NUTRIENT CYCLING IN GRAZING SYSTEMS

By

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A thesis submitted in fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

in the

Discipline of Grassland Science

School of Applied Environmental Sciences

Faculty of Science and Agriculture

University of KwaZulu-Natal

Pietermaritzburg

2004

DECLARATION

This thesis documents research conducted at the University of KwaZulu-Natal under the supervision of Professor KP Kirkman.

The results covered in this thesis are from the author's original work except where acknowledged or specifically affirmed to the contrary in the text. It has not been submitted for any degree or examination at any other university or academic institution.

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ABSTRACT

This research was conducted at the University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research encompasses five different studies to assess nutrient cycling in intensive and extensive grazing systems with a view to optimising livestock production.

The first study was designed to assess the effect of teff-lucerne mixtures on teff, lucerne and teff-lucerne mixture yields. Lucerne and teff-lucerne mixtures benefited from the association. The overall soil N content of the teff-lucerne mixture plots was greater than the teff alone plots.

The second study focused on teff-leucaena association evaluation. It had two leucaena plant row spacings as treatments, 180cm and 120cm, respectively. Teff grown in mixture with leucaena produced a total teff dry matter (DM) of 7931.57 kg ha^{-1} for the 180cm row spacing and 8329.57 for the 120cm row spacing compared to the 3548.93 kg ha^{-1} of DM obtained from the teff alone treatment. The teff-leucaena stand also had a greater DM yield response to leucaena row spacing compared to the teff alone. In terms of nutritive quality, all stands from the teff-leucaena plots were better than the quality obtained from the teff alone plots. Total N content of teff from the 180cm row spacing was 21.83 g kg^{-1} and that from the 120cm 16.07 g kg^{-1} compared to the total nitrogen (N) content of 19.77 g kg-1 of the teff alone treatment. The total phosphorus (P) content was 2.73, 1.96 and 2.07 g kg^{-1} for the 180cm, 120cm and teff alone treatments respectively. However, the total soil N content was higher for the teff alone plot than for the teff-leucaena plots, which are 1.91, 1.48 and 100 g kg^{-1} for the teff alone, 180cm and 120cm treatments respectively.

The third study was designed to assess the effects of different N fertilizer application rates on teff yield response. The rates applied were 0, 50, 100 and 150 kg N ha^{-1}. There was significant difference in teff response of the three N fertilizer application rates compared to the control and teff DM yield response was lower for the 150 kg N ha^{-1} (838 kg ha^{-1}) treatment compared to the control (553 kg ha^{-1}). Both teff DM and nutritive value were higher in the plots treated with N fertilizer than in the plot which received no N fertilizer (control). The soil N content was also higher in those plots treated with N fertilizer.

Study four was conducted on the Department of Grassland Science's grassland management techniques trial field at Ukulinga. The effects of nutrient cycling under different management techniques such as burning, mowing and grazing on grass yield response, plant quality and soil nutrients were assessed. However, the response of grass DM yield and P content was not significant but the three treatments had a significant effect on grass N content. Their effect on soil N content was also significant and the grazing plot had the greatest soil N levels.

The last study was conducted in the rural areas of Okhombe and Zwelitsha to assess the effects of grazing intensity on grass yield response, plant quality and soil nutrient status at different distances from homesteads. Grass DM yield and nutritive value declined when distance from the homestead increased. The soil N content also was higher nearer to the homestead than further away.

Most farmers, particularly in developing countries including those in Eritrea, often experience that their animals prefer forages from some plants such as lucerne, leucaena, and other indigenous leguminous plants. They also observe that they get greater yield from crops grown near leguminous plants or in rotation with legumes. They are also still using manure from their animals to fertilize their croplands. Therefore, it is still the duty of the researchers to demonstrate to farmers on farm studies to convince farmers that it is because leguminous plants have the ability to add quality and quantity to the feed of the animals and soil nutrients to the croplands. Hopefully, this study will convey to farmers the use of growing integrated grass/legume pastures and crops, and illustrate that livestock have their own role in transporting nutrients and hence use them as good means of distributors of soil nutrients.

ACKNOWLEDGEMENTS

I extend my gratitude to the following organizations and individuals:
The Government of the State of Eritrea which provided the financial assistance to conduct the study.

I am deeply indebted to my supervisor, Professor KP Kirkman for his guidance in conducting my study, his willingness to share his ideas and knowledge, his support, understanding, patience, and friendship.

Mention must be made of the Grassland Science technicians, LP du Toit in assisting with the setting of the trials at Ukulinga Research Farm and the rural villages of Zwelitsha and Okhombe and his regular follow up, and G Naiken in assisting with laboratory work and in providing all the necessary materials. I would also like to thank the staff members and Department of Animal and Poultry Science for helping and allowing me to use their laboratory tools and equipments in the chemical analysis of plant and soil samples.

I also thank Craig Morris and Richard Fynn for their valuable input and effort with regards to the statistical analysis of the data and its interpretation. Habteab Ghebrehiwot and Essayas in helping me in drawing the graphs using the PlotIt software. Mohamed Saleh Abdella for staying often by my side during bad and good times. I am grateful to M. Tau for giving me the information on the rural communities of the villages of Zwelitsha and Okhombe. I would like to extend my thanks to Ms. M. Goddard, B. Hoosen and T. Karalic for their help. The staff and students of the Grassland Science must be also mentioned for their comradery throughout my study life. Great mention is also made of people who contributed in different yet significant ways during the course of the study. Samanta, Thulani, Michael, Sam and others who helped me in the field work.

Finally, I deeply appreciate my parents and family for their patience and faith in me.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Pastures and rangelands cover about 6.7 billion hectares of the world's land area, and if all the uncultivated land with potential to support grazing/browsing is included, then rangelands comprise 70% of the total land area. Grasslands and savannas alone comprise natural vegetation of 33 million km^2 (25% of the earth's surface). Regardless of this big size, the rate of annual net primary production from these areas, however, typically falls in the range of 100-160 g m^{-2} yr^{-1}, although values above 1000 g m^{-2} yr^{-1} have been reported (Singh and Ghosh 1993).

Globally, the majority of rangelands support grazing/browsing animals in a variety of intensive livestock production systems ranging from privately and/or communally owned commercial livestock enterprises to subsistence sedentary/nomadic extensive livestock production systems. Irrespective of the livestock production system, any herbivore system on rangeland is dependent on the forage produced by the rangeland (Kirkman and de Faccio Carvalho 2003).

1.2 JUSTIFICATION

Currently, the feed supplying potential of rangelands is continuously declining due to increased human and animal populations and other anthropogenic influences, especially in the developing countries. Apparently, this leads to the cultivation of more lands that are less suited for farming to increase food supplies in order to balance the ever increasing food demands (Singh and Ghosh 1993; Cooper *et al.* 1996; Kirkman and de Faccio Carvalho 2003; Lekasi *et al.* 2003). The consequences are then increased livestock pressure on the remaining suboptimal rangelands, deterioration of both crop and rangelands in productivity, and eventually exposing farmers and pastoralists to other additional challenges that need solutions (Singh and Ghosh 1993).

For instance, about 80% of the rangelands and 60% of the croplands in the dry regions of developing countries are declining in productivity. Moreover, rangelands are shrinking because the best areas are used to grow crops. For example, in Asia, permanent cropland increased by 3.3% and total permanent pasture decreased by 2.8% between 1970-1985. A considerable loss of rangelands is also occurring in the semi-arid zones of sub-Saharan Africa. For example, in the Baringo district of Kenya pastoralists have lost 75% of their dry-season grazing areas to cultivators. In addition to increased population growth, expansion of cultivation to rangelands, the development of irrigation schemes, transfer of land from smallholders and pastoralists to large-scale private agribusinesses are also some of the possible causes for rangeland shrinkage (Singh and Ghosh 1993).

Moreover, forage quality in tropical grasslands varies seasonally, which negatively affects animal performance (Zacharias *et al.* 1991). Despite these limitations, however, animal husbandry from these natural feed resources still plays an important role in the economy of arid zones (Ogwang 1986; Singh and Ghosh 1993; Cooper *et al.* 1996; Tainton *et al.* 2000).

The smallholder is most affected by these factors because the limited number of animals makes him more prone to risks and lowers his financial security. Purchase of fodder is usually out of the question due to financial limitations. Thus, the whole system of livestock production in arid and semi-arid zones is facing countless feed shortage problems, resulting in increased requirements for scientific solutions (Singh and Ghosh 1993; Cooper *et al.* 1996; Mureithi *et al.* 2003).

