	14.77121	14.77121	0.67	0.4238

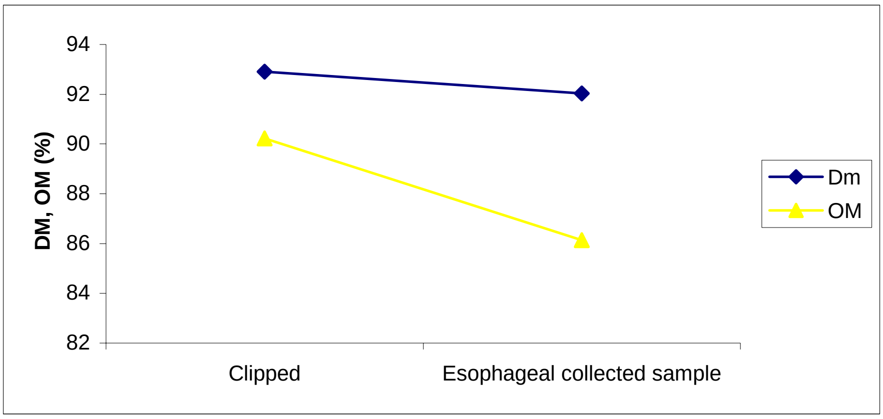

Figure 6.13 Dry matter (DM) and organic matter (OM) content of range grass samples collected by hand clipping and by esophageal fistula in the Allaidege rangeland in 2003 and 2004.

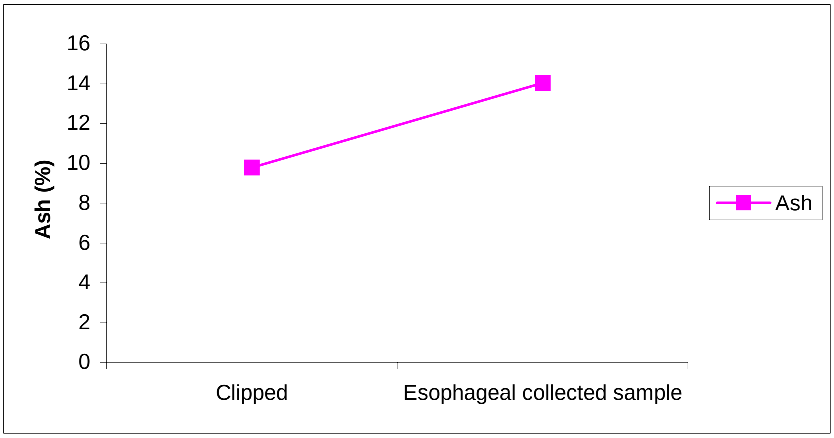

Figure 6.14 Ash content of range grass samples collected by hand clipping and by esophageal fistula in the Allaidege rangeland in 2003 and 2004.

The NDF analysis showed no significant differences in esophageal collected and hand clipped samples (P = 0.42) (Table 6.14) but the ADF analysis showed almost significant differences (P = 0.08) (Table 6.14). In contrast to the cell wall components, lignin differed significantly (P = 0.016) between esophageal collected and hand clipped samples (Table 6.14). The lignin content was 8.87% and 7.66% for hand clipped and esophageal collected samples respectively (Fig. 6.15).

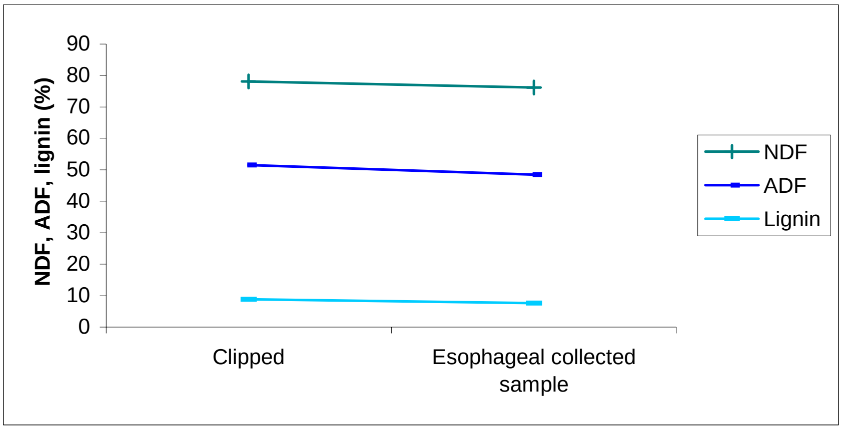

Figure 6.15 Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin contents of range grass samples collected by hand clipping and by esophageal fistula in the Allaidege rangeland in 2003 and 2004.

Regarding the CP content, no significant difference was detected between esophageal-collected samples and hand clipped samples (P = 0.087) (Table 6.14). CP showed an increasing trend from 3.5% to 6.0% from clipped to esophageal-collected samples respectively (Fig. 6.16). Although the CP content of clipped and esophageal collected samples did not differ significantly, the biological difference in terms of animal performance is important. A CP level of 6% is considered the minimum for sustained animal performance whereas a level of 3.5% would lead to serious loss of condition (Milford & Haydock, 1965).

IVDMD showed significant differences (P = 0.0145) between clipped and esophageal collected samples (Table 6.14). The IVDMD varied from 35.5% to 40% for clipped and esophageal collected samples respectively (Fig. 6.16).

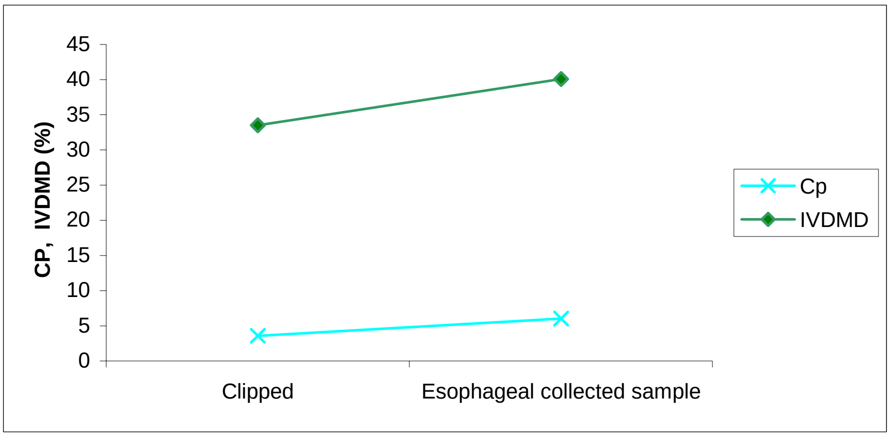

Figure 6.16 Crude protein (CP) and *in vitro* dry matter digestibility (IVDMD) of range grass samples collected by hand clipping and by esophageal fistula in the Allaidege rangeland in 2003 and 2004.

The P and Ca content showed no significant differences (P > 0.05) between clipped and esophageal fistula collected samples (Table 6.14). The P content varied from 0.10% to 0.22% and the Ca content from 0.34% to 0.67% for clipped and esophageal fistula samples respectively (Fig. 6.17).

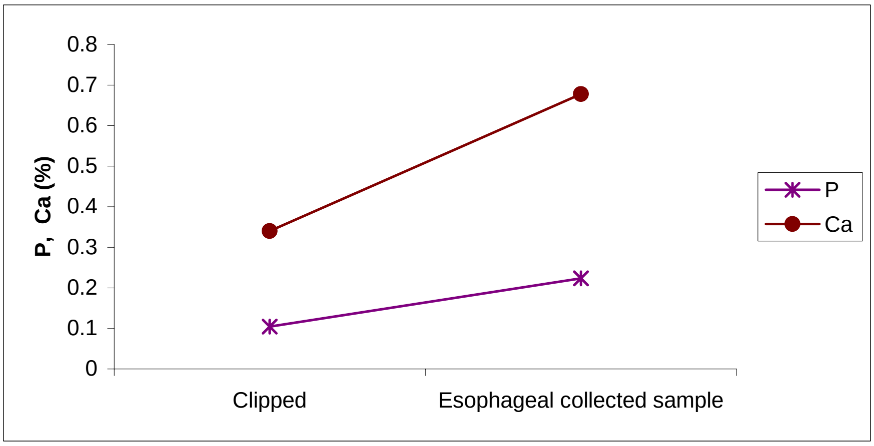

Figure 6.17 Phosphorus (P) and calcium (Ca) content of range grass samples collected by hand clipping and by esophageal fistula in the Allaidege rangeland in 2003 and 2004.

6.4. Discussion

6.4.1 Chemical analysis of forage samples

The most important factor controlling forage quality is the age of the plant and stage of growth (Tainton, 1981). The ageing of leaves and reduction in leaf to stem ratio are also major causes of forage quality decline (Tainton, 1981; Van Soest, 1982). As plants grow there is a greater need for structural tissues, therefore structural carbohydrates (cellulose and hemicellulose) and lignin increase (McDonald, Edwards & Greenhalgh, 1988). Concomitantly, as plants age/mature the concentration of protein decreases. In addition to the changes in CP and carbohydrates, changes also occur in the mineral constituents of the forage at maturity (McDonald *et al.,* 1988). Van Soest, (1982) has reported the increase in crude fibre (CF) to be attributed to plant maturity. This is probably the reason for differences observed both in NDF and ADF levels in 2003 and 2004 where fibre concentration in 2003 was high throughout the gradient. This was due to a 30 days delay in harvest in 2003. This eventually resulted in increased structural carbohydrates and reduced leaf - stem ratio. In both seasons, the grazing gradient revealed a decrease in NDF and ADF content close to the watering point. The result was in contrast to Nsinamwa, Moleele and Sebego (2005) who reported an increased CF content close to watering points.

Basically the difference in this study is due to the abundance of annual species found close to the watering point in the SD area. The grazing area was dominated by the annual grass, *Setaria verticillata,* which has a relatively good nutritional status. Van Oudtshoorn (1999) reported the ability of the species to retain its nutritional value even when mature and dried out. Further away from the watering point the annual grass component decreased and perennial grasses, which are more fibrous at maturity, as was revealed in the NDF and ADF contents, dominated. The other main component of the vegetation near the watering point were legume annuals which exhibited lower levels of cell wall components, in agreement with the studies of Meissner, Zacharias and O'Reagain (1999) and Vallentine, (2001). In general abundance of annual herbaceous species greatly influences forage quality of rangeland (Alami *et al*., 1997).

Increased fibre content also resulted in a decline in CP content in this study, confirming the reciprocal relationship between CP and CF content reported by McDonald *et al.* (1988). This was evident from the dominant annual grass and edible annual forb abundance in the SD area close to the watering point. However, beyond the SD area, the decrease in occurrence of the annual species did contribute to the very low prevalence of CP content of the vegetation in the area. In agreement with these results, Frost and Smith (1991) emphasized that annual species provide high quality forage. This study was also in close agreement with Nsinamwa *et al*. (2005) who reported the significant variation of CP with distance and the decrease in CP with increased distance from water. The low CP content of the vegetation in less degraded areas was exacerbated by the low contribution of total dry matter by the annual species. In addition, the perennial species, which are dominant in this area, tended to have a large proportion of the total dry matter contributed by stem material at maturity.

The CP comparison of the two years showed statistically significant differences. High CP levels were recorded for 2004 throughout the gradient. This was attributed to the delayed development (maturity) of the plants due to low rainfall as well as the fact that the plants were harvested 30 days earlier than in 2003. Van Soest (1982) has reported the delay in development and maturity of plants due to water stress. The 2004 year was drier than 2003, due to the fact that the amount of precipitation recorded in 2003 was 372.6 mm, which was 55.6 mm more than 2004. The SD and MSD areas met the 6-7% CP dietary requirements level of livestock suggested by Milford and Haydock (1965). This was ultimately achieved due to the contribution of the annual grasses and forbs that formed the major component of the vegetation in these grazing areas. However, the low forage production attained from these areas is a constraint exacerbated by the large communal livestock population in the area. This can only be rectified by urgent corrective measures such as de-stocking of animals. This can be achieved by creating greater awareness of the problem and the establishment of enough convenient market outlets.

On the other hand, the MD and LD areas had a slightly lower range of CP levels of 5-5.5%. Similarly, Seyoum and Zinash (1989) reported corresponding CP levels for native hay in Ethiopia. In both cases, the 2 years pooled mean CP content of the grazing gradient was considered.

Currently the grazing utilization of the SD and MSD areas by the community takes place early in the rainy season at an early growth stage. This is a deliberate strategy to exploit the lush green vegetation of the area relative to the grazing areas further away to achieve better performance of the animals. Late in the season, when the area has been completely over utilized, animals are moved to areas further away form the watering point. The varying species composition and nutritive value contents of the different grazing gradients should be considered in planning an alternative grazing system. Early or late grazing in particular areas could be planned to alleviate the late season milk drop of the livestock experienced in the area, while at the same time providing an extended rest period in the SD and MSD areas to facilitate good plant establishment and cover.

The pooled mean data revealed insignificant variation of P along the gradients. However, a steady increase was recorded from the SD to the MSD areas. This increase in concentration can be explained from the soil analysis data, which showed a mean range of soil P concentrations ranging from 37.4 meq 100 g^{-1} in the SD area to 46.2 meq 100 g^{-1} in the MSD area. Reid and Horvath (1980) and Norton (1982) reported that concentration of minerals in herbage corresponds to the mineral concentration in the soil. P contents varied significantly between 2003 and 2004. Two-fold higher P concentrations were recorded in 2004. This could be attributed to the 30 days earlier harvest carried out in 2004. This could be due to the seasonal P concentration variation caused by the maturity of the vegetation. McDonald *et al.* (1988) reported changes in mineral constituents with forage maturity. Little (1982) reported that changes in mineral content that occur with plant maturity were largely related to changes in leaf and stem proportions.

Contrary to P levels, Ca occurred in high concentrations in the SD area. In general the high Ca content of soils of arid regions was reported by different researchers (Tisdale & Nelson, 1966; Brady, 1974). In this study, it was apparent from soil analysis data that high concentrations of cations occurred in the experimental site in general and in particular in the SD area (See Chapter 7). Additionally, in the SD area the herbaceous species composition, consisting predominantly out of annual grasses and forbs, could play a role. The high Ca content of edible forbs (Ca concentration of *Ipomoea sinensis* = 2.22%) compared to grasses was evident from the analyses made in the study. High Ca concentrations in 2003 were ascribed to forage maturity during harvest. As plants mature, the stems make up a larger proportion of the total dry matter (Van Soest, 1982; Nsinamwa *et al.*, 2005). Calcium as structural component of cell walls was also reported by Thompson and Troeh (1978). Evaluating the concentration of these minerals with regard to dietary requirements of growing animals, Ca levels in all the grazing gradients was higher than the dietary requirement level provided by Little (1982). In contrast, P levels were below the required dietary level of 0.24 percent (ARC, 1980) in all the gradients. P deficiency could be associated with subnormal growth, rickets in growing animals and poor fertility, dysfunction of ovaries and reduction of milk yield in cows (McDonald *et al.*, 1988).

Digestibility of grasses is also one of the main factors determining nutritive value of forage (McDonald *et al*., 1988). Digestibility in tropical grasses continuously decline with advanced maturity (Norton, 1982). From the 2 years pooled average data, the IVDMD percentage was high for the SD area. This is linked to the low fibre content of the forage species close to the watering point. Norton (1982) reported low rates of decline in digestibility of *S. verticillata* compared to other species. The high IVDMD also has a relationship with low lignin contents of the forages in the SD and MSD areas. Van Soest (1982) also reported a close relationship between lignin and cell wall digestibility across species. The areas far from the watering point had low IVDMD percentages attributed to high fibre content of the forage in the area. Tainton (1981) also reported low digestibility in tropical grasses with high fibre contents.

6.4.2 Chemical analysis of clipped and esophageal collected forage samples

Forage selected by grazing animals has been collected for nutritional analysis since the development of the esophageal fistula (Torell, 1954). This study was carried out with the assumption that forage samples collected from the esophagus are more representative of forage consumed than hand collected samples (Van Dyne & Torell, 1964). However, forage samples obtained from an esophageal fistula are changed by saliva and mastication.

Significant differences were revealed for dry matter content between hand clipped and esophageal collected forage samples. This is consistent to the findings of Wallace, Hyder and Van Dyne (1972). Similarly, the high ash content attained for esophageal-collected samples in this study was consistent to reports from many researchers (Barth *et al.*, 1970; Barth and Kazzal 1971; Wallace *et al.*, 1972). All these reports attributed the high ash content of esophageal-collected samples to contamination with saliva with a high mineral content.