One of the greatest concerns of land degradation is a long-term soil fertility decline (Hartemink *et al.* 1996; Mureithi *et al.* 2003; Oyetunji *et al.* 2003). This is aggravated by the increasing cost and environmental unsustainability of inorganic fertilizers. As a result, scientific input to evaluate locally available organic fertilizers such as crop residues, animal wastes and other organic fertilizer sources is needed. Recently, research has focused on the evaluation of the quality, quantity and ways of utilization of such biological fertilizer sources (Lekasi *et al.* 2003).

Thus, rangeland managers have a wide range of options to overcome livestock feed deficits and rangeland degradation problems. As alternatives, the incorporation of forage legumes into grazing pasture/cropland systems, the use of crop residues for animal feed and soil fertility amendment, establishment of legume forage trees (Cooper *et al.* 1996; Kirkman and de Faccio Carvalho 2003; Mureithi *et al.* 2003), and proper application and use of animal wastes can partly substitute and cut the cost of inorganic fertilizers, and consequently the cost of livestock production systems (Smith *et al.* 2000).

1.3 OBJECTIVES

The aims of this study include:

1) Determination of the effect of various legume-grass mixtures on the dry matter yield and nutritive quality of herbage produced in relation to monocultures;
2) Comparison of the nutritive values of grass herbage samples obtained from nitrogen fertilizer treated plots and those obtained from legume-grass mixtures;
3) Investigation of nutrient distribution by grazing animals in grazing systems; and
4) Relating the above findings to livestock production systems in Eritrea.

CHAPTER TWO

OVERVIEW OF LIVESTOCK PRODUCTION SYSTEMS IN ERITREA WITH A FOCUS ON NUTRIENT CYCLING

2.1 INTRODUCTION

Nutrients in agricultural systems cycle through soil organisms, pasture plants and grazing livestock. When nutrients are cycled efficiently, they move through various soil organisms and pasture plants (e.g. legumes) then, when plants are ingested, through the grazing animal back to the soil again as faeces and urine. These all work together to produce quality soils that sustain good-quality pasture that is palatable to livestock, and harbours living organisms which are ready to break down manure and plant residues to be used again (Beetz 2002).

However, as the scale and intensity of livestock production systems increase, environmentally responsible and agronomically sound practices for the utilization of nutrients in organic materials such as animal manure are needed. Manure is a source of various plant nutrients, but it is most recognized and emphasized as a source of nitrogen. Thus, through proper management and application techniques, it can meet crop N requirements depending on cropping systems, environmental and soil factors, N demand and transformations and movement (Mooleki *et al.* 2002).

It is also believed that the calcium carbonates and organic acids in manure increase the pH of acidic soils by reducing the solubility of elements such as aluminium and manganese that hinder the absorption of macronutrients (Whalen *et al.* 2002). However, care is needed as excess and inappropriate applications of animal manure would cause crop damage, soil salinization, nutrient imbalances and excessive nutrient losses (Mooleki *et al.* 2002; Whalen *et al.* 2002).

Recycling of plant nutrients is of major concern in managing grazing systems (Wells and Dougherty 1997). The extent and rate of return back to the soil, however, greatly affects fertilizer requirements in intensive pasture systems because nutrients not only join the cycle from different sources but also get lost through different paths (Figure 2.1) such as through the harvest of plant or animal products and by products, fixation and precipitation of nutrients in the soil, volatilisation, and surface runoff (Follett and Wilkinson 1995).

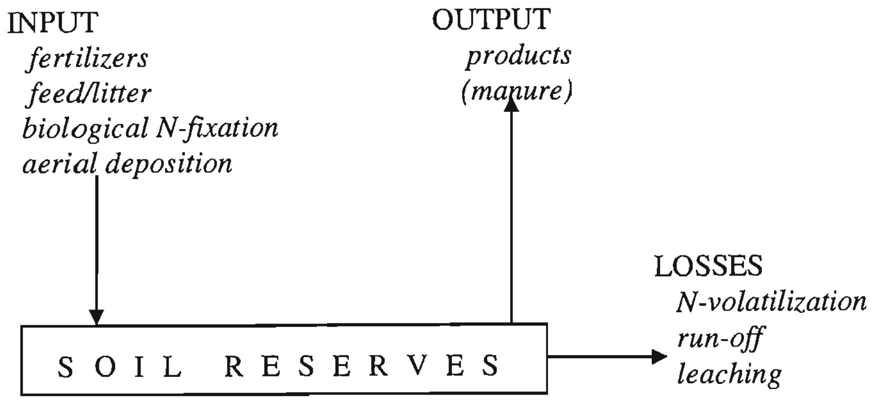

Figure 2.1 Nutrient flows in agro-ecosystems (Hermans and Vereijken 1995).

2.1.1 Crop-livestock farming systems

Nutrient balances are negative for many cropping systems due to greater product offtakes than inputs. Consequently, the removal of soil nutrients without adequate replacement has caused crop yields to decline over time. Furthermore, rather than replacing the removed nutrients, farmers prefer to cultivate more marginal lands to maintain crop production levels. Accordingly, grazing lands become scarce so that livestock have to depend more on crop residues, especially during the dry season. The consequence of this is an increase in grazing pressure on the grazing lands during the wet season. Thus, mixed farming systems become pivotal for sustainable livestock productivity. However, continuous and total removal of crop residues by grazing should be avoided. This, coupled with other crop residue removal activities, could leave soil underprotected against high temperatures, water and wind erosion. Animal and manure management, therefore, play a key role on how efficiently nutrients are cycled between livestock, soils, and plants (Powell and Williams 1993; Taddesse 2003).

There is a considerable potential for recycling nutrients by feeding crop residues to animals (McIntire *et al.* 1992; Nzuma and Murwira 2000; Taddesse 2003) and the interaction between the two systems has existed since ancient times. Crop residues feed the livestock and the animal excreta in turn maintain soil fertility. Livestock corralling is one of the simplest techniques of transferring livestock wastes to agricultural land. Through this method large quantities of nutrients can be applied locally, up to 3-14 t ha^{-1} of manure equivalent to 43-199 kg N ha^{-1} and 4.8-22.4 kg P ha^{-1} (Gandah *et al.* 2003) because, usually, grazing livestock use only a small proportion of the minerals they ingest, the rest, 80-90% of the nitrogen, phosphorus and potassium being excreted in cattle dung and urine (Mentis 1981; Powell *et al.* 1998).

Thus, the use of organic soil amendment is an important component for sustainable agriculture. Organic soil amendment, when properly applied, promotes sustainability. These include long-term positive effects on soil chemical and physical properties; recycling of plant nutrients; the possible substitution of readily available organic inputs for chemical fertilizers. The resultant of all of these is decreased dependence on external sources for costly inorganic fertilizers. In general improvement in crop yield and quality can be obtained when adequate rates of organic manures are incorporated into the soil (Jokela 1992; Motavalli *et al.* 1994; Hao and Chang 2003). It should be remembered also that any supplementary feed brought in from outside increases the supply of nutrients in the excreta of animals.

2.1.1.1 The grazing animal and soil productivity

Poor soil fertility and very low soil organic matter content in many regions of the Sahel have emphasised the need for the role of livestock in traditional soil management practices because these soils are deficient, particularly in nitrogen and phosphorus (Powell and Williams 1993; Taddesse 2003). Thus, biomass cycling through animal excreta forms the main bridge between livestock and soil productivity in grazing ecosystems and croplands (Figure 2.2). Manuring increases soil organic matter and nutrient availability; improves nutrient exchange, soil water holding capacities and soil structure; decreases soil crusting; and increases crop and forage yields (Powell and Williams 1993; Devendra 2000; Devendra and Chantalakhana 2002).

Usually, large quantities of dung and urine are deposited within grazing paddocks. Recent estimates indicate that animals on average use about 25% N, 20% P, and 15% K of what is consumed. This implies that 75% N, 80% P, and 85% K is eliminated in urine and faeces (Wells and Dougherty 1997). When recycled, these nutrients are or can become available to plants depending on the grazing practice implemented (Wells and Dougherty 1997), and the urination and defecation patterns of grazing animals (Weeda 1967). So, uniformity can be maintained by rotating grazing animals, and by controlling their stocking rate and water accessibility (Peterson and Gerrish 1995).

To manage grazing animals so that their wastes are distributed uniformly, it is good to know the frequencies of defecation and urination per day, and the area covered per elimination. On average, it is estimated at 10 defecations per bovine animal per day each covering about 0.09 m^2 for a daily total of 0.9 m^2 per head. Urination actions leave no visible short-term deposit on the surface to be quantified. However, the daily numbers of urinations are approximately the same as the number of defecations and are deposited in a similar manner over the field (Wells and Dougherty 1997; Owen-Smith 2000).