In this study the ADF content of the esophageal collected sample was lower than that of the hand clipped sample although not significant at $P = 0.05$. In the case of ADF, as well as ash, OM, CP, P and Ca, differences between hand clipped samples and esophageal collected samples was not significant at the $P = 0.05$, but was significant at $P = 0.1$. This indicates that the differences between the samples were quite substantial, but just not big enough to be significant at the 5% level. Possible reasons for the lack of significance at the 5% level may be the small number of replicates used in the esophageal collected samples. Due to unforeseen problems, only two steers were available to be used as experimental units. Therefore high variation occurred and prevented significant differences at the 5% level to occur. The trends however show that, had a bigger number of steers been used, differences should have been significant for most parameters measured.

Similar studies by Scales *et al.* (1974), reported a significant increase ($P < 0.05$) in ADF contents of forage collected through esophageal fistula in one year and non-significant ($P < 0.05$) the other year due to limited number of samples collected. In contrast Barth *et al*. (1970) and Barth and Kazzal (1971) revealed an increase of ADF in esophageal-collected samples. A similar report by Scales *et al*. (1974) on increased lignin content of forage in esophageal-collected samples was made, which is inconsistent with this study where there was a significant decrease in lignin content of esophageal collected samples.

No significant difference in CP content was observed between esophageal collected samples and hand clipped samples ($P = 0.08$) in this study. Scales *et al*. (1974) also reported similar findings where they observed small differences between samples. Though controversial, increased CP contents in esophageal-collected samples due to salivary contamination were reported by different researchers (Campbell *et al.*, 1968; Barth & Kazzal, 1971). On the other hand Galt and Theurer, (1976) concluded that the contribution of nitrogen from salivary sources is not sufficient to cause significant differences in CP content of the samples. In this study, there were no statistically significant differences in CP content between samples. However, when nutritional aspects of animals are considered, differences are more substantial. A CP content of 6 % in animal feed has an ill effect on the performance of an animal. This is because protein content of forages imposes a severe physical restriction by limiting intake when total protein contents is less than 6-7% (Milford & Haydock, 1965). However, a 6% CP level is far better for animal nutrition than the 3.5% level detected in the clipped samples. This could be an indication that animals select far superior quality forage compared to the hand clipped samples.

Invitro dry matter digestibility showed significant differences between hand clipped and esophageal collected samples. This agrees with the finding of Barth and Kazzal (1971) but a report by Scales *et al*. (1974) showed a non-significant increase IVDMD of esophageal collected samples. Conversely, Barth *et al.* (1970) showed decreased IVDMD of alfalfa samples collected from esophageal fistulas.

Higher levels of P content in esophageal-collected samples were reported in this study but it was not statistically significant. Scales *et al*. (1974) reported significantly higher levels of P in esophageal fistula collected samples. In general it appears as if the animals select a higher quality fodder than what is harvested by hand. Statistical analysis within the different collection periods was not possible due to the limitation of the low number of samples.

In conclusion, the study showed that there was differences in rangeland forage quality over the degradation gradient. In most quality parameters (CP, IVDMD, CF) the nutritive quality of the range forage close to watering point was better than forage further from the watering point. This effect is probably enhanced by the ability of animals to select better quality forage than is evident from hand clipped samples. The hypothesis that was tested was therefore rejected.

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CHAPTER 7

IMPACT OF GRAZING AROUND A WATERING POINT ON THE SOIL STATUS OF THE ALLAIDEGE RANGELAND IN NORTH-EASTERN ETHIOPIA

7.1 Introduction

The importance of soil as a reservoir of nutrients and moisture for the production of forage has been recognized since the beginning of range management as a science (Klemendson, 1970). Partial heterogeneity in nutrient availability affects not only the spatial patterning of vegetative cover but overall community structure and productivity (McNaughton, Wallace & Coughenor, 1983; Schlesinger *et al.,* 1990). Heterogeneity of nutrients levels in rangeland soils results from variability in native chemical and physical soil properties, fertilizer application patterns and the distribution of animal excreta (West *et al*., 1989). Soil physical properties are important characteristics that help determine the nutrient supplying ability of soil solids and the supply of water and air necessary for plant growth (Brady, 1990). Among the physical properties, soil textural class is of particular importance. Finer textured soils are reported to have higher porosity than coarse and medium textured soils (Brady, 1990).

Sandy soils are usually permeable to air, water and roots, but are limited by low water holding capacities and poor soil nutrient storage. The limited capacity of sandy soils to store water and plant nutrients is related to the small surface area of the soil particles (Thompson & Troeh, 1978). Contrary to this, clay is associated with large surface area of soil particles and is also negatively charged that makes it active in physicochemical processes. The large surface area and the negatively charged sites cause clay to have relatively high water holding capacities and the capacity to hold plant nutrients on the surface (Thompson & Troeh, 1978). The plant nutrients are those exchangeable cations that neutralize the excess negative charge of the soil clay particles (Hillel, 1971). This concurrently implicates the important aspect of cation exchange capacity (CEC) as potential component of soil fertility (Thompson & Troeh, 1978).

Organic matter (OM) is another important component of soil that serves to bind cations and prevent them from leaching, binds soil particles together and increases soil moisture holding capacity. It is also a major soil source of phosphorus (P) and sulfur (S) and the primary source of nitrogen (N) (Brady, 1990).

Another important factor of soil is the soil pH. The physical and chemical condition of soil is also related to pH. The soil pH influences the rate of plant nutrient release by weathering, solubility of all materials in the soil and the amount of nutrient ions stored on the cation exchange sites. Usually the optimum pH is between 6.0 and 7.5 in which all plant nutrients are available (Thompson & Troeh, 1978).

According to Halcrow (1989), the Allaidege rangeland soil is characterized by fine silt loam and silt clay loam textural fractions at the surface horizons. In some areas the soils appear to be darker heavier soil while other areas exhibit siltier and slightly lighter colored soils, which appear to coincide with the presence of strongly calcareous sub soils.

Despite the soil textural survey and report on overgrazing around watering points, no in depth study was undertaken with regard to the rangeland soil status. Many researchers have however revealed the relationship of physical and chemical properties of rangeland soil with grazing impact (Johnston, Dormaar & Smoliak, 1971; Smoliak, Dormaar & Johnston, 1972; Dormaar, Smoliak & Willms, 1990; Dreccer & Lavado, 1993; Profitt *et al*., 1993; Mathews *et al.*, 1994). Other researchers have also discussed the soil nutrient status of rangeland along the grazing gradient around watering points. Different spatial scales were suggested for the concentration of soil nutrients, but generally accumulation takes place in the proximity of the watering point (Tolsma, Ernst & Verwey, 1987; Turner, 1998).

The Allaidege rangeland has a lack of soil information for use in management planning and in the improvement or rehabilitation of the deteriorated and degraded rangeland. Therefore this study was initiated to determine the influence of long term livestock grazing on soil status of the rangeland along a grazing gradient from a watering point.

The objective of the study was to investigate the impact of livestock around a watering point on the rangeland soil status. The hypothesis tested was: there is no difference in the rangeland soil status at increasing distances from the watering point.

7.2 Materials and methods

The collection of the samples was carried out in the early dry season of 2003. Soil samples were collected from each plot in the different degradation areas (severely degraded area = SD, moderately to severely degraded area = MSD, moderately degraded area = MD and lightly degraded area = LD) from three sampling points at a depth of 0-15 cm because most grass roots are found with in this layer. A composite sample of 300-500 g sub-samples was prepared for analysis and the sample was oven-dried and ground to pas a 2 mm stainless steel sieve to remove foreign bodies that do not contribute to soil properties. Soil samples were analyzed for chemical and textural properties at the Werer Agricultural Research Center (WARC) laboratory in Melka Werer. Analyses were done for organic carbon (OC) content, total N, available P, exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), pH, CEC and particle size distribution (clay, silt and sand) following standard procedures. Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934) and soil texture was determined by the hydrometric method (Gee & Bauder, 1979). Soil pH was measured by means of a pH meter in a 1:1 (v/v) soil: water suspension (Mclean, 1973) while available P was determined by means of the Olsen method (Olsen & Dean, 1965) and measured by means of atomic absorption spectrometry (AAS). Total N was determined by the Kjeldahl method (Bremner, 1960). Cation exchange capacity was analysed by titrating ammonia, which occupy all the exchangeable cation sites after extraction with 1N ammonium acetate at pH 7 (ammonium acetate method). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were determined according to Schollenberger and Simon (1945) and the leachate was analysed for the cation concentrations by atomic absorption spectrometry (AAS). Electrical conductivity (Ec) was according to Rhoades (1982).

7.2.1 Statistical analysis

One-way ANOVA was used to compare averages between the different degradation areas. Bonferroni multiple testing was used for comparing pairs of degradation areas. In some cases where the data appeared to violate the ANOVA assumptions, the non-parametric bootstrap method (again using Bonferroni multiple testing) was used. Correlation analysis was done with soil parameters to investigate if soil impact has any relation to herbage yield. Due to the nature of the data, non-parametric Spearman correlations were used.

7.3 Results

7.3.1 Texture and electrical conductivity

The analysis showed no significant differences ($P > 0.05$) in clay, silt and sand contents of the soil along the grazing gradient implicating the uniformity of the parent material. However, clay content was slightly higher in MSD area, whereas the sand content was higher in the SD area (Fig. 7.1). Significant differences ($P < 0.05$) were observed for electrical conductivity (Ec) between the SD and LD areas, but not between the MSD and MD areas. The Ec recorded was 0.81 ds m^{-1} for the SD and 0.61 ds m^{-1} for the LD areas (Table 7.1 and Fig. 7.2)

7.3.2 Organic carbon, total nitrogen, available phosphorus and available potassium

No significant differences ($P > 0.05$) was observed in OC, total N, available P and available K along the grazing gradient, despite the gradual consistent increasing trend displayed for OC and N (Fig. 3.3 and 7.4). The recorded concentration of OC was 0.79%, 0.84%, 0.84% and 0.94% for the SD, MSD, MD and LD areas respectively (Fig 7.3). Similarly, the total N concentration was 0.06%, for the SD, 0.07% for the MSD, 0.07% for the MD and 0.09% for the LD areas (Fig. 7.4). Available P showed a similar increase but declined in the LD area (Fig 7.5), whereas the available K stayed almost constant along the grazing gradient (Fig 7.6).

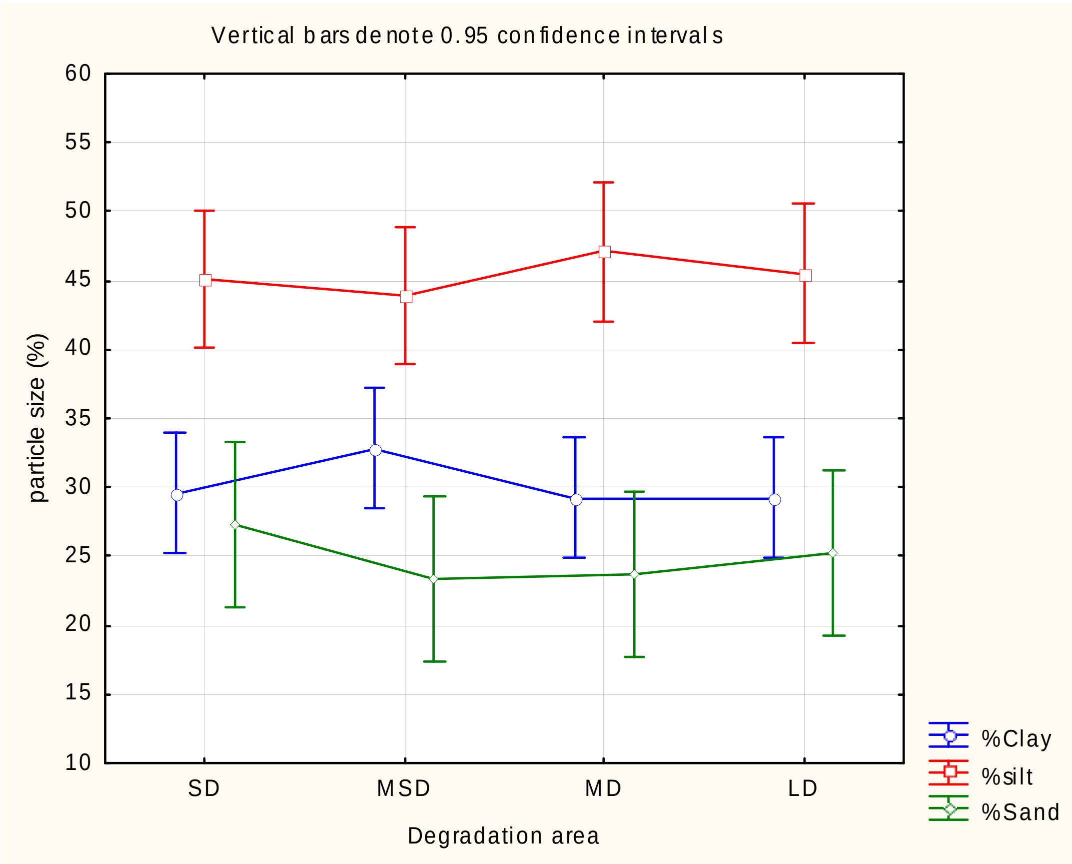


Figure 7.1 Particle size distribution of soil along the grazing gradient from a watering point in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 7.1 Bonferroni test to compare electrical conductivity (Ec) of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable ds/m (Spreadsheet270) Probabilities for Post Hoc Tests Error: Between MS = .01023, df = 16.000					
	Degradation	SD 0.812 d sm^{-1}	MSD 0.738 d sm^{-1}	MD 0.78 d sm^{-1}	LD 0.608 d sm^{-1}
1	SD		1.000000	1.000000	0.034217
2	MSD	1.000000		1.000000	0.354278
3	MD	1.000000	1.000000		0.096759
4	LD	0.034217	0.354278	0.096759	

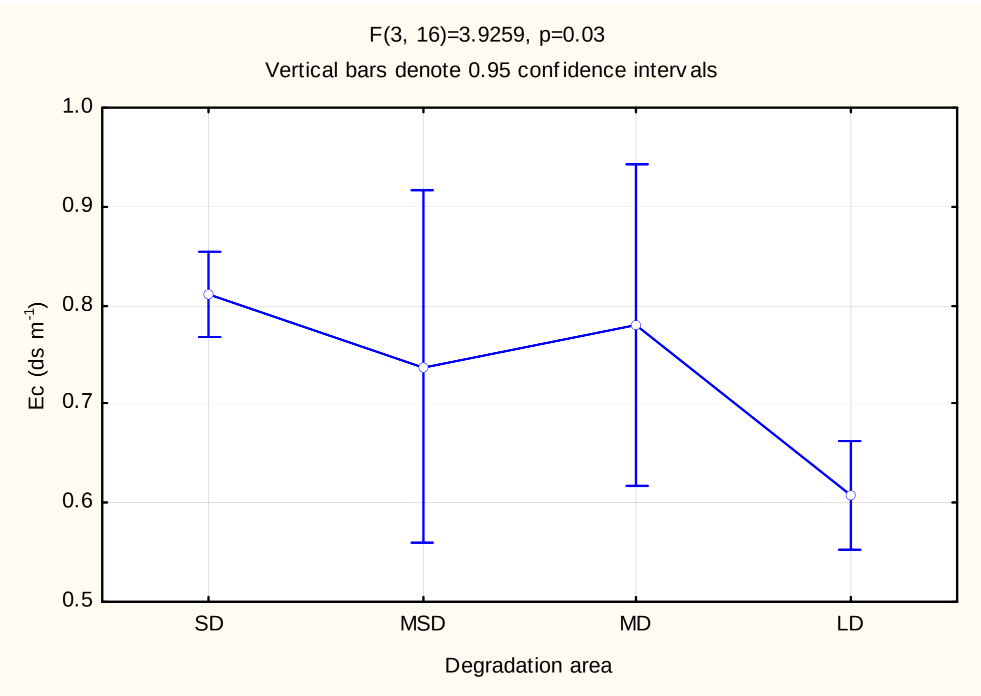


Figure 7.2 Electrical conductivity (Ec) of the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