All nutrients added to the soil in animal wastes may accumulate and to some extent increase the potential release of nutrients in plant available forms in subsequent years. However, the amount immediately available to plants varies with water content, how the material is stored and handled, application methods and rate of decomposition in the soil (Taddesse 2003).

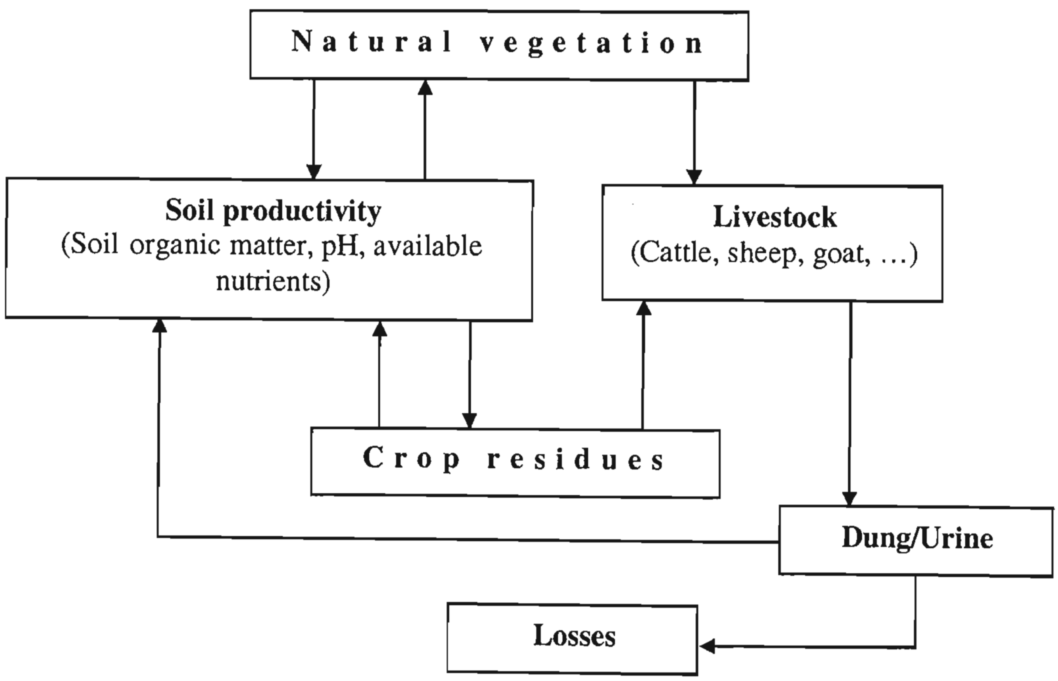

Figure 2.2 Livestock soil-productivity linkages in mixed farming systems (Powell and Williams 1993).

2.1.1.2 Factors affecting pattern of faecal and urine deposits distribution

Several factors influence the pattern of distribution of faeces and urine within a grazed field:

- Shade: provides loafing area for grazing animals and hence increased defecation and urination under shaded areas (Haynes and Williams 1993; Wells and Dougherty 1997).
- Field shape: depressions on the landscape also cause animals to congregate and, similar to shade, result in increased urination and defecation patterns (Wells and Dougherty 1997).
- Day/night time grazing: cattle defecate more during the night in areas where they rest than during the day when they move about and graze but they urinate more during the daytime (Wells and Dougherty 1997).
- Watering point proximity: excretal deposits are greater around water sources (Peterson and Gerrish 1995). Supplemental feeding sites within the field also have similar effects. Animals walking distances greater than 136.8m to water sources excrete nearly one fourth (22%) of their total manure deposits on the way to the water source (Wells and Dougherty 1997).
- Stocking rate and grazing duration: large grazing areas provide several days of grazing for the number of animals present and result in more deposits (Wells and Dougherty 1997).
- Animal species, age, size, and sex: affect herbage and nutrient retention and the ability to graze closely and selectively (Haynes and Williams 1993). Coupled with animal mobility behaviour these factors affect the return of nutrients in animal residues. For example, sheep tend to be more gregarious than cattle and enhance localization of excretal nutrient returns (Follett and Wilkinson 1995).

Generally, uncontrolled grazing will result in a net movement of nutrients from within the field to areas where animals congregate, thereby non-uniformly redistributing them and increasing the potential for increased nutrient, faecal material, and faecal bacteria runoff into surface water sources, following rainfall (Wells and Dougherty 1997).

2.1.1.3 Grazing management for efficient nutrient cycling

The types and amounts of manure nutrients available for recycling are highly affected by differences in land use and the spatial and temporal distribution of livestock dictated by animal management, and seasonal variability of feed. Under intensive cultivation and animal stall-feeding conditions, manure must be handled, stored, transported, and spread onto the field. However, all these processes contribute to nutrient losses, especially N decreasing its availability by about 50% of the total N originally excreted. Thus, it is always good to be aware that, intensified animal production systems could greatly reduce the amount of nutrients recycled. Likewise, in the extensive farming systems animals graze so that they are close to watering points. In these situations dung and urine deposition is highest in non-productive areas such as near watering points, resting areas and along animal passageways. This results in unnecessary accumulation of nutrients leading to a higher risk of nutrient losses (Powell and Williams 1993). Also nutrients are moved from remote areas to areas close to watering points, night grazing, homesteads (kraals), etc.

2.2 LIVESTOCK SYSTEMS IN RURAL LIVELIHOODS

In the agricultural system, in general, and in the livestock production sector, in particular, livestock provide incredible benefits to the rural and the urban societies. The importance of livestock production in tropical Africa is many-faceted. In addition to meat and milk, manure is a great offer by animals. It contains important plant nutrients that need major management both in the extensive and intensive livestock production systems to grow climatically adapted forage species and to sustain the system (Reynolds and Cobbina 1992; Wells and Dougherty 1997). According to Peterson and Gerrish (1995), 60-90% of nutrients consumed by grazing animals on average pass through the digestive tract. On the ground, these can promote up to 1 096 kg ha^{-1} pasture growth.

2.2.1 **Livestock production in Eritrea**

Eritrea is a country located 12°42' to 18°2' N and 36°30' to 43°20' E, in the northeastern part of Africa, as a crossroad bridge between the rest of Africa and the Middle East. The country comprises an area of about 124 000 km^2 (Ministry of Agriculture 1996; Kayouli *et al.* 2002; Weldeselasie 2003).

Agriculture is the foundation and mainstay of the country's economy and it is the basis of the rural development (Solomon 2002; Weldeselasie 2003). More than 70% of the population depends on agriculture for income, food and employment although agriculture accounts for only about 16% of the country's gross domestic product (GDP) and about 20-30% of its current merchandise exports (Solomon 2002).

Livestock rearing is an integral part of the Eritrean agriculture without which no single agricultural activity can be performed. They are used for ploughing cropping lands, draught power, source of income and wealth (Weldeselasie 2003). The livestock sub-sector alone accounts for about 25% of the agricultural GDP, a considerable part of the country's export earnings, and has a significant role in the socio-economical life of the rural community (Kayouli *et al.* 2002).

Livestock remains the main economic and family income generating activity. For instance, pastoralists derive more than 50% of their total food from livestock in the form of meat and milk. Livestock in Eritrea includes cattle, sheep, goats, camels and equine, as well as pig and poultry as non-grazing domestic animals. The livestock population is thought to have decreased by 50-70% because of frequent drought and war from 1970-1985. At present, there are 1.9 million cattle, 6.8 million sheep and goats, 319 000 camels, 518 000 equine and some 1.1 million poultry. The current livestock population is similar to that of the mid sixties (Mehretab *et al.* 2002; Mengistu 2002; Solomon 2002; Weldeselasie 2003).

The most common form of livestock production and rural land use is traditional grazing where livestock graze the rangelands freely through out the grazing period with no or little rotation. It has been estimated that 49% of the land is suitable for this use. The system has been under continuous pressure due to the shrinkage of grazing land and the progressive decline in carrying capacity as a result of rangeland degradation. One of the major causes of land degradation and low land productivity in Eritrea is soil fertility decline through soil erosion and cutting of trees for fuel and energy. Increasing population pressure and constant loss of pastoral lands to agricultural cultivation encroachments are also major constraints. Until recently few or no effective conservation measures were taken to halt soil erosion and improve soil fertility. As a result, the whole ecological resource base of the country has now reached a critical stage (Mengistu 2002; Solomon 2002).