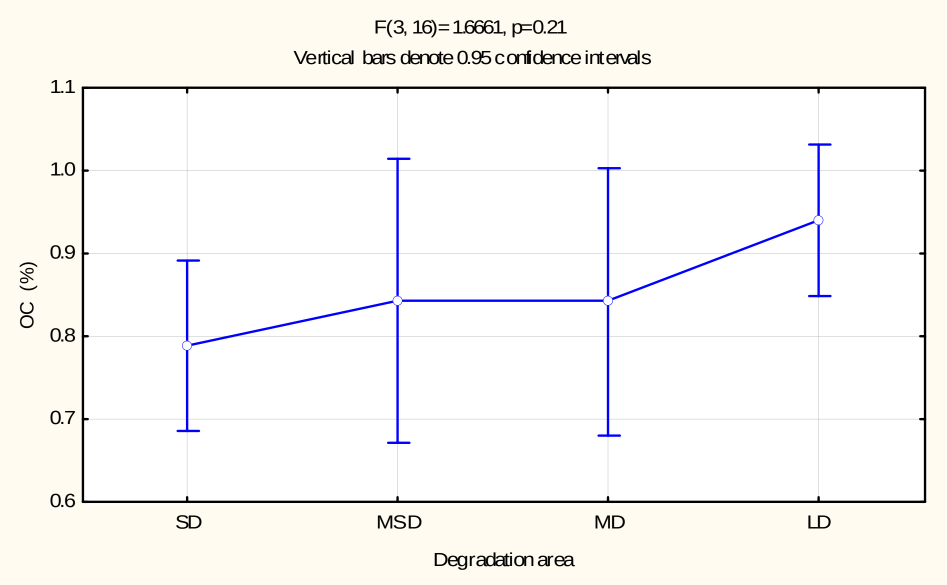


Figure 7.3 Organic carbon (OC) content of the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

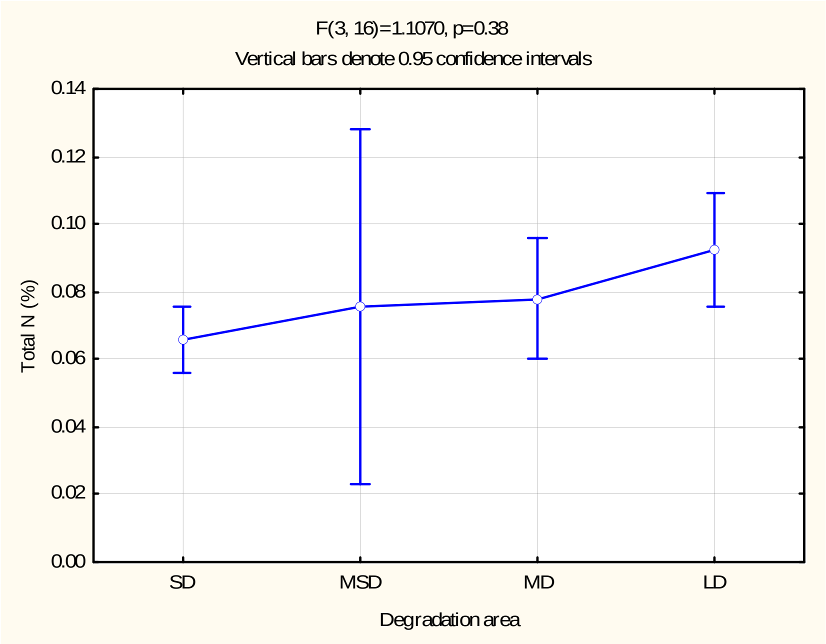


Figure 7.4 The average total nitrogen (N) content of the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

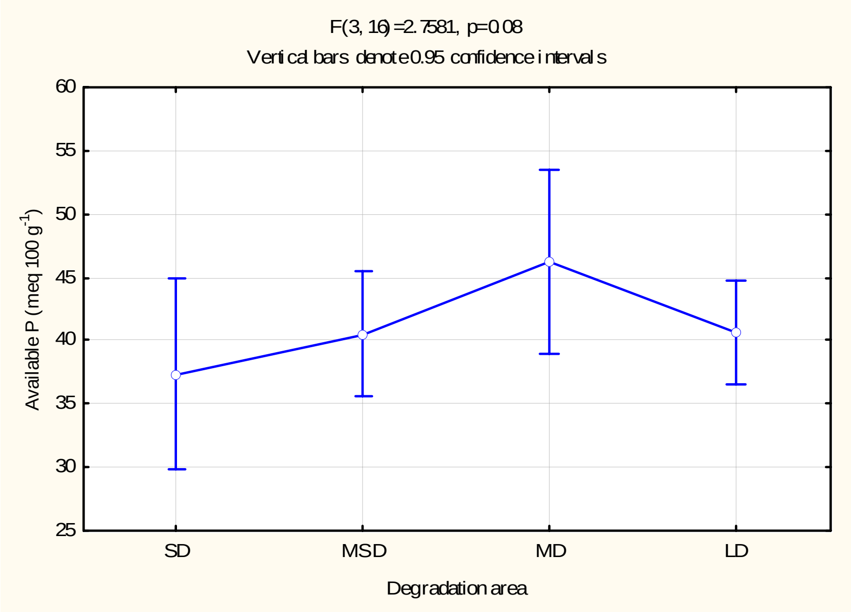


Figure 7.5 The average available phosphorus (P) content of the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

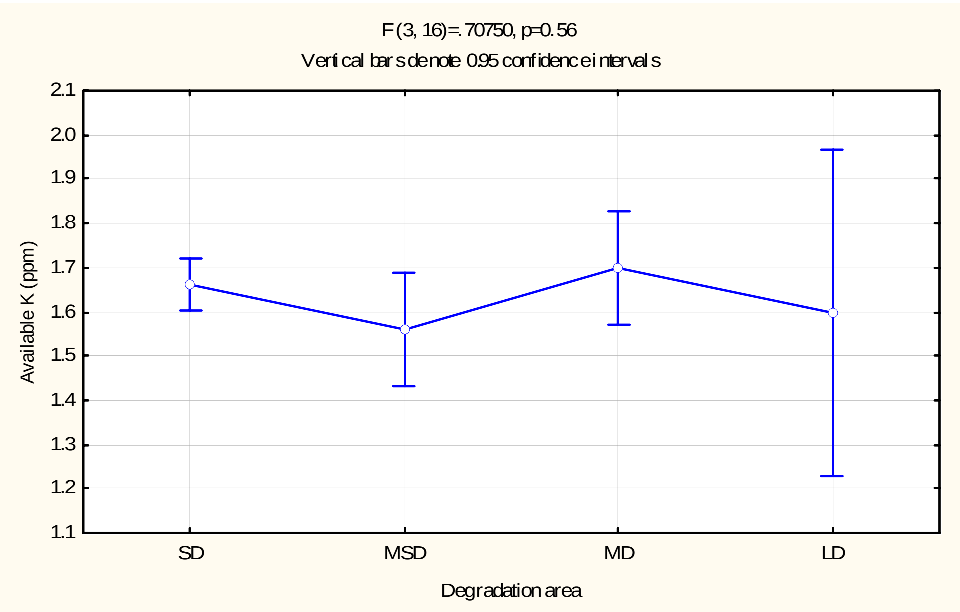


Figure 7.6 The average available potassium (K) content of the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

7.3.3 Exchangeable bases and acidity (pH)

There was no significant difference ($P > 0.05$) or noticeable trends detected in the concentration of exchangeable Ca^{2+}, Mg^{2+} and K^{+} along the grazing gradient away from the watering point (Fig. 7.7, 7.8 and 7.9). However, significant differences ($P < 0.05$) were noticed along the gradient for Na^{+} concentration (Table 7.2). Significantly higher values were displayed for the SD area close to the watering point. The concentration of Na^{+} increased from 0.711 meq 100 g^{-1} in the LD area to 2.57 meq 100 g^{-1} in the SD area (Fig. 7.10). Soil pH exhibited a significant difference ($P < 0.05$) along the grazing gradient (Table 7.3), ranging from 8.45 in the LD area far from the watering point to 8.93 in the SD area close to the watering point (Fig. 7.11). No significant differences were however detected between degradation areas further away from the watering point.

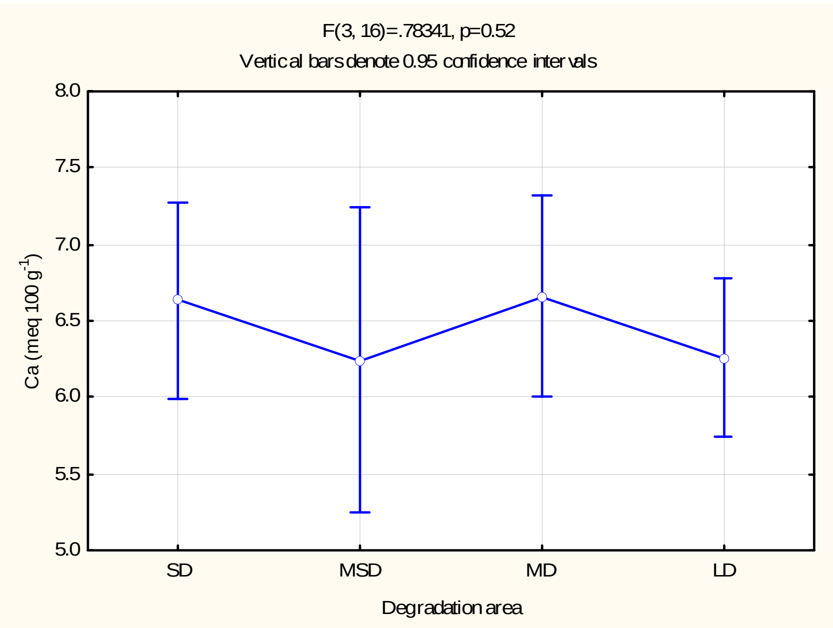


Figure 7.7 The average calcium (Ca) levels in the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

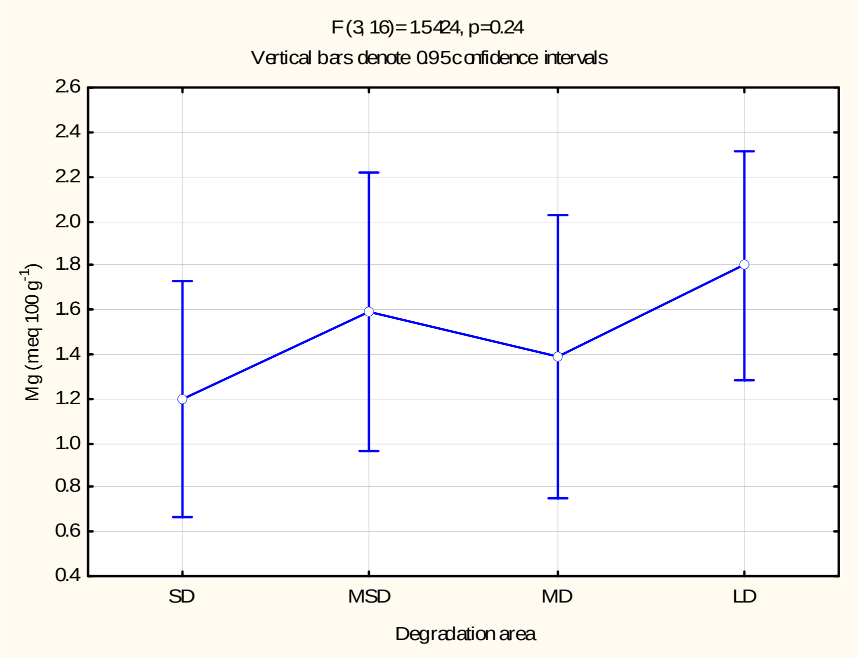


Figure 7.8 The average magnesium (Mg) levels in the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

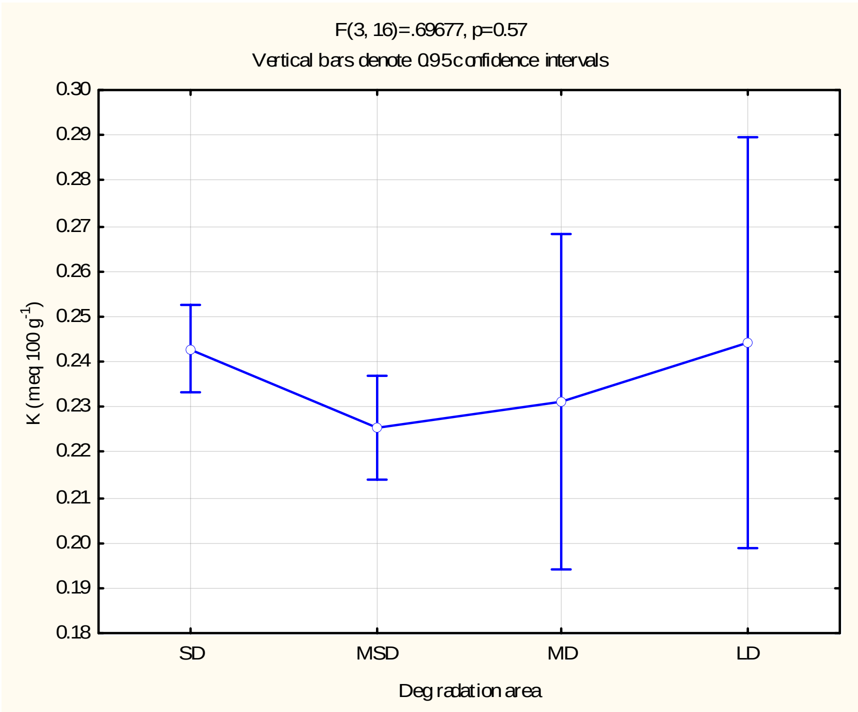


Figure 7.9 The average potassium (K) levels levels in the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 7.2 Bonferroni test to compare sodium (Na) concentration of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable Na (Spreadsheet270) Probabilities for Post Hoc Tests Error:Between MS = .15089, df = 16.000				
Degradation area	SD 2.5680 meq 100 g^{-1}	MSD 1.642 meq 100 g^{-1}	MD 1.118 meq 100 g^{-1}	LD .7114 meq 100 g^{-1}
1.SD		0.010069	0.000134	0.000007
2.MSD	0.010069		0.292604	0.009679
3.MD	0.000134	0.292604		0.704365
4.LD	0.000007	0.009679	0.704365	

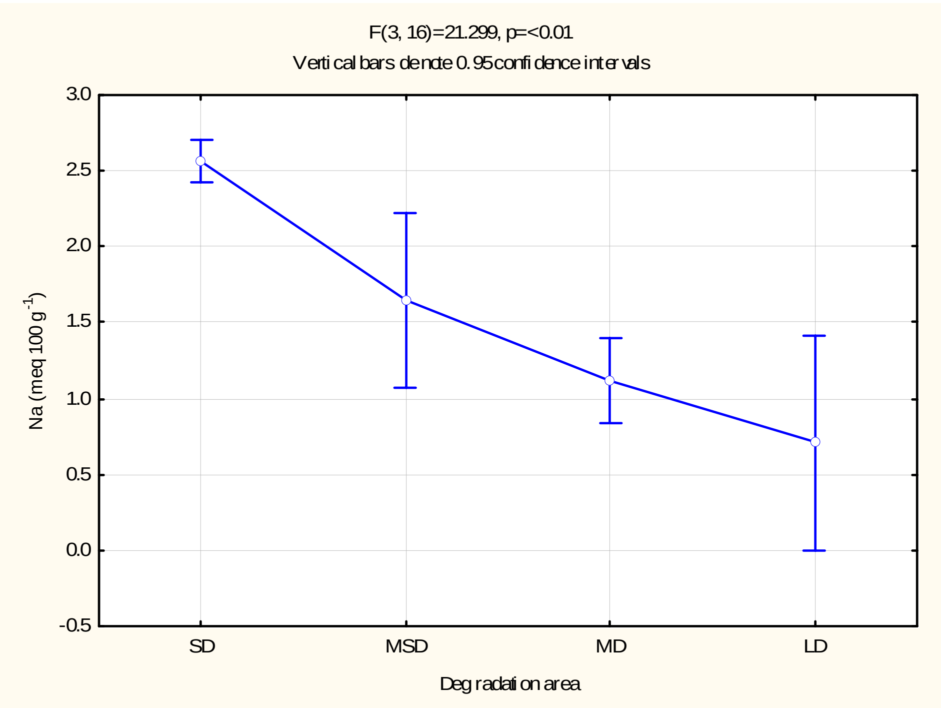


Figure 7.10 The average sodium (Na) levels in the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 7.3 Bonferroni test to compare pH levels of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable pH (Spreadsheet270) Probabilities for Post Hoc Tests
Error: Between MS = .01118, df = 16.000

	Degradation area	SD 8.93	MSD 8.51	MD 8.51	LD 8.45
1	SD		0.000062	0.000059	0.000015
2	MSD	0.000062		1.000000	1.000000
3	MD	0.000059	1.000000		1.000000
4	LD	0.000015	1.000000	1.000000	

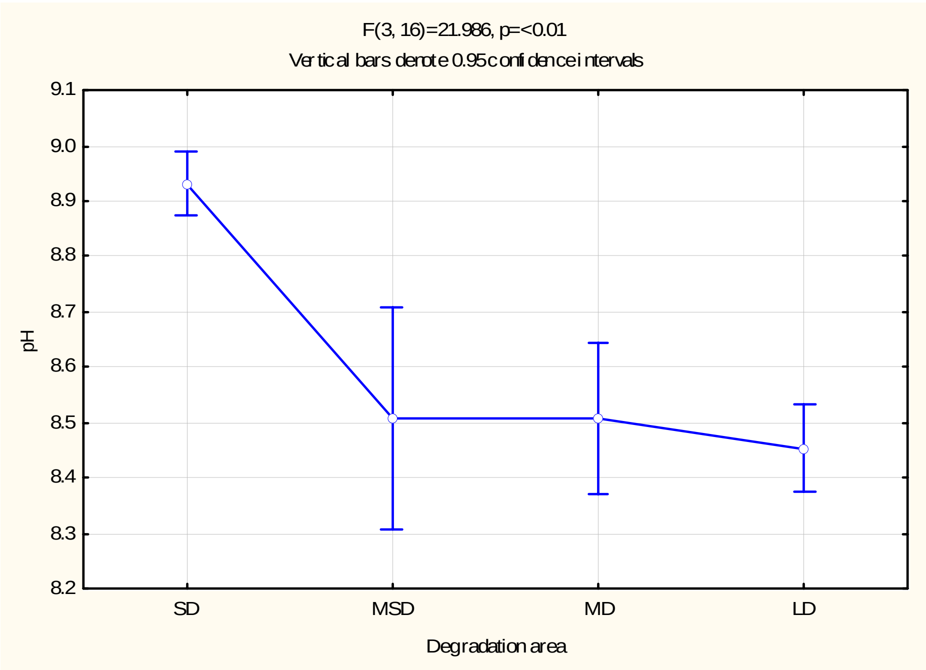


Figure 7.11 The average pH levels in the soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

7.3.4 Cation exchange capacity, total exchangeable bases, exchangeable sodium percentage and base saturation

Cation exchange capacity exhibited a significant ($P < 0.05$) declining trend from the MSD to the LD areas (Table 7.4). Apart from an increase in CEC from the SD to the MSD areas, CEC was consistently declining from 27.06 meq 100 g^{-1} in the MSD to 20.07 meq 100 g^{-1} in the LD area (Fig. 7.12). The total exchangeable base (TEB) concentration showed a significant decline ($P < 0.05$) from the SD area to the other areas further away from the watering point (Table 7.5). Significantly higher values were recorded for the degradation area closest to the watering point. The TEB concentration declined gently further along the grazing gradient, ranging from 9.6 meq 100 g^{-1} soil in the MSD area to 9.01 meq 100 g^{-1} soil in the LD area (Fig. 7.13). Base saturation was different in each degradation area ranging from 23.06% to 31.17% for Ca^{2+}, 4.99% to 8.98% for Mg^{2+}, 5.13% to 11.15% for Na^{+} and 0.84% to 1.21% for K^{+} in the gradient (Appendix 7.1). Thus Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}, satisfied the average percentage base saturation of 28.34%, 6.63%, 6.84% and 1.4% of the exchange complex of the CEC of the degradation areas respectively (Appendix 7.1). The SD area revealed relatively high percentage Na^{+} saturation (11.15), which could be detrimental for the growth of the forage plants (Appendix 7.11). The variation of Exchangeable Sodium Percentage (ESP) revealed significant differences ($P < 0.05$) along the grazing gradient (Table 7.6). A significantly higher ESP content was exhibited for the SD area. The ESP decreased from 11.15% in the SD area to a relatively constant level of 5% throughout the rest of the grazing gradient (Fig. 7.14).

Table 7.4 Bonferroni test to compare the cation exchange capacity (CEC) content of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable CEC (Spreadsheet270) Probabilities for Post Hoc Tests
Error: Between MS = 10.736, df = 16.000

	Degradation area	SD 24.02 meq 100 g^{-1}	MSD 27.06 meq 100 g^{-1}	MD 22.06 meq 100 g^{-1}	LD 20.07 meq 100 g^{-1}
1	SD		0.968981	1.000000	0.448550
2	MSD	0.968981		0.168164	0.023194
3	MD	1.000000	0.168164		1.000000
4	LD	0.448550	0.023194	1.000000	

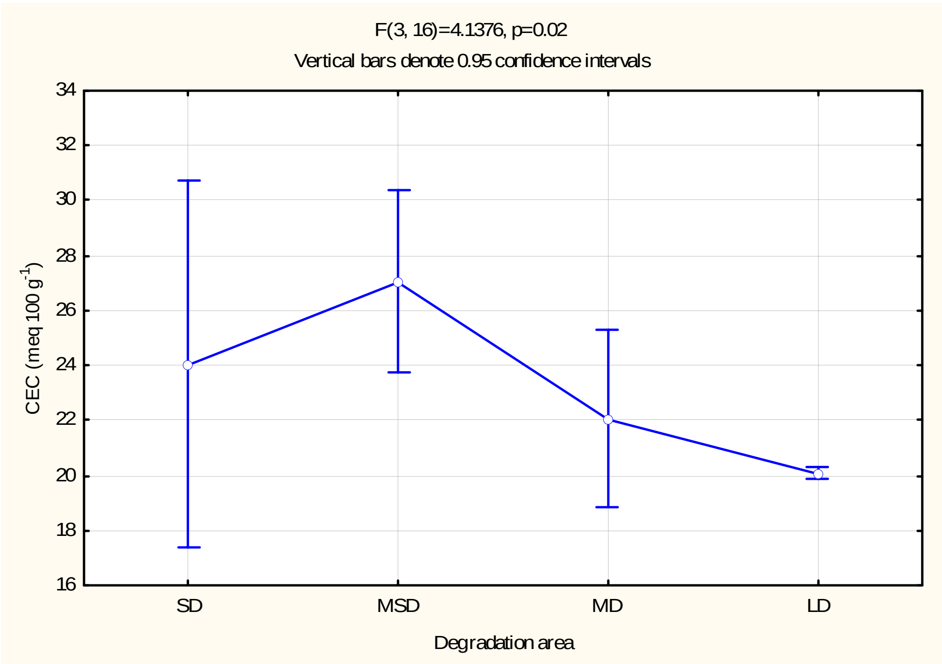


Figure 7.12 Cation exchange capacity (CEC) content of soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 7.5 Bonferroni test to compare the total exchangeable base (TEB) content of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable Total exchangeable (Spreadsheet270) Probabilities for Post Hoc Tests Error: Between MS = .20716, df = 16.000					
	Degradation area	SD 10.65 meq 100 g^{-1}	MSD 9.70 meq 100 g^{-1}	MD 9.40 meq 100 g^{-1}	LD 9.01 meq 100 g^{-1}
1	SD		0.028866	0.003078	0.000207
2	MSD	0.028866		1.000000	0.172408
3	MD	0.003078	1.000000		1.000000
4	LD	0.000207	0.172408	1.000000	

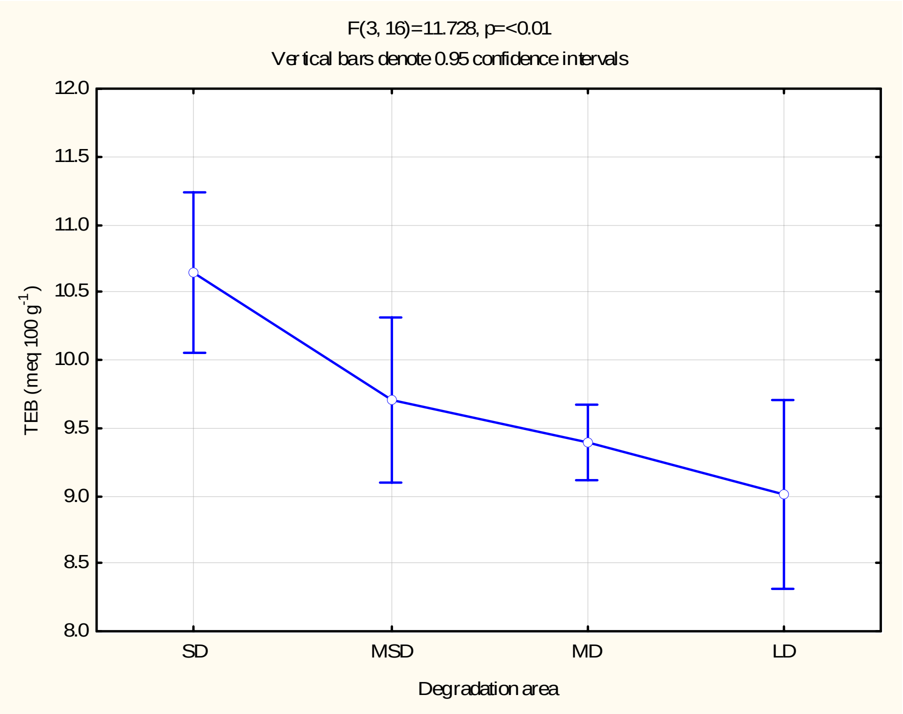


Figure 7.13 Total exchangeable base (TEB) content of soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

Table 7.6 Bonferroni test to compare the exchangeable sodium percentage (ESP) contents of the soil in the different degradation areas along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area)

Bonferroni test; variable ESP (%) (Spreadsheet270) Probabilities for Post Hoc Tests
Error: Between MS = 2.2641, df = 16.000

	Degradation area	SD 11.15%	MSD 5.44%	MD 5.05%	LD 5.13%
1	SD		0.000113	0.000052	0.000061
2	MSD	0.000113		1.000000	1.000000
3	MD	0.000052	1.000000		1.000000
4	LD	0.000061	1.000000	1.000000	

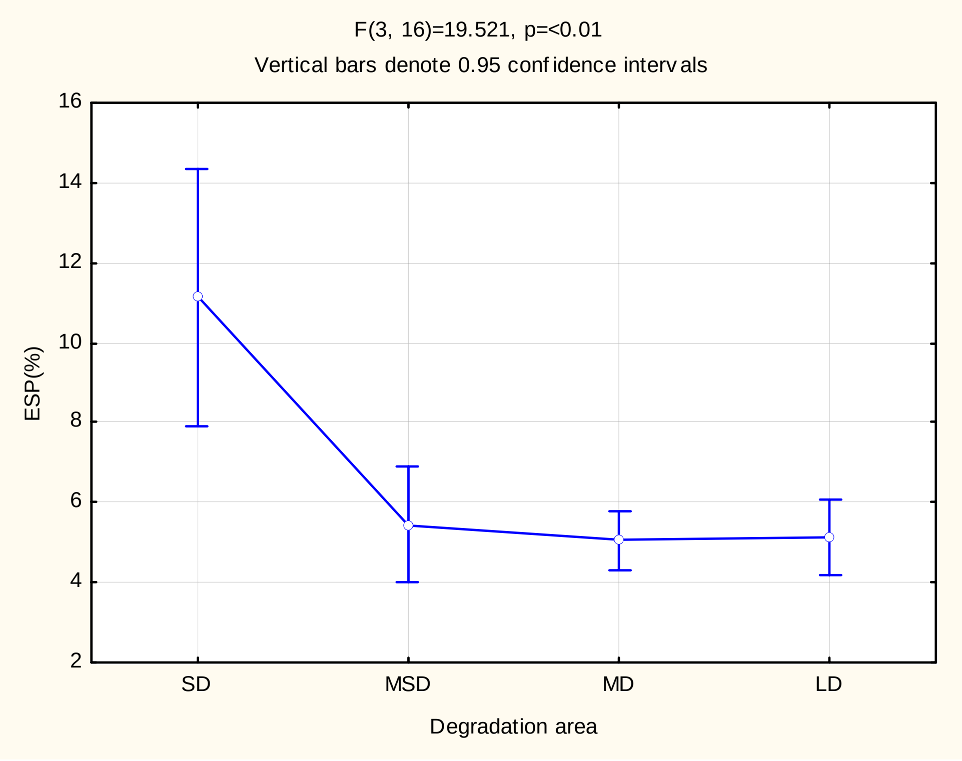


Figure 7.14 The exchangeable sodium percentage **(**ESP) content of soil along a grazing gradient in the Allaidege rangeland (SD = severely degraded area, MSD = moderately to severely degraded area, MD = moderately degraded area and LD = lightly degraded area).

7.3.5 Correlation analyses of soil factors with dry matter yield

A correlation analysis was carried out to investigate the impact of soil factors (organic matter content (OM), electrical conductivity (Ec), pH, average potassium content (K), average phosphorus content (P), total soil nitrogen (N) and compaction) on dry matter yield. The analysis identified a significant negative correlation (r = -0.58, P = 0.01) for pH (Fig. 7.15) and a positive correlation for P (r = 0.54, P = 0.01) and N (r = 0.48, P = 0.03) for 2003 (Fig. 7.16).

No significant correlation was recorded for Ec, OM, K and compaction for the two seasons. Higher pH values appeared to be correlated with lower herbage yields and more severely degraded areas while the opposite are true for higher P values. No significant P effect on yield was realized along the grazing gradient, but increase in P concentration was similar to the yield increase pattern observed in the grazing gradient. N showed an increasing trend along the gradient and a slight significant effect of N on dry matter yield was noticed from the correlation.

The 2003 soil analysis data was correlated with the dry matter yield of 2004 with the assumption that soil characteristics would not change in a period of one year. No significant correlations were recorded between any of the soil parameters and dry matter yield. This was probably due to the low dry matter yield attained in the season.

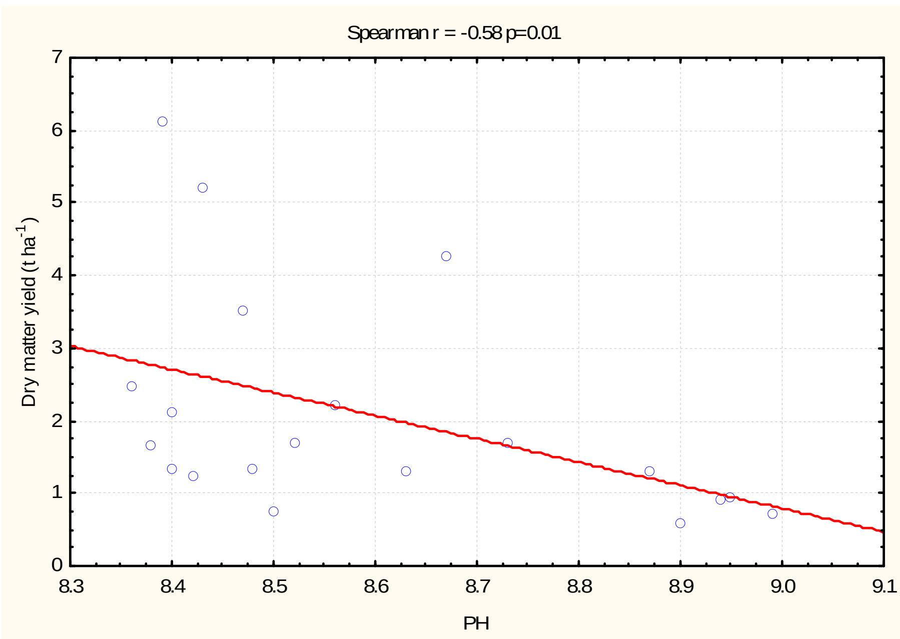
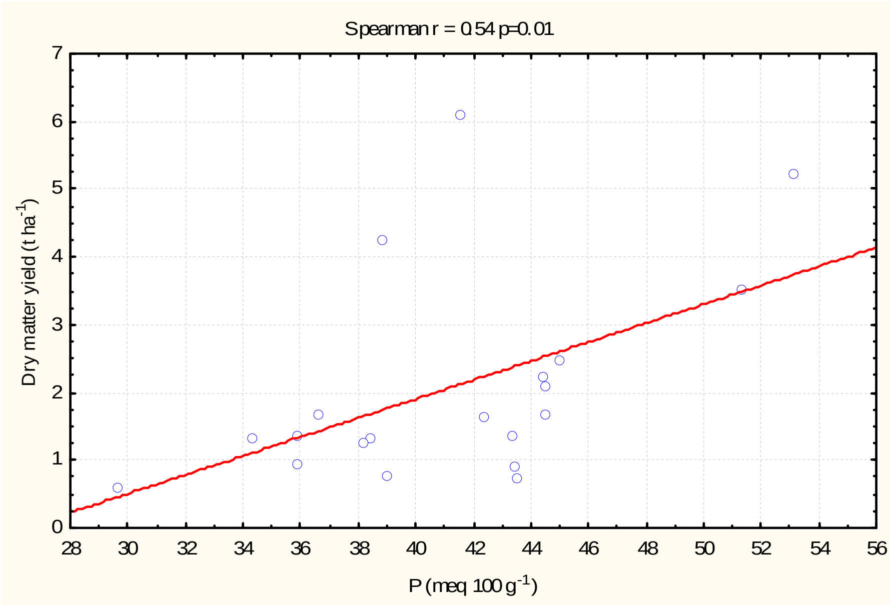


Figure 7.15 The negative correlation between soil pH and dry matter yield along a grazing gradient in the Allaidege rangeland in 2003.

a



b

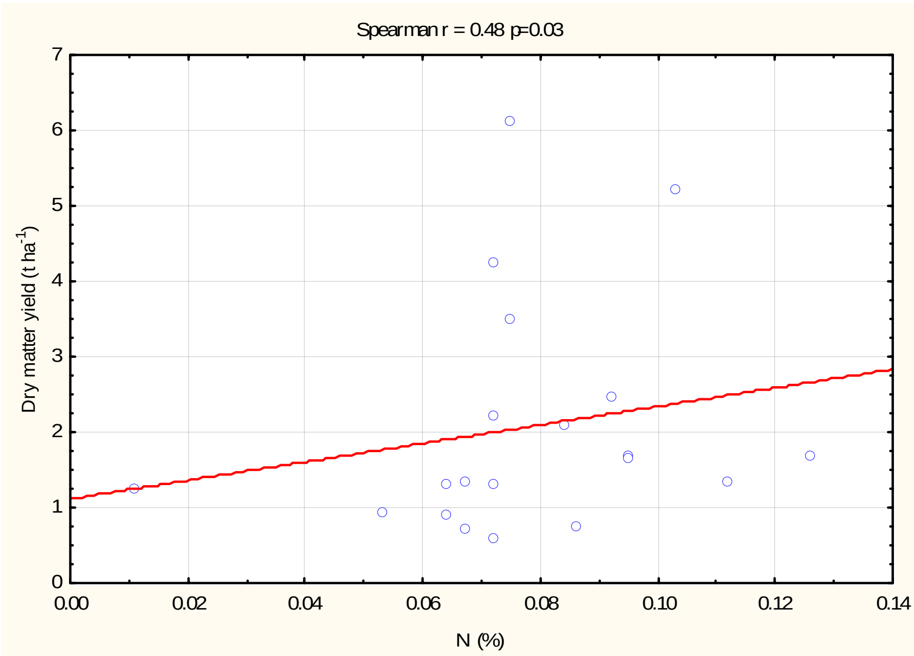


Figure 7.16 The positive correlation between a) soil phosphorus (P) and b) soil nitrogen (N) and dry matter yield along a grazing gradient in the Allaidege rangeland in 2003.