Most farming activities are interrelated and support each other. For example, small-scale livestock farming systems support crop farming by supplying draught power and manure to fertilize fields (Weldeselasie 2003). Global development experiences indicate that livestock should play an important role in the horn of Africa economy as the human population increases and economies grow. Animal agriculture will, thus, do this both by developing the rural economy and through generating employment opportunities for urban societies (Ndikumana *et al.* 2002).

About 12% of the economy of the country depends on agriculture. Nearly all crop and livestock production is based on smallholder traditional agriculture characterised by subsistence farming and low productivity. Regarding the social structure of the country, the population is mainly rural and a large part of the economically active society (78-80%) is associated with agricultural business and livestock-related activities that make use of 56% of the 12 200 000 hectares available or a browsing and grazing land equivalent to 6 820 000 ha (Kayouli *et al.* 2002; Mehretab *et al.* 2002).

Livestock management practices vary considerably among the different agro-ecological zones. In the highlands, cereals and livestock are managed in closely integrated systems where animals graze hillsides and stubble[1] left on fields after harvest; and crop residues used as supplementary feed during critical periods. In low rainfall areas agro-pastoralists complement their grazing livestock with crop residues while the pastoralists migrate long distances in search of grazing. Apart from some peri-urban commercial production, livestock production is primarily carried out traditionally under natural conditions (Kayouli *et al.* 2002; Ndikumana *et al.* 2002).

Among the major constraints limiting the potential development of livestock production, inadequate feed availability is a crucial bottleneck. The bulk of livestock feed comes from grazing pastures, stubble and residues which are often of poor quality. In most areas, especially during the dry period, common daily rations cannot even meet maintenance requirements during at least six months of the year. Thus, most ruminants are consequently subject to chronic under nutrition (Kayouli *et al.* 2002; Ndikumana *et al.* 2002; Weldeselasie 2003).

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[1] Stems left on the ground after the crop has been harvested (Cambridge international dictionary of English 1995, Cambridge University Press).

2.2.1.1 The pasture resource

As in most parts of Africa, rangeland based livestock production is the dominant economic activity in Eritrea (Mengistu 2002). In terms of the forage and rangeland resources in Eritrea not much research has been done. Thus, most of the documented information is based on general descriptions from survey type works and some development projects. However, the initial potential for increasing the total feed resource is by optimising the natural production of the rangelands. The bulk of livestock feed (about 90%) comes from grazing rangelands and stubble, conserved crop residues including straw and stover from sorghum, millet, wheat, barley, teff, maize, and industrial crops and agro-industrial by-products. In general, forage supply shortages are amplified by their poor quality. The limited locally grown poor-quality forage is not the only problem, but management practices of forage production and its utilization also cause under nutrition as a major factor in low productivity of livestock. In 1994, the overall feed balance indicated that feed is in short supply by 20% for energy and 30% for protein requirements (Kayouli *et al.* 2002).

2.2.1.2 Chances for improving fodder resources

It was mentioned earlier that most of the information on forage and rangeland resources in Eritrea is not research based, but rather developed from survey type works and development projects. Nevertheless, there is no doubt that the optimisation of the potential of the rangelands could reduce the feed shortage problem in the long run. However, under the current systems of constant and complete utilization of the natural forage, the total production of edible grasses and herbs does not allow animals to reach their maximum yield potential (Kayouli *et al.* 2002).

Cultivation of high quality legumes and grasses could, thus, be a possible alternative. Therefore, there are opportunities to complement the cropping system with the production of high quality, high value fodder. Production of legumes such as *Medicago sativa* (lucerne) would provide an extra source of income while improving soil fertility. Also the integration of forage with crops would optimise both short-term financial returns and long-term sustainability. Forage production fills a number of roles. The sown perennial pasture legumes prevent soil erosion (which is often inherent in annual cropping systems) and provide high quality feed to supplement diets of crop residues; and leguminous forage contributes to the nitrogen budget of the system and maintains soil fertility (Kayouli *et al.* 2002).

2.2.1.3 Rangeland reseeding

The natural grasses of Eritrea are the best-adapted grasses for the local environment. However, some reseeding may be desirable in areas where the grasses have been completely destroyed and where they are not productive due to degradation of the environment or other factors. A higher priority is to introduce leguminous forages into natural grazing by broadcasting them on undisturbed rangeland. However, cultivating the site, creating micro-water pondage and removing animals during the plant establishment and development stage significantly increases their chances of success. The chance of success is also dependent on the amount and distribution of rainfall (Kayouli *et al.* 2002).

2.2.1.4 Establishment of fodder trees

Browsing and grazing provide about 90% of feed consumed by ruminants in Eritrea. Planting fodder trees is gaining acceptance in many tropical countries and particularly in the semi-arid zone where they have been developed for multipurpose uses. There are hundreds of fodder tree species in the world with a wide range of productive features. Tree legumes such as *Leucaena leucocephala* have great forage production potential. Therefore, special emphasis should be given to shrubs best adapted to arid and semi-arid conditions; to species that are tolerant to poor soil fertility and that are drought resistant (Kayouli *et al.* 2002).

In general, as Devendra (2000) and Devendra and Chantalakhana (2002) have suggested, all strategies to increase feed availability should finally target the development of sustainable year-round feeding schemes, appropriate to the prevailing situations and feed availability. This crucial target can possibly be achieved through crop and forage interspersing; intensive use of available crop residues; and establishment of best adapted forage legumes.

2.3 INTENSIVE FEED PRODUCTION FOR LIVESTOCK

Land is the most important farm resource. In recent times there is increased population pressure expanding into the natural rangelands. There is a need to identify sustainable farming systems such as crop-livestock systems that allow continuous cultivation of the same piece of land with a mutual interdependence between crops and livestock to halt the problem (Karbo and Agyare 1998).

The soil-plant-animal-human relationship plays an important role in soil fertility. Soil nutrients taken up by plants are made available to animals when ingested. Some of these nutrients are later voided off as by-products in the form of faeces and urine that frequently account for soil nutrient balances and thereby enhancing crop production. Nutrients in the plant or animal products used by humans as food are usually shipped away to urban areas and not returned to their place of origin for nutrient balance purposes. The complete neglect of these two sources of nutrient recycling in the bio-geochemical flow resulted in widespread low soil fertility and degradation of both grazing and arable lands (Karbo and Agyare 1998).

2.3.1 **Crops and crop residues**

The use of crop residues for animal feed is the crop contribution to the integrated system. Crop residues, which would have otherwise been of no nutritional value to humans, are transformed by the ruminant animals into highly nutritious food substrates for human consumption (Karbo and Agyare 1998). Moreover, they are often costed into a livestock production system at a zero cost as they are considered to be a by-product of a cropping system (Kirkman and de Faccio Carvalho 2003). The faeces and urine voided by the animals in turn are mixed with the soil. However, this crucial linkage is broken by the direct incorporation of crop residues into the soil as mulch, often with results inferior to using manure. Firstly, the decomposition of the residues is very slow, especially, with crop residues having a high C:N ratio (always >30). Secondly, their nutrient release pattern may not coincide with the growth of the crop, unlike the nutrient release pattern of manure (Karbo and Agyare 1998).

2.3.1.1 *Eragrostis tef* (Zucc.) Trotter (Teff)

Teff is one of the dual-purpose cereal crops whose grain is consumed by man and the straw used for livestock feeding, especially during the dry season, in Eritrea and Ethiopia (Wilson 2002). In Kenya, South Africa, Australia, and other parts of the world, however, teff is grown exclusively as a forage hay and summer grazing pasture (Mengesha 1966; Purseglove 1972; Kassier 2002).

In Eritrea, teff, locally known as taff, is one of the most commonly grown cereal crops (Figure 2.3) next to barley, wheat, sorghum, and millets (Solomon 2002). It is commonly grown in the highlands but also has shown good performance in the lowlands.

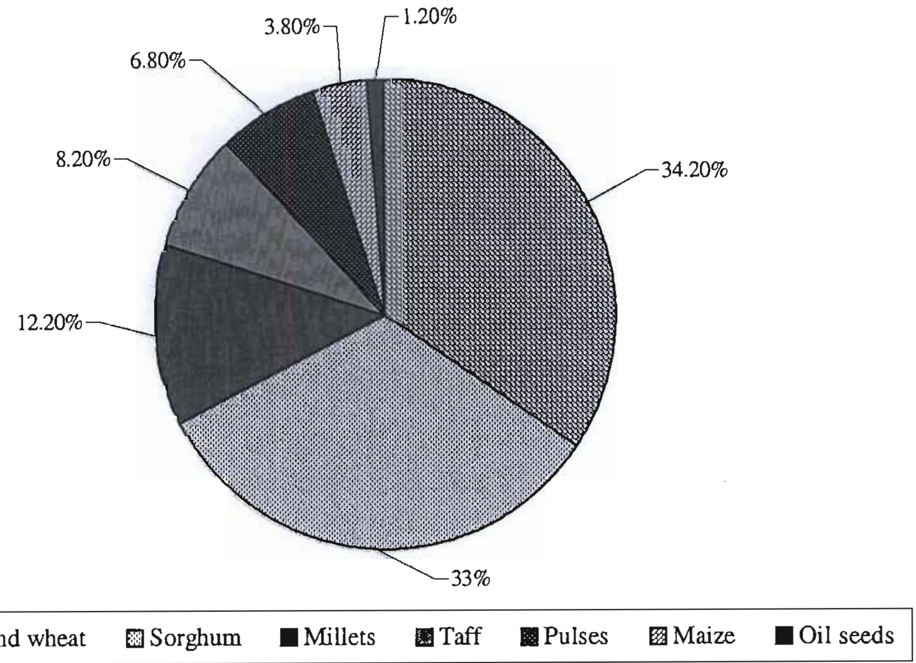

Figure 2.3 Main crop coverage in percentages, 2001 (adopted from Solomon 2002).

General information and description of teff

Teff originated from northeastern Africa (Gibbs Russell *et al.* 1990; van Oudtshoorn *et al.* 1992) specifically Ethiopia or the Yemen highlands (Puseglove 1972; Jones 1988). It was domesticated during times of food scarcity. Archaeological reports indicate existence of teff seeds in the pyramids of Dassur in Egypt, built in 3349 BC (Ketema 1986). Seeds were also found in Jewish ruins 1400-1300 BC (Mengesha 1966). Although, the exact reason why, when and how teff was domesticated is unknown (Ketema 1986), these archaeological findings show that teff is an ancient crop (Kassier 2002).

Distribution

In 1866 the Royal Botanic Gardens at Kew distributed teff seed to India, Australia, the United States of America and South Africa. In 1916, teff was introduced to California, Malawi, Zaire, Sri Lanka, New Zealand, Argentina and again to India and Australia by Burt Davy. Teff distribution was further extended by Sykes 1911 to other African countries such as Zimbabwe, Mozambique, Kenya, Uganda and Tanzania, while in 1940 Horiutz introduced it to Palestine (Kassier 2002). From all these introductions teff became an established crop outside Ethiopia and Eritrea only in South Africa. In 1936 the main gramineous hay crop in South Africa was teff, with a total of 0.14×10^6 ha being planted annually (Pole *et al.* 1936).

Taxonomy

Compared to maize, sorghum, wheat and barley, teff is a typical grass and it resembles the pasture grasses (*Poa* spp.) and bents (*Agrostis* spp.) of northwestern Europe. Teff belongs to the eragrostoid grasses of the tropical and subtropical group adapted to semi-arid environments and is the only species of that group developed as a cereal (Jones 1988). It is from the family Poaceae, sub-family Eragrostidae, tribe Eragrosteae and genus *Eragrostis* (Costanza *et al.* 1979; Ketema 1993; Stallknecht *et al.* 1993). The sub-family has centres of diversity in the arid and semi-arid tropical and sub-tropical regions. The genus contains about 300 species (Costanza *et al.* 1979).

The most likely ancestor of teff is *E. pilosa*. It is very similar to teff and has the same chromosome number (2n=40). Teff chiefly differs from *E. pilosa* in that it has larger grain size which is retained longer in the head and does not shed its glumes (Jones 1988).

Its morphological variability, however, makes it difficult to give teff one botanical description because of the domestication process of *E. pilosa* beginning at around 3000 BC through various selections for local agro-ecological and climatic conditions suitability (Kassier 2002). In general, *E. tef* is a tropical to sub-tropical, self-pollinated, with high chlorophyll a/b ratios, annual C_4 grass (Kebede *et al.* 1989). The panicle inflorescence ranges from very loose to completely compact. Gibbs Russell *et al.* (1990) described teff as loosely tufted up to 600 mm tall. Leaf blades are up to 300 mm long and 4 mm wide; spikelets 5.5-9.0 mm long and 1.5-

2.0 mm wide; branches are usually more than 40 mm long, flexible and slender; pedicels are slender.

Its ability to grow under considerably variable rainfall, altitudinal and edaphic conditions resulted in the development of numerous ecotypes which have given rise to vast genetic diversity and adaptation to different agro-ecological conditions (Cheverton and Chapman 1989).

Agronomic requirements and importance

Teff is a rescue[2] crop that survives and grows with the remaining low moisture conditions unsuitable for maize and sorghum production. It also withstands waterlogged and anoxic conditions better than maize, wheat, or sorghum (Ketema 1993). Teff is also preferred on badly eroded areas to initially improve the habitat for the seedlings of the less hardy species because it provides a cover to the soil (Tainton *et al.* 2000).

Teff can grow in areas with seasonal rainfall ranging from 300-1 000mm (Ketema 1986). For early maturity types (45-60 days), however, as little as 150mm seasonal rainfall is sufficient (Cheverton and Chapman 1989). These adaptabilities enable teff to thrive in regions ranging from semi-arid through humid to high rainfall areas (Kassier 2002).

Different literature sources reported various altitudinal preferences (Mersie and Parker 1983; Ketema 1986, 1993; Skerman and Riveros 1990) ranging from sea level to 3 000m, a limit above which teff distribution is restricted by frost. However, it performs best at 750-850mm per annum rainfall and a growing season rainfall of 450-550mm, and a temperature range of 10-27 °C (Kassier 2002). The crop thrives on a wide range of soil types and associated edaphic chemistry growing in sandy loam to heavy clays and withstands the anaerobic condition of vertisols during water logging. Considering that vertisols (clay soils) cover 80 million ha of Africa, it is a very useful attribute that assists in making use of a wide range of agro-ecological conditions and areas with limited agricultural potential that are marginal to other crops (Jones 1988; Riley *et al.* 1994; Kassier 2002).

[2] A crop that survives unfavourable conditions and saves the farmer from loses of other crop failures caused by some unfavourable conditions.

The soil P and K levels should be raised above the levels of 0.015 and 0.1 g kg^{-1} respectively for South African conditions. Two dressings of 50 kg N ha^{-1} are recommended on low fertility soils. No nitrogen fertilization is recommended for high fertility soils (Kassier 2002). On light and heavy soils 40 kg N ha^{-1}, and 60 kg N ha^{-1} and 26 kg P ha^{-1} are recommended, respectively (Bechere 1995).

Climate

Teff is the most reliable cereal for conditions of unpredictable rainfall. In some drought-prone areas teff will produce a crop when no other cereal will, while at others (e.g. on vertisols) it will out-yield all possible competitors (Ketema 1993; Jones 1988). It can be grown throughout the summer rainfall area, but does best in the cooler districts having well distributed rainfall. In areas with a mean annual rainfall of over 625mm it grows well even in heavy soils, but where the rainfall is between 500 and 625mm, the lighter soils should be preferred (Donaldson 2001).

Sowing

The seed can be either drilled or broadcast (Kassier 2002) at a planting depth of 5-15mm (Skerman and Riveros 1990; Ketema 1993; Stallknecht *et al.* 1993).

Recommended seeding rates are 7-10 kg ha^{-1} on sandy soils and 12-15 kg ha^{-1} on clay soils; 25-30 kg ha^{-1}, if broadcast by hand, and 15 kg ha^{-1} when broadcast or drilled mechanically. Generally, although the above figures do not specifically show the use for which the crop is established, sowing rates will make a difference for which purpose the crop is used, for either haymaking or grain production; but one can easily assume that the sowing rates reported from places where teff is used for hay production represent seeding rates for hay production and reports from places where it is used for grain production that teff was used for seed production (Kassier 2002). In her study on the effect of sowing rate Kassier (2002) reported that herbage yield to be greatest at 20 kg ha^{-1}.

Recommended sowing dates are 15 to 21 July on andosols and 21 to 31 July on vertisols in Ethiopia. Generally, teff can be sown during a season where the rainfall is reliable and well distributed (Ketema 1993). No information on sowing dates is available for other countries, particularly for countries located in the southern hemisphere (Kassier 2002).

Teff for human consumption

Teff is superior to other cereal crops in its value as human food because its protein content is high and its amino acid content is closest to human dietary requirements. It is particularly rich in essential amino acids which cannot be synthesized in the body (Jones 1988).