7.4 Discussion

7.4.1 Organic carbon, total nitrogen and available phosphorus

The standardization of organic matter/organic carbon content of soil into low, medium and high were adopted from Baruah and Barthakur (1997). The rating was considered high, medium and low for OC contents of 0.75%, 0.50-0.75% and <0.50% respectively. Accordingly, the OC content of each degradation area was found to be high with mean scores higher than 0.75%.

Even though no significant variation was observed along the gradient, higher concentrations of OC was observed further away from the watering point, where the forage ground cover was relatively good. Presumably, the increase in OC concentration can be attributed to higher litter deposition to the topsoil due to the better ground cover. The increase of soil OC content under grassland vegetation cover was reported by many different studies (Thompson & Troeh, 1978; Brady, 1990).

Similarly, as could be expected, insignificant slight changes in total N concentration occurred along the gradient. The total N concentration has a similar pattern to that of OC. Much of the soil N is in organic matter forms. The recycling of N and the slow mineralization from old plant material (litter) was discussed by Berliner and Kioko (1999). Available P was also statistically similar along the grazing gradient. In natural ecosystems, the P cycle is virtually closed, and most plant P is recycled by microbial breakdown of litter and organic debris (Berliner & Kioko, 1999). The decline of P in the LD area which was higher in organic matter content could be due to less biological activity in the area. In general, OC, total N, P and K contents were not different along the grazing gradient further than 1500 m from the watering point. This was consistent with earlier findings of Beukes and Ellis (2003) who found that soil properties stayed constant at distances further than 1500 m from the watering point but suggested that soils closer to the watering point (<1500 m) varied due to the effects of concentrated herbivore activity.

Similarly, Tolsma *et al.* (1987) in Botswana reported high concentrations of total N, available P and K in the vicinity of the borehole up to 100 m, whereas no significant change of the soil nutrients took place between 100 m and 1500 m, which was in line with the results obtained in this study that no significant change of soil nutrients along the grazing gradient was observed beyond the SD area (further than 1500 m from the watering point). Likewise, Turner (1998) found no variation in OC, total N and available P concentrations along distances further than 200 m from watering points. Perkins and Thomas (1993), in all six ranches studied, reported that OC, total N, P and K showed marked increases in nutrients in the zone 0-50 m from the boreholes. No noticeable variation was observed in grazing areas beyond 50 m, which support the findings of this study. The cause of the increase in nutrient status close to watering points was attributed to the concentration of livestock urine and dung. In effect, livestock graze throughout the ranch but their daily activities focus around the boreholes. Together with their nighttime kraaling in the zone close to the watering point, this causes a centripetal movement of nutrients (Tolsma *et al.*, 1987).

7.4.2 Exchangeable bases and acidity (pH)

The soil acidity (pH) in the SD area close to the watering point was around 8.9, categorized as strongly alkaline soil (Thompson & Troeh, 1978), compared to areas further away from the watering point. In this study, Ca^{2+} and Mg^{2+} were the dominant exchangeable cations, particularly in the SD area where it makes up 73.6% of exchangeable cations. This agrees with Berliner and Kioko (1999) who reported that Ca^{2+} was usually the dominant exchangeable cation in soil colloids with 60-80% of exchangeable cations in most soils with Mg^{2+}. Because of this Ca^{2+} plays an important role in determining pH of most soils (Brady, 1974). This was consistent with Nsinamwa *et al*. (2005) who reported high pH values close to watering points in communal grazing areas of Botswana.

This study has recognized high concentrations of Na^{+} and the exchangeable Na^{+} was more than 15% of the total exchangeable cations in both SD (24.08% exchangeable Na^{+}) and MSD (16.9% exchangeable Na^{+}) grazing areas, which could have deleterious effects on the physical condition of the soil. Thompson and Troeh (1978) has reported that dispersion of the colloids was likely to occur causing low permeability to water, air and roots if exchangeable Na^{+} exceeds 15% of the total exchangeable cations. The presence of considerable Na^{+} and the likelihood of dispersed soil colloids above soil pH values of 8.5 were also reported by Thompson and Troeh (1978). Plant growth was markedly reduced where colloids are dispersed and was completely eliminated where the condition was severe (Thompson & Troeh, 1978). The high concentration of Na^{+} in the severely degraded area was due to the movement of highly soluble salts like Na^{+} upward in the profile through capillary action when the upper horizons are drier than the lower, which was mostly attributed to poor vegetation cover. This is the existing scenario threatening the rangeland particularly in the SD area where a quick remedy is needed to restore the growth and productivity of the area to a more sustainable level.

The concentration of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) was not different and not consistent along the grazing gradient, but Na^{+} concentration exhibited a significant decreasing trend along the gradient further away from the watering point. Similarly, Perkins and Thomas (1993) observed similar trends for distances beyond 50 m for Ca^{2+} and Mg^{2+} concentrations but not for Na^{+} concentrations. Previous findings by Georgiadis and Mcnaughton (1990) revealed a two to three times increase of Na^{+} concentration in heavily grazed soil around a watering point, which holds true for this study, but Ca^{2+} and Mg^{2+} concentration varied significantly and inconsistently. Others like Tolsma *et al.,* (1987) observed a decrease in concentration of K^{+} and Ca^{2+} from 100 m to 1500 m away from the borehole but Mg^{2+} did not change, as was also found in this study. The electrical conductivity of the soil in the study site was less than 1ds m^{-1} for all the gradients, characterizing the range soil to be non-saline. Soils are classed saline if the conductivity of the saturation extract exceeds 2 ds m^{-1} (Brady, 1990).

7.4.3 Cation exchange capacity, total exchangeable bases and base saturation

The CEC was declining along the gradient from the MSD to the LD area. No satisfactory explanation could be given but it could have been due to soil mineralogy differences. The specific exchangeable cations associated with soil colloids differ from climate to climate. In low rainfall areas Ca^{2+}, Mg^{2+} and Na^{+} are the dominating cations (Brady, 1990). The proportion in any soil of the CEC satisfied by a given cation is termed the percentage saturation. The base saturation of a soil is a good measure of how much the CEC was utilized to store plant nutrients. Therefore a capacity to hold certain milli-equivalents does not ensure the presence of higher concentrations of essential plant nutrients (Thompson & Troeh, 1978). The percentage base saturation of essential elements such as Ca and K greatly influences the uptake of these elements by growing plants.

Total exchangeable base was significantly declining along the grazing gradient, a trend similar to Ca^{2+} and Mg^{2+} cations. This was due to the fact that the exchange complex of the soil was saturated with Ca^{2+} and Mg^{2+}. Calcium ion accounted for 66% and Mg^{2+} for 15.31% of the total exchangeable bases in the study. Apart from this, the centripetal dung transport might contribute to high exchangeable bases close to the watering point (Tolsma *et al.,* 1987; Perkins & Thomas, 1993).

From this study we conclude that there are soil status differences in the grazing gradient caused by impact of grazing, particularly in the SD area. Correlations of herbage yield with some soil parameters were investigated, particularly in the case of the SD area, which was lower in yield in both years. No soil parameter correlation was exhibited for the rest of the grazing areas. The SD area was found to be significantly higher in sodium concentration and soil acidity (pH) affecting the physical condition of the soil in the area. Soil conditions are thus not conducive to good plant growth in this area. The hypothesis posed is therefore rejected.

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CHAPTER 8

IMPACT OF RE-VEGETATION TECHNOLOGIES ON SEVERELY DEGRADED RANGELAND IN THE ALLAIDEGE RANGELAND IN NORTH-EASTERN ETHIOPIA

8.1 Introduction

Rangeland re-vegetation emerged as an applied science in the United States of America about 100 years ago, following a noticeable downward trend in range condition associated with the settlement and intensive use of arid and semiarid areas (Call & Roundy, 1991). Early re-vegetation efforts relied heavily upon conventional agricultural principles and practices and were largely unsuccessful because seed was only available for cultivated forage plants adapted to more mesic environments and site preparation methods were often inadequate (Stoddart, Smith & Box, 1975).

Re-vegetation and improvement of degraded grazing land was extensively practiced after development of better techniques of seedbed preparation and planting methods were realized. Favorable micro sites for seeding establishment have been described by Harper *et al*. (1961) as cited by Winkel, Roundy and Cox (1991) and re-named by Harper (1977) as cited by Winkel, *et al*. (1991) as “safe sites”. Seed germination and establishment in natural and artificial re-vegetation is a result of the number of seeds in favorable micro sites or ‘safe sites ‘ in the seedbed rather than the total number of available seeds (Harper, Williams & Sagar, 1965).

Up to now various techniques were introduced in the rangeland re-vegetation process to improve micro-sites for sown seed and increase the seed germination rate and establishment. For instance, Van der Merwe (1997) used a number of restoration techniques consisting of biological and mechanical approaches to reclaim degraded rangeland. The biological approach includes planting methods of the seeds with manure, gravel and straw. The mechanical approach included the use of farm implements to disturb the soil. Similarly, Winkel *et al*. (1991) also reported that the effects of gravel and litter on seedling emergence were favorable when compared to seeds growing in cracks and on the bare soil surface. Rickert (1970) and Jordaan and Rautenbach (1996) were also successful when using organic mulches to establish grass seeds in heavy clay soil.

The objective of all these various methods used was to create favorable micro sites to enable seeds to germinate and establish more successfully. These re-vegetation techniques were practiced when insufficient desirable forage plants remained (Vallentine, 1989) and when sound rangeland management practices could not restore it to its original grazing potential (West *et al.*, 1989; Jordaan, 1997). Moreover, natural re-vegetation of perennial grasses is slow in many areas (Hyder, Everson & Bement, 1971; Stoddart *et al.,* 1975) therefore species adapted to sowing is often desirable.

The rangeland scenarios that manifested in the study area were a deteriorated rangeland in general and in particular the severely degraded area (SD) that was completely denuded of preferred species. The SD area about 1000 m from the water point was out of production notwithstanding the dominant cover of the unpalatable forb species and the gradual encroachment of the alien *Prosopis* species in some sites of the grazing area. Thus the need for a quick remedy of the area was obvious: there was a clear need to reverse the situation by seeding grass species to restore and increase forage production and improve grazing capacity of this denuded rangeland by using some of the various restoration techniques developed. The objective of the study was to determine and quantify viable restoration strategies for forage species on the degraded Allaidege rangeland. The hypothesis tested was: there is no difference in the success rate of different restoration techniques in a severely degraded area.

8.2 Materials and methods

Using the identified grazing gradients, the SD area close to the watering point was selected to observe the impact of inorganic fertiliser, manure and mulch on seeded local and exotic species as a strategy approach of revegetating the rangeland (Plate 8.1). During the study period, the annual rainfall was 372.6 mm in the first season. Soil analysis of the study area indicated that the soil texture was a silty clay loam with 35% clay, 50.8% silt and 14.2% sand. The pH, electrical conductivity (Ec) (ds m^{-1}), total nitrogen (N) (%), organic matter (OM) (%), potassium (K) (meq 100 g^{-1}) and phosphorus (P) (meq 100 g^{-1}) were 8.24, 1.32, 0.19, 1.79, 0.08 and 35.6 respectively (climatic details are given in Chapter 3).

The experiment was a randomized complete block design with eight factorially combined treatments randomly applied. The treatments were replicated three times making the total number of plots including the control plots 27 per replication. The treatments evaluated were control (C), no dung + no fertiliser + no mulch (NNN), no dung + fertiliser + mulch (NFM), dung +fertiliser + mulch (DFM), no dung + no fertiliser + mulch (NNM), dung + no fertiliser + no mulch (DNN), no dung + fertiliser + no mulch (NFN), dung + fertiliser + no mulch (DFN), dung + no fertiliser + mulch (DNM). The control plot without a treatment and with no grass seeds sown in was included to observe the re-appearance of the natural vegetation, in particular the preferred species. The experiment was laid out in a 10 m x 10 m plot. The area was ploughed by disc plough to a depth of 40-45 cm to improve the soil condition and enhance the infiltration of water as well as the germination of seeds.

The study plots were fenced to avoid any grazing by livestock. In each plot six grass species (three locally collected and three species of which the seed was imported) known to be tolerant to water stress and/or palatable, were sown. The local seeds were collected from the range area and the imported seeds came from Australian collections. Both the locally and imported seeds were sown in plots for seed multiplication at the nearby Werer Agricultural Research Center (WARC). The first season's seeding was done in the first week of July 2003 after the first rain commenced. In the second season (2004), the plots were laid out on an adjacent area to the previous trial to avoid carry-over effects, but due to heavy rain and subsequent soil movement germinated seeds were buried too deeply by sediment deposits to emerge. Reseeding was carried out after rehabilitating the soil surface of the field, but germination and establishment failed due to water stress caused by discontinued rainfall. Therefore only the 2003 data are presented. The sowing was done in two strips of 10 m length and 0.07 m between strips. A total of 12 strips per plot were prepared for seeding. The six grass species used in the study were locally collected species *Ischaemum afrum*, *Enteropogon rupestris*, *Tragus berteronianus* and imported species *Chloris gayana*, *Panicum coloratum* and *Cenchrus ciliaris*. The sowing rate was 4 kg ha^{-1} for all the species.

The inorganic fertilizer mix (urea (1.7 kg) and triple phosphate (4 kg) applied at a rate of 5 kg $plot^{-1}$ resulting in N and P application rates of 0.8 kg each was broadcasted on the surface of the entire area receiving fertiliser with the aim of enhancing the growth of the seedlings. This was assumed from the recommended fertilizer rate application of 80 kg N ha^{-1} and 80 kg P ha^{-1} (Personal communication with researchers in the center, based on past use of urea and triple phosphate)

The dry dung organic manure treatment was dressed on the planted strips as a seed cover of 1 mm thick and a very light hand raking was applied in plots where dung treatment was not applied.

The mulch treatment consisted of clipped grass material found locally in the range. When harvesting the grass mulch precaution was made not to introduce seeds of the grass mulch in the experimental site. However, since the harvest was made before the rainy season the grass was dry and over matured and no remnants of seed was expected; to make sure trashing of the grass was carried out to remove seeds left in the panicles or other plant parts.

The grass mulch was applied on the soil surface in the sown rows approximately 1cm thick (Plate 8.2).

The treatments were evaluated by measuring their effect on dry matter production. Collecting the sample was done by harvesting the whole strip at ground level three months after seeding. Sub-samples were oven-dried for 72 h at 65ºC and then weighed to determine the production attained in dry matter per hectare.

8.2.1 Statistical analysis

Three-way ANOVA analyses were used to determine the combined effect of dung, mulch and fertiliser on dry matter yield of the grass. In most cases due to the ill conditioned nature of the data, non-parametric bootstrap analyses were done, making use of the Bonferroni post hoc testing analysis. For comparison of the species, one-way ANOVA and the corresponding non-parametric bootstrap analysis were employed.

Plate 8.1 The severely degraded area in the Allaidege rangeland where the re-vegetation study was executed (note the unpalatable forb species dominating the vegtation).

8.3 Results

8.3.1 Species performance in the treatments

The 2003 rainfall was better than the preceding year, which was dry but it was still 200 mm lower than the long-term average, which is 500 mm per annum. The seed germination and establishment was generally good, fair and poor in the different strips (Plate 8.3, 8.4 and 8.5). The analysis treated each species yield separately to investigate the effect of dung, fertiliser and mulch and has also considered the total pooled yield of all the species for analysis of the same treatment effects**.** Three-way factorial ANOVAs were done to determine the simultaneous effect of fertiliser, mulching and dung on biomass yield. It should be noted however that the ANOVA results could not be deemed reliable due to the presence of outliers in the data. For that reason, the analyses were augmented by non-parametric bootstrap analyses.

In the analysis, the locally collected grass *I. afrum* showed a significant (P = 0.003) positive response to the mulch treatment (Table 8.1) but no significant response to either dung or fertiliser treatments or interactions between the factors could be determined. The mulch treatment has realized a dry matter yield of 900 kg ha^{-1}, where the no mulch treatment yielded about 100 kg ha^{-1} (Fig. 8.1). In general the dry matter yield performance of *I. afrum* was high compared to the other species.

Table 8.1 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Ischaemum afrum* in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Species 1 yield (dung fert mulch.sta) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	6736153	1	6736153	18.84262	0.000506
dung	54676	1	54676	0.15294	0.700899
fertiliser	423744	1	423744	1.18531	0.292405
mulch	4281159	1	4281159	11.97542	0.003221
dung*fertiliser	14682	1	14682	0.04107	0.841961
dung*mulch	156927	1	156927	0.43896	0.517055
fertiliser*mulch	329674	1	329674	0.92218	0.351192
dung*fertiliser*mulch	11607	1	11607	0.03247	0.859267
Error	5719928	16	357496		

Plate 8.2 The mulch cover being applied in the mulch treated blocks of the study site in the severely degraded area of the Allaidege rangeland.

Plate 8.3 Well established sown grass species (that received a mulching treatment) in the severely degraded area of the Allaidege rangeland.

Plate 8.4 Moderately well established sown grass species in the severely degraded area of the Allaidege rangeland.

Plate 8.5 Poorly established sown grass species (that received no mulching treatment) in the severely degraded area of the Allaidege rangeland.

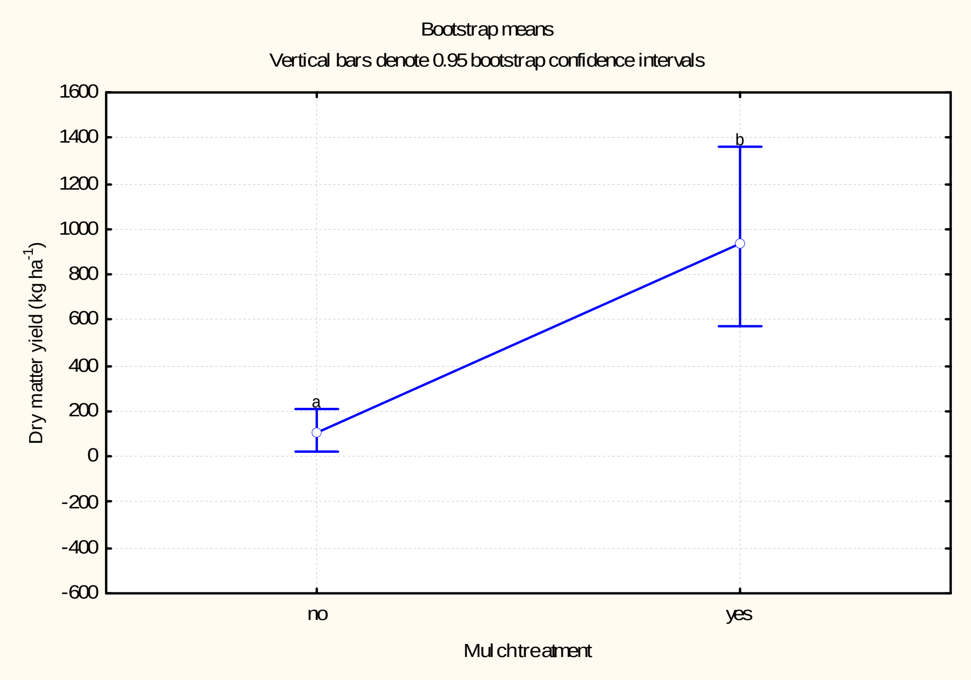

Figure 8.1 The influence of mulch application on dry matter yield of sown *Ischaemum afrum* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

Similarly, *Enteropogon rupestris* and *Tragus berteronianus,* the two locally collected species (Table 8.2 and 8.3) and imported species *C. gayana* and *P. coloratum* (Table 8.4 and 8.5) depicted similar significant ($P < 0.05$) results for the mulch treatment but no significant effects on grass dry matter production was recorded for the dung and fertiliser treatments. The yields recorded for *E. rupestris, T. berteronianus, C. gayana* and *P. coloratum* were between eight- and 20-fold higher for the mulch treatments than for those that received no mulch (Fig. 8.2, 8.3, 8.4 and 8.5). The highest yield was recorded for *T. berteronianus* which was more than 800 kg ha^{-1} for the mulch treatment and close to 50 kg ha^{-1} for the no mulch treatment. *Enteropogon rupestris* and *C. gayana* both recorded above 300 kg ha^{-1} for the mulch treatment and close to 50 and 10-15 kg ha^{-1} for the no mulch treatments respectively. *Panicum coloratum* recorded a yield of approximately 250 kg ha^{-1} for the mulch treatment, which was the lowest yield compared to the other sown species.

Table 8.2 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Enteropogon rupestris* in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Species 2 yield (dung fert mulch.sta)
Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	982765.4	1	982765.4	42.09912	0.000007
dung	4535.9	1	4535.9	0.19430	0.665256
fertiliser	1836.1	1	1836.1	0.07865	0.782724
mulch	661715.9	1	661715.9	28.34619	0.000068
dung*fertiliser	4563.9	1	4563.9	0.19551	0.664290
dung*mulch	2150.8	1	2150.8	0.09214	0.765391
fertiliser*mulch	24518.4	1	24518.4	1.05031	0.320682
dung*fertiliser*mulch	822.0	1	822.0	0.03521	0.853507
Error	373505.3	16	23344.1		

Table 8.3 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Tragus berteronianus* in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Species 3 yield (dung fert mulch.sta)
Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	4236851	1	4236851	35.91304	0.000019
dung	180556	1	180556	1.53046	0.233894
fertiliser	97154	1	97154	0.82351	0.377621
mulch	3895858	1	3895858	33.02266	0.000030
dung*fertiliser	143736	1	143736	1.21836	0.286007
dung*mulch	259578	1	259578	2.20027	0.157417
fertiliser*mulch	88279	1	88279	0.74828	0.399806
dung*fertiliser*mulch	132895	1	132895	1.12646	0.304290
Error	1887605	16	117975		

Table 8.4 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Chloris gayana* in the severely degraded area of the Allaidege rangeland

.Univariate Tests of Significance for Species 4 yield (dung fert mulch.sta) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	636245.2	1	636245.2	22.68528	0.000212
dung	24184.0	1	24184.0	0.86228	0.366900
fertiliser	57261.0	1	57261.0	2.04164	0.172277
mulch	568374.2	1	568374.2	20.26535	0.000362
dung*fertiliser	9608.4	1	9608.4	0.34259	0.566504
dung*mulch	25100.4	1	25100.4	0.89495	0.358208
fertiliser*mulch	42938.7	1	42938.7	1.53098	0.233818
dung*fertiliser*mulch	11400.1	1	11400.1	0.40647	0.532785
Error	448745.7	16	28046.6		

Table 8.5 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Panicum coloratum* in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Species 5 yield (dung fert mulch.sta) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	554201.2	1	554201.2	25.93395	0.000109
dung	8850.8	1	8850.8	0.41418	0.528975
fertiliser	69209.6	1	69209.6	3.23868	0.090803
mulch	408921.8	1	408921.8	19.13557	0.000472
dung*fertiliser	43209.9	1	43209.9	2.02201	0.174234
dung*mulch	39623.2	1	39623.2	1.85417	0.192166
fertiliser*mulch	82027.6	1	82027.6	3.83850	0.067750
dung*fertiliser*mulch	34055.9	1	34055.9	1.59365	0.224895
Error	341915.5	16	21369.7		

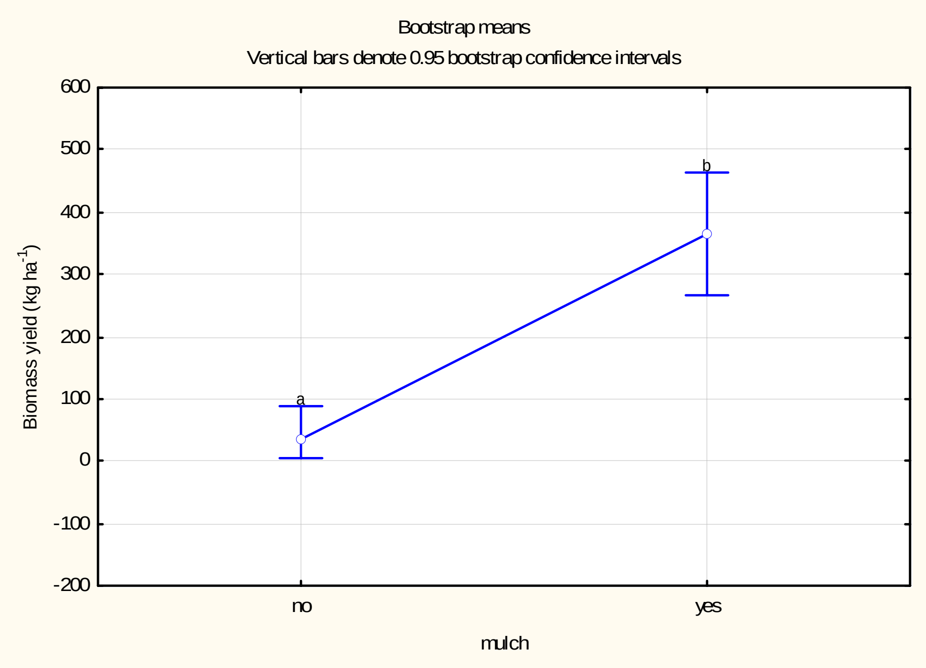

Figure 8.2 The influence of mulch application on dry matter yield of sown *Enteropogon rupestris* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

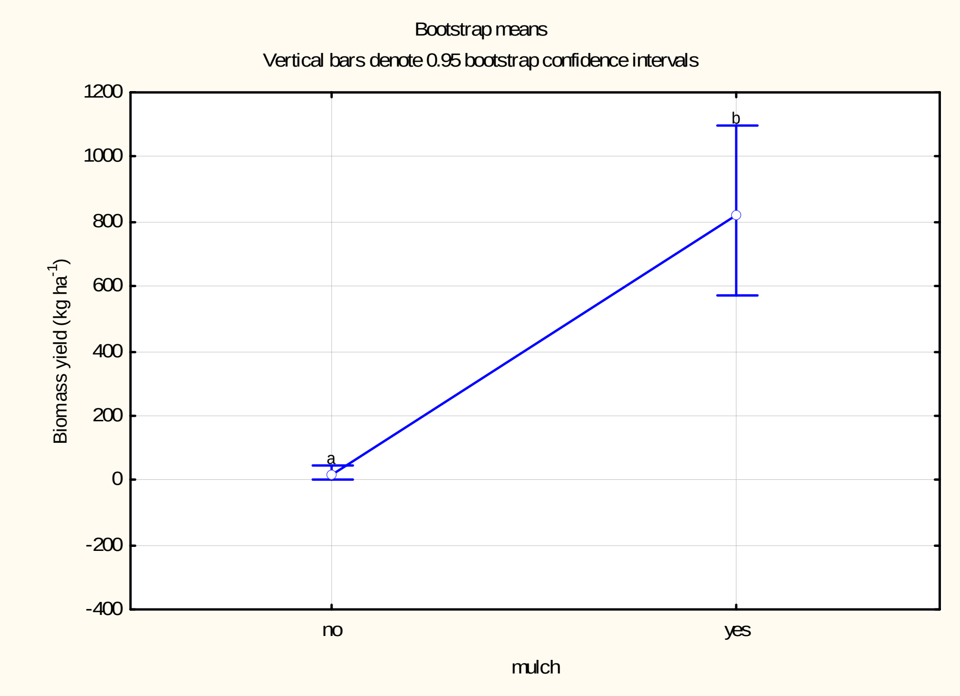

Figure 8.3 The influence of mulch application on dry matter yield of sown *Tragus berteronianus* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

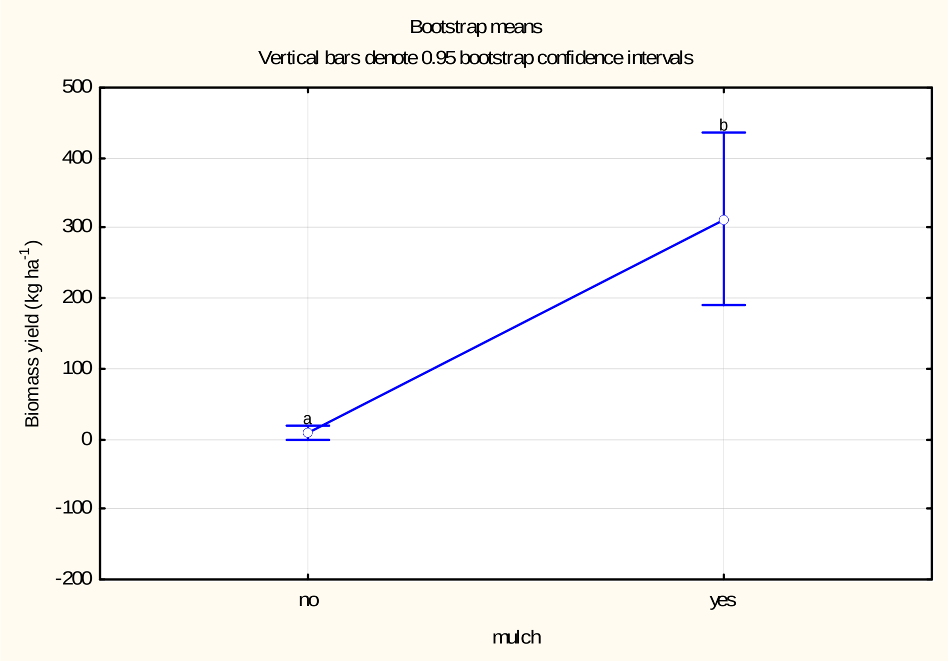

Figure 8.4 The influence of mulch application on dry matter yield of sown *Chloris gayana* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

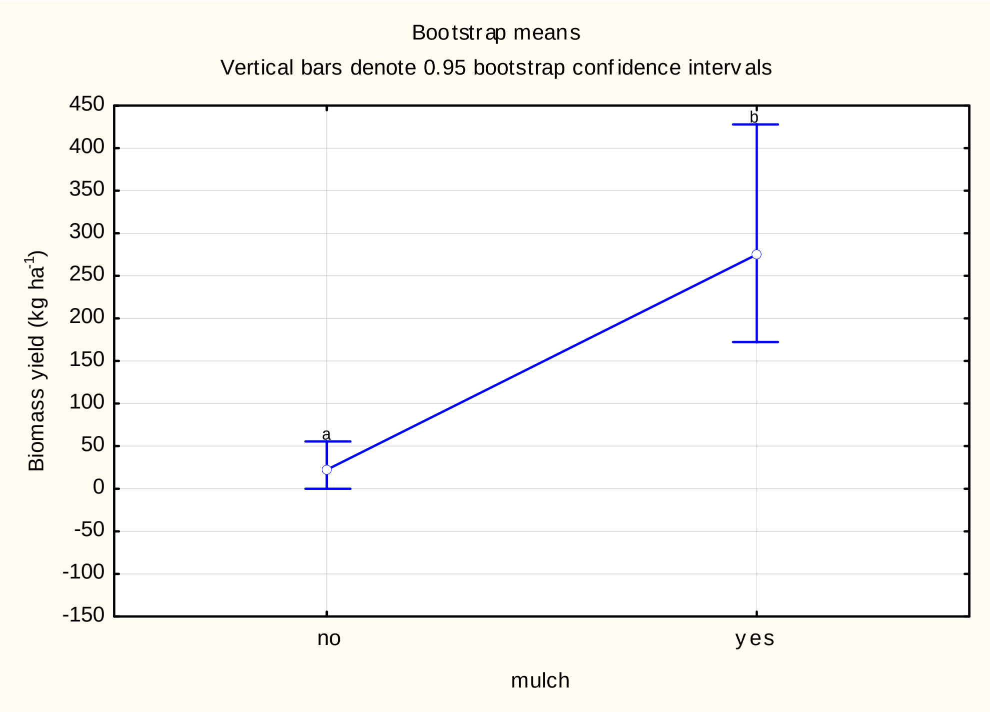

Figure 8.5 The influence of mulch application on dry matter yield of sown *Panicum coloratum* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

An almost significant (P = 0.053) interaction between mulch and fertlizer occurred in the case of *C. ciliaris* (Table 8.6). In the fertilized and mulched treatments, *C. ciliaris* produced less than 100 kg ha^{-1} in the no mulch treatment of both fertilized and not fertilized plots (Fig. 8.6) and no significant difference was recorded between fertilized and not fertilized plots (Fig. 8.6). This implicated that fertiliser did not significantly increased the yield of *C. ciliaris* in the no mulch treatments. However, a yield increase was noted for both treatments when mulch was part of the treatment (Fig. 8.6). The fertilized and mulched treatments produced more dry matter than the non-fertilized mulched treatments. In the presence of mulch, dry matter production responded to fertiliser by a two-fold yield increase compared to the mulch treatment without fertiliser (Fig.8.6).