Teff for livestock feeding

As fodder, teff is cheap to raise and quick to produce. It is both nutritious and extremely palatable to livestock (National Research Council 1996). Teff is a rapid-growing, soft, fine-stemmed summer annual which produces easily cured palatable hay. It is a good supplement when fed with legume hays and is a useful nurse crop in establishing perennial grasses and legumes (Donaldson 2001).

Cattle prefer teff straw to the straw of any other cereal. Nutritionally, among cereals, teff straw is relatively the best and is comparable to a good natural pasture/hay (Table 2.1). The value of teff as a hay crop lies in its palatability, high nutritive value, narrow albumin ratio, high yield, rapid growth, drought resistance, and ability to smother weeds. Teff can produce more than twice as much forage as weeping love-grass (*E. curvula*), producing an average of 14.5 t ha^{-1} green material in three months (Ketema 1993).

Concerning its cell wall content digestibility, teff has tropical grass characteristics. As is the case with most grasses, protein content and digestibility of teff decrease with increased maturity. Protein content of teff forage produced in South Dakota ranged from 19.5-12% and 13.7-9.6% in Montana, as the plant matured. Teff has a very high calcium content, and contains high levels of phosphorus, iron, copper, aluminium, barium, and thiamine (Stallknecht *et al.* 1993).

According to chemical analysis by the Department of Agriculture KwaZulu-Natal (1995), teff hay in the early bloom stage has a crude protein (CP) content of 121 g kg^{-1} and 86 g kg^{-1} in the full bloom stage. As is the case in other cereals, lysine is the first limiting amino acid in teff

(Kassier 2002) but it has an excellent essential amino acid balance and the ratio of essential to non-essential amino acids in teff is high for a cereal product (Jansen *et al.* 1962; Cheverton and Chapman 1989).

Table 2.1 Teff straw yield and chemical composition compared to various other crop residues on DM basis (Ketema 1993).

		Composition				
Crop residue	Yield (kg ha^{-1})	DM%	EE	Ash	CP	NDF
Barley straw	10,000	92.6	2.3	8.4	4.7	71.5
Teff straw	5000	92.6	1.9	8.4	5.2	72.6
Wheat straw	9000	93.1	1.2	9.0	3.9	79.8
Faba bean	3800	91.7	0.8	10.4	7.2	74.3
Field pea	5000	91.9	1.2	6.1	6.7	73.6
Natural pasture (hay)	4100	92.2	1.5	9.5	6.6	73.8

DM = dry matter; EE = ether extract; CP = crude protein; NDF = neutral detergent fibre

2.3.2 **Constraints to crop-livestock production systems**

According to Karbo and Agyare (1998) the major constraints to crop-livestock systems, particularly, in Northern Ghana, but which may also apply to most of sub-Saharan Africa are:

- Problem of keeping the two components (livestock and crops) separate during the growing season of the crop;
- Communal system of land ownership prohibits efficient land management;
- Free range grazing systems don't allow efficient manure collection and distribution;
- Improper livestock management discourages correct livestock health care;
- Theft of livestock;
- Insufficient feed for livestock in the dry season;
- Carrying collected manure to grazing/croplands is heavy and labour-intensive;
- Alternative uses of crop residues and manure (e.g. as a fuel) make them less available for crop-livestock systems; and
- Limited information on the indigenous knowledge on crop-livestock and economically proven viable systems.

2.3.3 **Forage legumes in livestock farming systems**

Given the prevailing economic conditions, Africa will have to depend on intensive use of pastures to improve the nutritional status of livestock. The cost of other feed sources is generally too high to be recommended for widespread use under the current management levels. However, the productivity of both native and planted pastures is limited primarily by nitrogen deficiency in most soils in Africa. In order to increase pasture productivity and quality significantly, the low N status of the soils could be supplemented either by applying fertilizer N or by growing forage legumes. However, N fertilizer is expensive and this is reflected in its low consumption in Africa. Thus, a cheaper and more effective way of increasing the N status of the soil would be to introduce legumes, which fix considerable amount of atmospheric N and contain high levels of protein, minerals and vitamins. Furthermore, this high quality can be maintained over a long period and their inclusion in grass pastures may prolong the grazing season (Ogwang 1986; Reynolds and Cobbina 1992; Aucamp 2000).

Natural grasslands not receiving fertilizer N normally produce 1000-2000 kg ha^{-1} but yields can be higher depending on climate and soils. Nitrogen fertilizer has been used to increase production; however, the use of legumes to replace fertilizer N in forage production has become more economically attractive as the cost of N fertilizers rise. Moreover, legumes in pastures not receiving fertilizer N not only increase total herbage yield but also the yield of N and crude protein content, due to transfer of N from the legumes to the grasses (Aucamp 2000; Craig *et al.* 1981; Reynolds and Cobbina 1992; Ledgard and Steele 1992). Worldwide estimates of biological nitrogen fixation (BNF) range from 13-682 kg N ha^{-1} yr^{-1} (Ledgard and Steele 1992). Legumes achieve this by sourcing N from the atmosphere through N-fixation (Reynolds and Cobbina 1992; Gathumbi *et al.* 2003).

However, BNF depends on legume persistence and production, soil N status and competitive ability of legumes with the companion grasses (Figure 2.4); factors in turn that are affected by soil moisture status, soil acidity, nutrition, pests and diseases (Ledgard and Steele 1992). The importance of forage legumes in nutrient cycling in grazing pastures is summarised in Figure 2.5.

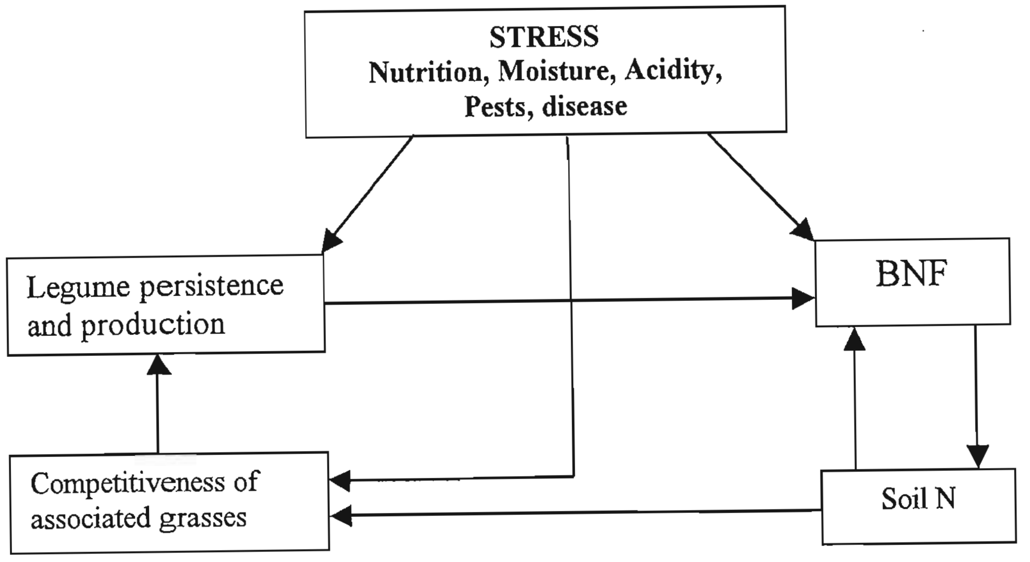

Figure 2.4 Major factors determining the level of BNF, and the secondary effects of stresses on these factors (Ledgard and Steele 1992).

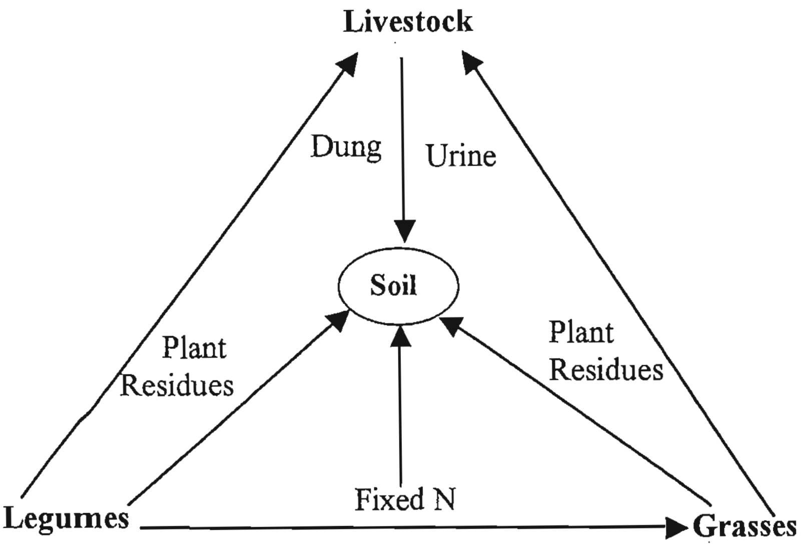

Figure 2.5 Forage legumes in nutrient cycling (Tarawali and Ikwuegbu 1995).