Table 8.6 Analysis of variance of the effect of dung, fertiliser and mulch treatments on dry matter yield of sown *Cenchrus ciliaris* in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Species 6 yield (dung fert mulch.sta)
Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of	MS	F	p
Intercept	1379138	1	1379138	28.67929	0.000064
dung	24585	1	24585	0.51125	0.484903
fertiliser	229396	1	229396	4.77031	0.044186
mulch	969873	1	969873	20.16860	0.000370
dung*fertiliser	265	1	265	0.00550	0.941795
dung*mulch	65	1	65	0.00136	0.971081
fertiliser*mulch	210256	1	210256	4.37228	0.052840
dung*fertiliser*mulch	2023	1	2023	0.04207	0.840080
Error	769413	16	48088		

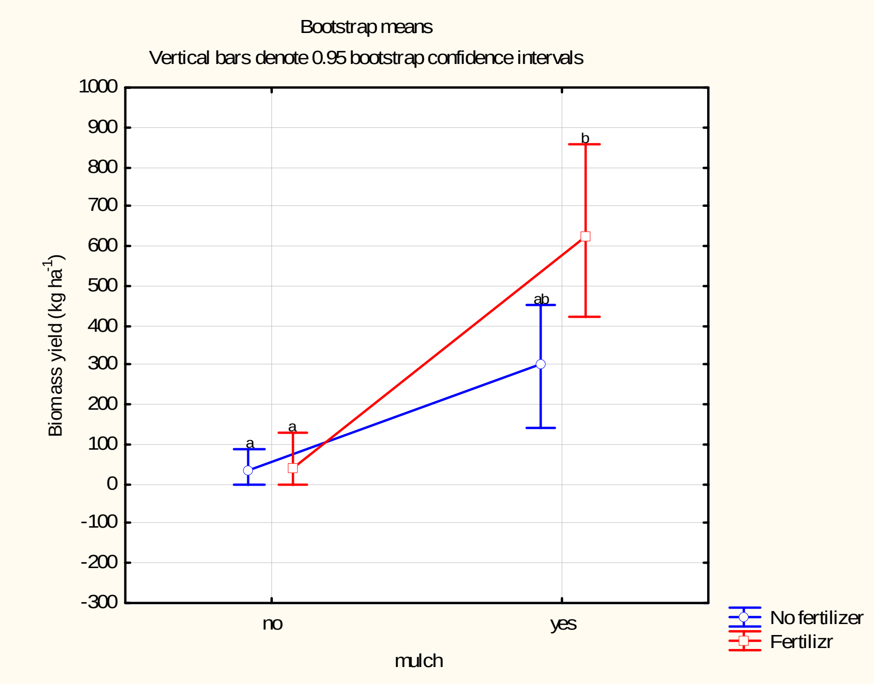

Figure 8.6 The influence of mulch application on dry matter yield of sown *Cenchrus ciliaris* in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at P = 0.05).

Table 8.7 Analysis of variance of the effect of dung, fertiliser and mulch treatments on the total dry matter yield of all the sown species in the severely degraded area of the Allaidege rangeland

Univariate Tests of Significance for Yield (dung fert mulch stacked.sta) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of**	**MS**	**F**	**p**
Intercept	11652671	1	11652671	95.19502	0.000000
dung	165929	1	165929	1.35554	0.246351
fertiliser	78184	1	78184	0.63871	0.425570
mulch	8723108	1	8723108	71.26233	0.000000
dung*fertiliser	15670	1	15670	0.12801	0.721056
dung*mulch	289330	1	289330	2.36365	0.126515
fertiliser*mulch	115283	1	115283	0.94179	0.333540
dung*fertiliser*mulch	10642	1	10642	0.08694	0.768558
Error	16647543	136	122408		

8.3.2 Total biomass data

The other aspect of the analysis considers the combined dry matter yield of all the species, where consideration was given to species as replicates. Similar to the results of the individual species the use of mulch significantly ($P < 0.05$) increased yield, but application of dung and fertiliser did not (Table 8.7). No significant interaction occurred between any of the factors.

In general, the analysis implicated the value of the use of mulch when planning to restore degraded land by means of oversowing practices. The use of mulch increased biomass yield significantly over that of no mulch ($P < 0.05$). Yield was increased from about 40 kg ha^{-1} to about 550 kg ha^{-1} by the application of mulch (Fig. 8.7).

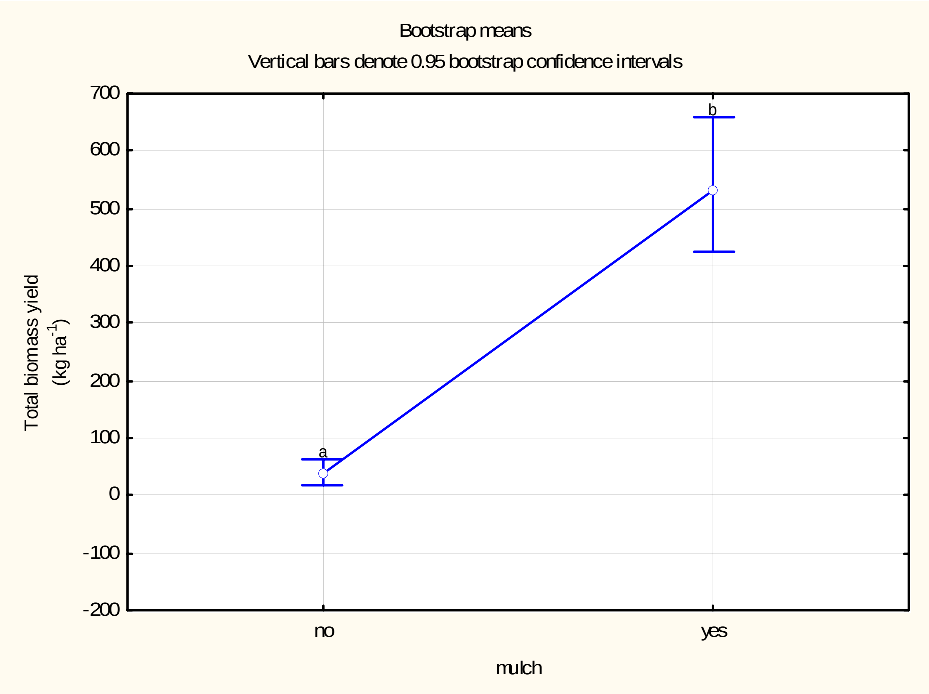

Figure 8.7 The influence of mulch application on the combined dry matter yield of all the sown grass species in the severely degraded area of the Allaidege rangeland in 2003 (Data points with different superscripts differ at $P = 0.05$).

Comparisons between mean dry matter yields of the species were made by using one-way ANOVA and subsequent bootstrap analysis. The comparison was made only for the mulch treatment, which showed a significant positive effect on dry matter yield in the analysis. Among the six species, *I. afrum* and *T. berteronianus* produced significantly more dry matter than *E. rupestris*, *C. gayana* and *P. coloratum* but *I. afrum* did not differ significantly from *C. ciliaris*. *Ischaemum afrum* and *T. berteronianus* each produced more than 800 kg ha^{-1}, while *C. ciliaris* produced just over 400 kg ha^{-1} dry matter. *Enteropogon rupestris*, *C. gayana* and *P. coloratum* attained the lowest yield of between 200 and 400 kg ha^{-1} (Fig. 8.8). However, their ability to cover the soil and the role they play to improve soil conditions outweigh the poor yield performance.

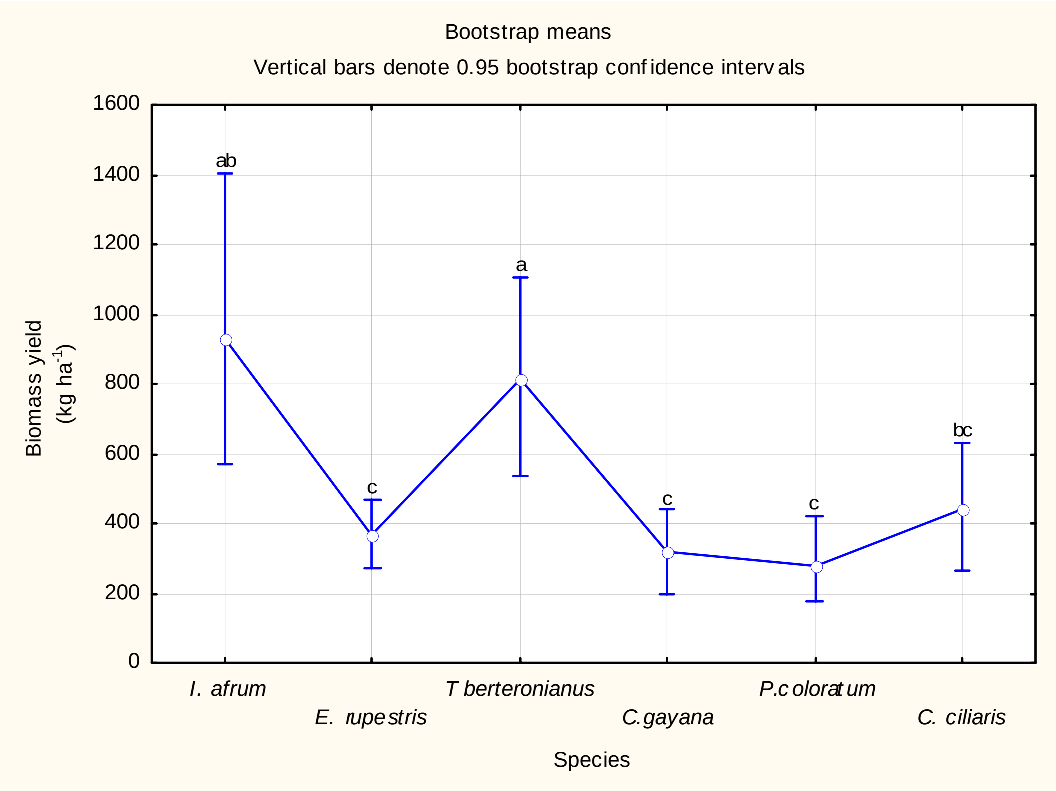

Figure 8.8 The dry matter yield of each species sown in the severely degraded area of the Allaidege rangeland where mulch was applied in 2003 (*I. afdrum* = *Ischaemum afrum, E. rupestris* = *Enteropogon rupestris*, *T. berteronianus* = *Tragus berteronianus*, *C. gayana* = *Chloris gayana*, *P. coloratum* = *Panicum coloratum* and *C. ciliaris* = *Cenchrus ciliaris*) (Data points with different superscripts differ at P = 0.05).

8.4 Discussion

The mulch treatments resulted in a significant dry matter yield increase for all the sown species. The finding in general entailed the importance of moisture and its role in affecting plant germination and establishment in arid and semi-arid areas. To this effect, Hassanyar (1977) emphasized the harsh environmental conditions of arid and semi-arid areas and suggested mulched seedbeds when grass species are to be seeded. In addition, Call and Roundy (1991) reported the success and failure of re-vegetation being affected by climatic factors: primarily low and erratic precipitation and extreme temperatures. This study indicated that mulch application had ameliorated the environmental conditions for better seed germination and establishment. Hopkins (1954), Rickert (1970), Lavin, Johnson and Gomm (1981), Jordaan and Rautenbach (1996) and Van den Berg and Kellner (2005) reported the successful germination and establishment of seeds through the use of organic mulches by altering constraints associated with moisture and temperature. Recently Dannhauser (2004) reported the importance of mulch in improving dry matter production in an already established sparse *C. ciliaris* pasture. This is due to the organic mulch lowering the soil temperature and consequently increasing moisture content by reducing evaporation.

Among the seeded species in this study *I. afrum* produced the most dry matter (close to 900 kg ha^{-1}) compared to the other species. This species is not often utilized by animals in the mature state but grazed mostly in the early growing season (Personal communication with clan leaders & herdsmen, 2003). Despite this the community prefers it for household purposes such as cover for shelters, bedding material etc. It has economic benefit at household level and is a good grass to cover the soil due to its rhizomatous stems (Van Oudtshoorn, 1999) and improve growing conditions for other perennial grasses in the later successional stages. These factors contributed to the species being ranked as a high priority grass within the pastoral community.

On the other hand *C. ciliaris* was the only species to react differently showing a significant positive response to fertiliser treatment. The fertilized mulched plot had an increase of 300 kg ha^{-1} relative to the unfertilized mulched treatment plots (Fig. 8.6). This agrees with the findings of Bogdan (1977) who reported the response of *C. ciliaris* to P and N application. The significant yield response of *C. ciliaris* to the use of N and P fertilisers was also reported by other researchers (Mutz & Drawe, 1983; Wiedenfeld, Wooward & Hoverson, 1985; Rao, Singh, & Wight, 1996). It is however not practical to advocate the use of fertiliser taking into account the cost of fertiliser. In contrast, dung is freely available in the area. The use of dung had implicated a yield difference of 150kg ha^{-1} for the mulch and dung application compared to the yield difference of 100 kg ha^{-1} attained from the use of mulch and fertiliser treatments. The small quantities of dung applied (1 mm thick on the seeds in the row) could have been the cause of the poor response to the organic manure treatment. Application of more substantial quantities of dung may cause more significant responses in dry matter production.

Cenchrus ciliaris is a drought resistant grass growing under annual rainfall ranging from 270-300 mm (Bogdan, 1977) or in growing season rainfall of 180 and 250 mm where it reaches its genetic productivity potential (Rao, *et al*., 1996). In this study, *C. ciliaris* produced the best in yield compared to the other seeded imported species. It is the most popular cultivated pasture in the more arid parts with characteristics of a deep root system and endurance to trampling (Van Oudtshoorn, 1999).

In conclusion this study could give us a better understanding of the type of species and restoration technologies to be applied to restore degraded patches in similar arid environmental conditions of the country. Hence, from the results of this study, we reject the null hypothesis and accept the alternative hypothesis indicating the difference in success rate of different restoration techniques in the severely degraded area.

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CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

The Afar Region is endowed with a total rangeland surface area of about 91,172 km^2, which comprises about 99% of the Regional area. This rangeland is characterized by low precipitation, high temperature and excessive evaporation unsuited to stable rain fed agriculture (MCE, 2000). These rangelands are the main animal feed source and backbone of the economy of the region in general and the mainstay of the people in particular. However, natural and human catastrophies (climatic factors and poor management) are putting much pressure on the feed resources of the region causing overgrazing of the range (Beruk, 2000). Among the prominent extensive grasslands, the Allaidege rangeland is under continual pressure by livestock and is now considered as a rangeland where range resource degradation is taking place at an alarming rate. This grazing induced ecosystem change leads to change in vegetation and soil status of the grazing area especially in the vicinity of the boreholes that was established.

This study indicated an average yield production of 1520 kg ha^{-1} dry matter over the two growing seasons of 2003 and 2004. Based on this production figure, the 200 000 ha rangeland will produce 304 000 t ha^{-1} dry material. The utilizable forage is calculated based on the principle of graze half and leave half system (MCE, 2000). If it is assumed that a Tropical Livestock Unit (TLU) ingests 5 kg dry matter day^{-1}, the average number of animals that the range will sustain is estimated to be 83 333 TLU per year or is expressed as 2.4 ha TLU^{-1} (see Chapter 5 for detail). This is the maximum stocking rate possible without damaging the vegetation or other related resources, although the actual stocking rates do fluctuate with season due to a fluctuation of available forage production.

The grazing capacity of the rangeland was related to the livestock (cattle and sheep) population of the administrative zone estimated as 1 201 814 cattle and 381 285 sheep (MCE, 2000). Although the livestock population of the zone is probably exaggerated, it was decided to adhere to the numbers considering the intensity of degradation observed in the range. Accordingly, about half of the total stock numbers, *i.e.* 451 717 TLU of cattle and sheep are assumed to utilize the Allaidege rangeland, exceeding the capacity of the rangeland by 368 384 TLU. To make the calculation, the livestock numbers were first converted to standardized livestock units (MCE, 2000), where TLU is equivalent to an animal weighing 250 kg, therefore, cattle = 0.72 TLU and sheep = 0.1 TLU. Consequently, the approach to the stocking rate was made considering the total TLU of cattle and sheep of the zone, mainly on account of the fact that they are the primary grazers. From this population 50% of the total TLU of cattle and sheep are assumed to graze in the Allaidege rangeland because of the dependency of the local people on the rangeland and from the perception that it is the rangeland with the highest potential in the area.

This excessive stocking rate contributed to range degradation, which leads to reduction in biomass production, cover and quality. In areas where watering points are located there is a very high livestock pressure resulting in overgrazing and trampling of the vegetation. This is clearly observed in this study in the severely degraded (SD) and moderate to severely degraded (MSD) areas, where perennial grasses are almost non-existent and are limited in abundance ultimately reducing the potential biomass yield of the area.

Concurrently, the injudicious grazing practices also caused a shift in species composition from palatable perennial species dominated vegetation cover to annual grass and unpalatable forbs dominated cover. These species vegetation cover is what characterized the SD and MSD grazing gradients of the study area close to the watering point. This is illustrated by the abundance of *Setaria verticillata*, a pioneer annual grass and the less palatable perennial grass species *Sporobolus ioclados* and *Paspalidium desertorum*. This decrease of palatable perennial grasses is attributed to selective grazing (Tainton, 1972; Noy-Meir; Gutman & Kaplan, 1989) due to the fact that selectivity by animals is positively associated with protein, potassium and phosphorus content (Heady, 1964). Boudet (1975) also confirmed that loss of animal preferred species is usually associated with a decline in the nutritional value of the available forage. In this study, the frequency of abundance of perennials was decreasing along the grazing gradient closer to the watering point. Overgrazing being evident in the country and the fact that the traditional grazing practices have been applied for decades throughout the lowland rangelands, the trend in vegetation change is very likely to exist throughout the other lowland grazing territories of Ethiopia, with annual grasses and unpalatable species dominating the grazing area close to watering point. Alemayehu (Undated) identified overgrazing as a major feature of lowland rangelands and stated that grazing areas near watering points where the vegetation cover is dominated by unpalatable plants is most affected. In the Borana rangeland of southern Ethiopia, range degradation, particularly species composition change was reported around grazing areas where water development interventions was established (Oba, 2001). Similar to this study, the grazing area was dominantly covered by annual grasses and unpalatable species (Oba, 2001; Homann & Rischkowsky, 2005). However, study on botanical composition and basal cover by Ayana and Baars (2000) in the Borana rangeland did not show significant differences at varying distances from water sources. The fact that grazing areas less than 2 km from water sources were not included in their study explains the inconsistency with this study in Afar and other studies in Borana. The loss of nutritional quality attributed to the loss of perennial species was not apparent in the study, which agrees with the finding of Alami *et al*. (1997) and Van Oudtshoorn (1999). However, the fact that the herbaceous vegetation has a high nutritional quality does not necessarily mean that intake of the vegetation will be satisfactory – palatability of the species will influence the fodder value of the species. Nevertheless, very low biomass yield of these species was recorded in the study.

In context of the important implications of perennial species in sustaining both animal production and soil conservation the need to capitalize on these species should be a central focal point of range management studies. Even though no conclusive data was presented, Alemayehu (Undated) had generally reported the risk of degradation of soils near watering points implicating the reduction of both infiltration and water holding capacity. Ayana and Baars (2000) carried out a preliminary study on soil condition in the Borana rangeland and found insignificant differences in terms of soil erosion and compaction in sample sites at various distances from water sources. The loss of vegetation cover resulting in deleterious effects on soil status was reported in this study, where it caused high concentrations of sodium in the SD area. This causes dispersion of colloids; low permeability of water and air and reduction of plant growth. This in general emphasizes the need for quick remedial attempts before conditions become extreme and reach an irreversible stage, particularly in the SD area. In order to stop the degradation this study made a preliminary investigation into the rehabilitation of the area through the use of active restoration procedures. Disturbance of the soil to break the soil crust for ease of infiltration of water was made before seeding the local and exotic species in the respective treatments. The study exhibited a significant yield performance difference of the seeded species under the grass mulch cover, providing evidence of the importance of moisture in enhancing plant germination and establishment in arid and other moisture deficit areas.

Trained range management personnel to start with extensive range management activities at field level are a prerequisite to radically improve conditions in the rangeland. Currently, at national level, let alone at regional level, there is a shortage of trained staff in range management at both professional and technical levels. The situation is extremely serious in the Afar Region where no single trained professional or technical staff member is available. The Regional Bureau of Agriculture should take the lead to fill these technical and professional positions to implement quick and effective measures to improve the range resource in the region. The staff in this discipline should have the interest and commitment to share the responsibility to address the lack of knowledge by creating opportunities to educate the community. Secondly, they should be dedicated to change the views of the pastoral community by means of intensive extension systems that involve the local leaders of the community.

The extension as well as the training delivered should make use of a holistic approach (animal feed, animal production, marketing and related social aspects (population increase)) to address the constraints of the rangeland improvement activity. The active participation of locally organized institutions and other social set-ups are key aspects of range management and development actions from initiation to implementation of the plan. UNDP (1984) recognized a broad base rationalization program that could enable the production system to perform better. Settlement around the river basin as a viable alternative was mentioned because it will prevent more people from settling on the rangeland and creating additional pressure.

The other aspect to be considered is the creation of efficient marketing services (finishing and processing plants) for livestock in strategic production centers to narrow the gap between producer and processing plants. Last but not least, because of the size of the production system in the country and the important role it plays in the national economy, attention should be given to the establishment of autonomous institutions to concentrate on local affairs in the different areas.

Sufficient knowledge and technology at their disposal should bring about a change in the traditional management systems of local communities. This could lead to optimal use of resources such as the proper matching of the feed resources and sizes of herds and the use of feed resources to a level where recovery of the vegetation becomes possible.

In conclusion, the study indicated how the current management system in rangelands exacerbates the deteriorating vegetation and soil resources. However, rangeland as the central livelihood of the people of Afar, along with its contribution to export earnings at national level makes it a vital economic sector. Thus the community should be (1) aware that overstocking is causing range deterioration and implementation of remedial measures to overcome the problem (mainly resting the grazing area and removing the excess unproductive animals) should be a priority. (2) The degradation is also more aggravated by the permanent settlement of the community close to the watering point, leading to unrestricted grazing in the area, which needs to be seriously controled and restricted by the community.

(3) Moreover, a large size of the SD area has lost vegetation cover, resulting in deleterious effect on soil status, which needs quick remedial action by the community before extending deep into the grazing area. Hence, the community should agree to actively participate in rehabilitating the SD area. (4) Simultaneously, the need to apply alternate resting periods to the rangeland in appropriate seasons is of paramount importance to initiate recovery of the grazing land before overgrazing is severe and degradation reaches an irreversible stage and extend in size deep into the range area. This necessitates at the same time the introduction and application of rotational grazing systems. It is important to integrate indigenous knowledge of the community to support the practical application of such systems in the future (Oba, 2001). In addition the promotion of applied research-based information with the intention to fill the gap in the knowledge base in the country in general and in Afar Regional State in particular is of paramount importance. More-over, climate, especially rainfall is known to be the primary determinant of species composition of arid and semi-arid areas (O'Connor, 1985; O'Connor, 1991). Thus rainfall variability as an important influence of species compositional change has to be confirmed in the future. In addition the estimation of grazing capacity of the range is done from the recorded yield of the study area, which represents a relatively small portion of the range. Hence the best way to carry out the study is to collect samples in different areas of the range repeatedly over a number of years to obtain reliable data. The use of faecal analyses to determine the quality of fodder selected by animals could be investigated as a tool to determine forage quality and carrying capacity of rangeland (Mbatha & Ward, 2006).

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APPENDIX

Appendix 4.1. Summary of classification tree methodology

In the case of classification trees the dependent (response) variable y is a discrete variable consisting of 2 or more classes (eg yes/no, present/not present, low/medium/high). (For continuous response variables, a similar technique called regression trees can be used.)

The concept of entropy

The concept of entropy (chaos) is used as basis for constructing classification trees. To explain entropy in the framework of classification trees, consider a response variable with 2 classes namely yes/no. If a data set consists of 50% yes and 50% no responses, then the entropy of that data set is a maximum because the data will have only a 50% chance of correctly predicting the class of the response variable. As the proportion of one of the classes tends to 100%, the lower the entropy becomes, and it reaches a minimum when a data set consists of 100% of one class. In this case the data will have a 100% chance of correctly predicting the class of the response variable.

Entropy can be calculated from a dataset using various methods of which the Gini measure is probably the most common in classification trees.

The aim of a classification tree is to divide the data set into subsets such that the subsets have a lower entropy than the full data set. Thus it strives to group the classes together into subsets as best possible based on the independent or predictor variables. This is achieved as follows:

Case 1: One continuous independent variable(*x*)

The method selects a point x_p between the minimum and maximum of x that splits the data into two sets (or nodes in a tree). All the cases for which $x \leq x_p$ goes to the left node and all the cases where $x > x_p$ goes to the right node.

The point where the split is made is the point that decreases the entropy from the parent node to the child nodes the most.

The procedure above is then repeated for each of the two nodes. Thus a binary split is made on each node using the criteria mentioned above.

Stopping rules are used to decide when the splitting process should stop. For example a minimum number of cases per node can be specified, and if that minimum number is reached, the node will split no further.

Case 2: One categorical independent variable

In the case of a categorical independent variable, all combinations of binary splits of the levels of the variable are considered and the combination that most successfully decreases the entropy are used as splitting criteria. For example if a variable has three levels namely *a*,*b* and *c* then the following combinations of splits will be considered:

Left node	Right node
a	*b*,*c*
a,*b*	*c*
a,*c*	*b*

Case 3: More than one independent variable (combination of continuous and discrete)

The procedure described above is applied to each variable independently. Then the variables are compared with one another and the one that provides the best split over all the variables is used as the splitting variable.

Variable importance

A variable importance factor in terms of its effect on the response variable can be derived once the tree has been built. This variable importance is calculated based on the number of times the variable was used as splitting variable and how well it separated the classes of the response variable.

Appendix 4.2. Summary of regression tree methodology

In the case of regression trees the dependent (response) variable y is a continuous variable. (For categorical response variables, a similar technique called classification trees can be used.)

Case 1: One continuous independent variable(*x*)

The method selects a point x_s between the minimum and maximum of x that splits the data into two sets (or nodes in a tree). All the cases for which $x \leq x_p$ goes to the left node and all the cases where $x > x_p$ goes to the right node.

The point where the split is made is the point that most successfully separates the high response values from the low ones. This is done by minimising the variance of the response variable in each of the two sets.

The procedure above is then repeated for each of the two nodes. Thus a binary split is made on each node using the criteria mentioned above.

Stopping rules are used to decide when the splitting process should stop. For example a minimum number of cases per node can be specified, and if that minimum number is reached, the node will split no further. Also, if the reduction in variance of *y* from a parent node to the child nodes is not "significant", it will stop splitting. Usually, stopping rules will be slack, so as to build a large tree. A process of pruning will then combines nodes and reduces the size of the tree to an "optimal" size.

Case 2: One categorical independent variable

In the case of a categorical independent variable, all combinations of binary splits of the levels of the variable are considered and the combination that most successfully separates the high response values from the low ones are used as splitting criteria. For example if a variable has three levels namely *a*,*b* and *c* then the following combinations of splits will be considered:

Left node	Right node
a	*b*,*c*

a,*b*	*c*
a,*c*	*b*

Case 3: More than one independent variable

The procedure described above is applied to each variable independently. Then the variables are compared with one another and the one that provides the best split over all the variables is used as the splitting variable.

Variable importance

A variable importance factor in terms of its effect on the response variable can be derived once the tree has been built. This variable importance is calculated based on the number of times the variable was used as splitting variable and how well it separated the low values from the high values.

Appendix 7.1. Summary of soil analytical data for samples collected from each grazing gradient.

				Excha. cations					% base saturation						
Field	Plots No.	Ca	Mg	Na	K	TEB	CEC	Ca (%)	Mg (%)	Na (%)	K (%)	ESP (%)	SAR	pH	EC ds/m
1	1	7.02	1.01	2.76	0.248	11.038	20.1	34.93	5.02	13.73	1.23	13.73	1.38	8.95	0.86
1	2	7	1	2.58	0.251	10.831	19.95	35.09	5.01	12.93	1.26	12.93	1.29	8.99	0.77
1	3	6.05	1.97	2.54	0.241	10.801	29.95	20.2	6.58	8.48	0.8	8.48	1.27	8.94	0.83
1	4	7.02	1	2.46	0.243	10.723	29.85	23.52	3.35	8.24	0.81	8.24	1.23	8.87	0.79
1	5	6.09	1.01	2.5	0.231	9.831	20.25	30.07	4.99	12.35	1.14	12.35	1.33	8.9	0.81
mean		**6.64**	**1.19**	**2.56**	**0.24**	**10.63**	**24.02**	**28.76**	**4.99**	**11.15**	**1.05**	**11.15**	**1.3**	**8.9**	**0.81**
2	6	7	1	2.24	0.238	10.478	29.85	23.45	3.35	7.5	0.8	7.5	1.12	8.73	0.71
2	7	7.01	1.08	1.57	0.228	9.888	30.15	23.25	3.58	5.21	0.76	5.21	0.78	8.4	0.78
2	8	5.09	1.98	1.98	0.228	9.278	25.3	20.12	7.83	7.83	0.9	7.83	1.05	8.63	0.93
2	9	6.08	1.92	1.27	0.214	9.484	25	24.32	7.68	5.08	0.86	5.08	0.64	8.36	0.53
2	10	6.04	1.98	1.15	0.219	9.389	25.01	24.15	7.92	4.6	0.88	4.6	0.58	8.42	0.74
mean		**6.24**	**1.58**	**1.64**	**0.22**	**9.7**	**27.06**	**23.06**	**6.07**	**6.04**	**0.84**	**6.04**	**0.83**	**8.51**	**0.74**
3	11	7.09	0.98	1.12	0.258	9.448	24.85	28.53	3.94	4.51	1.04	4.51	0.56	8.43	0.79
3	12	7	1.05	1.49	0.216	9.756	25	28	4.2	5.96	0.86	5.96	0.75	8.4	0.71
3	13	7.04	1.01	1.08	0.233	9.363	20.25	34.77	4.99	5.33	1.15	5.33	0.54	8.47	0.67
3	14	6.08	1.99	0.93	0.189	9.189	20.03	30.35	9.94	4.64	0.94	4.64	0.47	8.67	1
3	15	6.09	1.91	0.97	0.26	9.23	20.15	30.22	9.48	4.81	1.29	4.81	0.49	8.56	0.73
mean		**6.66**	**1.38**	**1.11**	**0.23**	**9.39**	**22.05**	**30.37**	**6.51**	**5.05**	**1.06**	**5.05**	**0.56**	**8.51**	**0.78**
4	16	6.05	2.01	1.15	0.224	9.434	20.1	30.1	10	5.72	1.11	5.72	0.58	8.39	0.56
4	17	6.09	1.99	1.19	0.248	9.518	20.15	30.22	9.88	5.91	1.23	5.91	0.60	8.52	0.67
4	18	7	1.06	1.04	0.204	9.304	19.95	35.09	5.31	5.21	1.02	5.21	0.52	8.5	0.57
4	19	6.08	2	0.097	0.243	9.293	19.85	30.63	10.08	4.89	1.22	4.89	0.49	8.38	0.63
4	20	6.05	1.95	0.08	0.302	9.102	20.3	29.8	9.61	3.94	1.49	3.94	0.40	8.48	0.61
mean		**6.25**	**1.8**	**0.711**	**0.24**	**9.33**	**20.07**	**31.17**	**8.98**	**5.13**	**1.21**	**5.13**	**0.52**	**8.44**	**0.61**

Fields with the numbers represent each grazing gradient & plots are sample
Collection sites
Field 1=SD, Field 2=MSD, Field 3= MD,
Field 4 =LD
exchangeable cations, TEB & CEC are in meq100gm^{-1}.