2.3.3.1 Herbaceous perennial forage legumes

In the tropics declining soil fertility and the inadequacy of livestock feeds, particularly the lack of protein during the dry season, are major production constraints in many smallholder mixed crop-livestock farming systems, partly due to land limitations that cause farmers to practice continuous cropping and grazing, and partly from inadequate or lack of use of fertilizers. Herbaceous legumes provide an alternative to the use of commercial nitrogen sources for cereal crops and livestock production. Interspersing of leguminous crops has been evaluated in many parts of the tropics. However, the use of forage legumes has generally been low. For increased adoption, legume-based forage practices must fit into the overall farming strategy because the primary objective of most farmers is to grow sufficient food for the family (Reynolds and Cobbina 1992; Nyambati and Sollenberger 2003).

2.3.3.1.1 *Medicago sativa* (Lucerne)

Lucerne was one of the first forages to be domesticated. It is the highest yielding of the temperate forage legumes and the most widely grown in warm temperate areas as well. Its worldwide area coverage exceeds 30 Mha, with the USA, the former Soviet Union and Argentina accounting for about 70% of that area. Other countries such as Canada, Italy and China grow about 2.5 and 1 Mha, respectively (Frame *et al.* 1998).

Lucerne originated near Iran. Related wild species also exist scattered over central Asia. Its value as a forage feed was described as early as 490 BC by the Roman writers Pliny and Strabo. It was spread to Europe and later South America by invading armies, explorers and missionaries. Later three types that were not winter-hardy reached Africa in 1924 (Barnes and Sheaffer 1995).

The plant is commonly called either lucerne in all European countries, South Africa, Australia and New Zealand, or alfalfa in the USA and other countries (De Kock 1978; Frame *et al.* 1998). Here the word 'lucerne' will be used throughout.

Globally, lucerne cultivation started to expand rapidly only since the beginning of the 20th century. Better cultivars, improved methods of cultivation, and tremendous successes with lucerne as a forage crop also encouraged its distribution and production, and led to the naming of lucerne as "King of the forage crops" (De Kock 1978).

Lucerne is an herbaceous perennial legume (Barnes and Sheaffer 1995) and can survive for 10-20 years or longer, depending on the growth conditions and purpose of utilization (De Kock 1980; Frame *et al.* 1998). There are three *Medicago* species commonly recognized as lucerne. The common purple lucerne (*M. sativa*), yellow lucerne (*M. falcata*) and the varigated hybrid or sand lucerne (*M. media*). The species commonly cultivated throughout the world is, however, common purple lucerne. It is characterized by a strong taproot, purple flowers, spiral-shaped pods and rapidly growing stems (De Kock 1980; Frame *et al.* 1998).

Agronomic requirements and importance

Lucerne is distributed all over the world. It can survive temperatures below -25 ^{0}C and above 50 ^{0}C and is highly drought tolerant. For example, average yield of drought-stressed lucerne was 120% greater than yields of drought-stressed birdsfoot trefoil and cicer milkvetch, and 165% greater than the yield of similarly stressed red clover. Water requirements vary with climate, cultivar, and soil fertility, but the average ranges from 5.6 to 8.3 cm ha^{-1} per ton dry forage (Barnes and Sheaffer 1995).

Its resistance to drought makes lucerne suitable for dryland cultivation, in areas where rainfall is marginal for most crops. After proper establishment, an annual rainfall of only 400-500mm is sufficient for lucerne performance and growth. However, dryland production is better in areas with a higher rainfall and yields in moist areas are very good (De Kock and Birch 1978).

Lucerne grows best in deep and loam soils. Provided that other conditions are favourable, lucerne has a wide tolerance regarding to soil adaptations and thrives in soils ranging from sandy to clay, and shallow to deep. Where the water table is near the soil surface, or where its depth varies considerably, lucerne will not thrive. Good drainage in the root zone is then a precondition as lucerne is sensitive to waterlogging (De Kock and Birch 1978).

Seed inoculation is important for effective growth of seedlings. Either the seed or the soil should be inoculated with the right rhizobium before seeding. However, seed inoculation is the easiest method of spreading the inoculant over the field. Lime coating is also recommended preferably where lucerne is to be planted on slightly acid or marginal soils; where soil moisture or soil temperature is likely to be unfavourable for the survival of the rhizobia; and where the seed is likely to come into contact with the fertilizer or where aerial seeding is used (Birch and Strydom 1978).

The crop germinates throughout the year but the optimum time of seeding depends mainly on soil moisture conditions and the weed problem of the area. Usually lucerne is sown in the autumn-winter period since weeds present fewer problems at this time (Birch and Engelbrecht 1981).

The annual rainfall, and whether the lucerne will be irrigated influence the quantity of seed required to ensure a productive stand of lucerne under optimum seeding conditions. Recommendations for the various conditions are given in Table 2.2. Depending on rainfall intensity and soil, it will be necessary to slightly modify these recommendations. In areas where the rainfall is more effective, larger quantities of seed per hectare and closer row spacings or even broadcast stands should be used. The reverse applies to lands where the rainfall is less effective (Birch and Engelbrecht 1981).

The optimum seeding depth is dependent on the soil type, soil compaction and soil moisture. Due to its miniature seed size, however, lucerne should be seeded as shallow as possible to obtain a good stand. Seeding 5-20 mm deep is suitable for most soils. However, where the rapid drying off of the top layer soil could adversely affect germination, as it is the case with coarse textured soils, slightly deeper seeding depth (10-30mm) is recommended, but seeding depth deeper than 30 mm will markedly reduce seedling emergence and development of stands (Birch and Engelbrecht 1981).

Where soil moisture is low and seeding depth is shallow, light compaction of the surface soil after seeding brings seed into close contact with the soil and water, promotes germination (often by over 50%), and minimises the drying out of the topsoil (Birch and Engelbrecht 1981).

Table 2.2 Lucerne seeding rates under various conditions and sowing methods (Birch and Engelbrecht 1981).

Mean annual rainfall (mm)	Lucerne seeding rate (kg ha^{-1})	Sowing method
Irrigation	25 to 30	Broadcast or rows 100-200mm apart
>600	20	Broadcast or rows 100-300mm apart
>600 low potential soils	10	Rows approx. 500mm apart
500-600	10	Rows approx. 500mm apart
<500	5	Rows approx.1 m apart

Lucerne forage quality and importance

Lucerne is the most important leguminous forage crop in the world (De Kock and Birch 1978; Barnes and Sheaffer 1995; Bartholomew 2000). Under good management lucerne has lower production costs than grass and its inclusion in the diet of animals could significantly lower feed costs (Doyle and Thomson 1985).

It is exceptionally palatable, thus animals take it in larger amounts per day than grass hay (Zeeman 1980). Lucerne has a relatively high protein content and produces more protein per hectare than any other crop. It is also rich in calcium and vitamins A and D. Animal growth rate and milk production are much higher than with most other forage crops and natural grazing (De Kock and Birch 1978). Lucerne yields on different farms vary significantly from 9000-13000 kg dry matter ha^{-1} a^{-1} (Doyle and Thomson 1985). Despite the above advantages, lucerne has a relatively low digestible energy. Thus, lucerne can be used more effectively when supplemented with energy rich feeds that contain little protein (Zeeman 1980).

It is also an outstanding hay crop that can be used as grazing, silage or as a zero-grazing crop, especially where it is cultivated together with perennial grasses. Since lucerne can be stored for long periods, it is extremely suitable for reserves in times of scarcity (De Kock and Birch 1978; Meissner 2000).

Lucerne pasture mixtures

Lucerne is frequently grown in mixtures with one and occasionally with many grasses to produce a high yielding pasture of good quality with low production costs. The mixture fulfils complementary functions. The lucerne provides a high protein feed and improved soil fertility. The grasses make use of the improved soil fertility to produce a larger yield of good quality forage (Birch 1981).

Vigorously growing lucerne is the most effective fixer of nitrogen to meet its own nitrogen needs and that of the grass growing in association with it in a well-balanced mixture thereby eliminating repeated applications of expensive nitrogen fertilizer. This is especially important since the energy crisis (shortage of fuel for N fertilizer production) drastically increased nitrogen fertilizer costs, which in turn increased the cost of grass pastures fertilized with nitrogenous fertilizer to a level where many such pastures are relatively uneconomical (Birch 1981).

Estimates of N fixation by lucerne vary widely but are generally higher on an annual basis than for other temperate forage legumes. Annual fixation rates have ranged from 85-360 kg N ha^{-1} (Ta and Faris 1987b). In their study Ta and Faris (1987b) reported that the N transfer from lucerne to associated timothy (*Phleum pratense* L.) contributed up to 22% in the first year and 30% in the second of the total N yield of timothy and amounted to up to 13 kg N ha^{-1} yr^{-1}. This transfer increased with progressive cuts and with an increased proportion of lucerne in the mixture. Also Lory *et al.* (1992) have reported that symbiotically fixed N (SFN) from interspersed legumes can represent a significant proportion of the nonlegume N budget. Although values from 20-30% are more typical in the literature, reed canarygrass (*Phalaris arundinacea* L.) obtained up to 68% of its N from N_2 fixed by alfalfa. Generally, the quantity of SFN transferred by alfalfa to an interspersed non-legume can reach 20 kg N ha^{-1} yr^{-1}.

2.3.3.2 Tropical forage tree legumes

The use of tree legumes in tropical farming systems dates back to the beginning of domestic agriculture. Traditionally they were used for a variety of purposes as food, firewood, construction and shade. In some areas, especially in the arid and semi-arid zones of the world, tree legumes have always been mainly used for forage. In these dry regions, tree legumes provide a part of total herbage intake and most of the protein intake for livestock, particularly during the dry periods. Thus the introduction of tree/shrub legumes into livestock feeding systems offers promise for meeting the increasing demand for feed resources worldwide (Reynolds and Cobbina 1992; Shelton 2000).

When herbaceous species are not available, the adoption of deep-rooted, drought-tolerant leguminous forage trees is always the best option for improving forage diets in arid and semi-arid regions. Other additional purposes of forage tree legumes include functioning as living fences, source of nitrogen-rich mulch for cropping systems, enhancing the sustainability of farming systems, enhancement of fertility and physical stability in the landscape, supporting climbing crops, provision of shade for plantation crops, offering opportunities for sustainable intensification of agricultural production, stabilization of sloping lands and sand dunes against erosion, provision of habitat for wildlife, and acting as a sink for carbon dioxide, with positive effects on climate. When sold/exported fresh and/or pelletized, they are sources of income for farmers. This flexibility makes forage tree legumes significant for smallholder subsistence farms and large-scale commercial livestock enterprises (Reynolds and Cobbina 1992; Shelton 2000).

Tree legumes are widespread in Africa and many are valuable for fixing atmospheric nitrogen. Evaluation of the nodulating ability, N_2 fixation, and agroforestry potential of woody legumes has been the subject of many recent reports and these recent studies prove that a high percentage of the trees examined form effective nodules.

2.3.3.2.1 *Leucaena leucocephala* (Lam.) de Wit

Leucaena leucocephala (leucaena) is one of the deep-rooted, multi-purpose leguminous trees with considerable potential in the tropics and subtopics (Maclaurin *et al.* 1982; Tukel and Hatipoglu 1989; Shelton 2000).

History and distribution

The fodder value of leucaena was recognised over 400 years ago by the Spanish conquistadors in Central America and the Yucatan Peninsula of Mexico. From this centre of origin the Spanish army carried leucaena feed and seed on their galleons to the Philippines to feed their stock (Brewbaker and Sorensson 1990).

With the advent and development of sea transport, leucaena became truly pantropic, and it exists in Central and South America, the East and West Indies, Australia, tropical Africa, the Indian and Pacific islands and the Far East, far from its centre of origin Mexico. However, its breeding, cultivation and use as forage started mainly in Hawaii, Australia, Malawi and other countries. It is estimated to cover 2-5 Mha worldwide (Guevarra *et al.* 1978; Maclaurin *et al.* 1981; Maclaurin *et al.* 1982; Brewbaker and Sorensson 1990; Akingbade 2002). Despite the above mentioned advantages of leucaena, it receives little attention as a forage plant in South Africa from a pastoral point of view. Firstly, it is toxic to animals (Underwood 1993; Henderson 2001). Secondly, the plant is considered as a weed (a prohibited plant that must be controlled) in Western Cape Province and an invader plant elsewhere in the country (Henderson 2001). In the latter case leucaena can be grown in separate areas, given that permission has been provided and enough steps were taken to avoid uncontrollable distribution (Henderson 2001).

During the 1970s and 1980s, leucaena was known as the 'miracle tree' being a globally long-lived, highly nutritious forage tree and the variety of uses of forage trees mentioned under the section 2.3.2.2 (Maclaurin *et al.* 1982; Tukel and Hatipoglu 1989; Brewbaker and Sorensson 1990; Akingbade 2002).

Botanical description and characteristics

In the past, leucaena has been wrongly ascribed various names including *Acacia glauca*, *Mimosa latisiliqua*, *M. leucocephala*, *Leucaena blancii*, *L. glabrata*, *L. latisiliqua*, *L. salvadorensis* and *L. glauca*. Of all, the name *L. glauca* (L.) Benth. was the most accepted name until 1961. Common names used in the literature include leucaena, koa haole, ipil-ipil, wild tamarind and jumbie bean (Maclaurin et al. 1981; Maclaurin et al. 1982).

Leucaena is a member of the Mimosaceae of the family Leguminosae. The genus leucaena includes 10 species. Probably due to intra-and interspecific variations, the plant has various botanical descriptions in different parts of the world. However, it is generally botanically well described by Maclaurin et al. (1981) and Maclaurin et al. (1982). The authors further grouped leucaena strains into three distinct types based on growth habit, vegetative vigour and time of flowering as the Hawaiian (bushy, short, up to 5m tall); Salvador or Hawaiian giant (tall, up to 20 m, used mainly for timber due to the thick almost branchless trunks); and the Peru (the most vigorous type, intermediate, up to 15m tall, extensive branching low down on the trunk with large quantities of foliage).

Agronomic preferences and importance

Leucaena grows best in areas with rainfall ranging from 750-1 800mm. It is also able to grow in areas with annual precipitation as low as 250mm. Leucaena tolerates a hot climate (30 °C) and requires a relatively frost-free environment. Compared to *Desmodium* spp. and *Centrosema* spp. leucaena is less affected by frost (Maclaurin *et al.* 1981; Maclaurin *et al.* 1982).

Leucaena is adapted to a wide range of soil types, land terrains and soil salinity levels. It grows best in deep, free-draining neutral to alkaline soils, but has been reported to grow naturally on acid soils. It grows on soils with textures ranging from sandy to clay-loam. On acid soils, applications of phosphatic fertilizers increased yields. Magnesium is important for nitrogen fixation and nodulation has been found to be affected by trace elements such as boron, copper, iron, magnesium, manganese, molybdenum and zinc. Nitrogenous fertilizers, even in quite small quantities, enhance forage yields (Maclaurin *et al.* 1981).

The hard, waxy and impermeable seed coat causes slow, uneven and poor germination. This can be improved by treating the seed either mechanically or with acid or hot water. Soaking seeds in water at 80 $^{\circ}$C for four minutes then in cool aerated water for two to three days is the cheapest, safest and most effective method of breaking this obstacle (Maclaurin *et al.* 1981; Maclaurin *et al.* 1982).

Usually leucaena can be planted by either seed or bare stem. Although transplanted seedlings give best results, large areas are best planted by seed. It is also cheaper and more practical to plant seeds directly into the field provided that adequate soil moisture is available (Maclaurin *et al.* 1981).

Due to slow initial growth of seedlings, weed control is essential until the seedlings are well established. This may be done by hand, mechanical cultivation or by the use of pre-and post-emergence herbicides (Maclaurin *et al.* 1981).

Seeding rates of 1-2 kg ha^{-1} at depths of 20-30mm are usually recommended. Sowing is best done early in the growing season with reliable rainfall using good weed control measures to minimize competition as leucaena seedlings are very sensitive in the root zone (Shelton and Brewbaker 1994).

Depending on its purpose of utilization, leucaena may be planted as single plants, single or multiple hedgerows. In the latter case, hedgerows may be closely spaced (75-100cm) to achieve maximum yield per hectare for cut-and-carry feeding or more widely spaced (300-1000cm) for alley cropping or grazing. Intra-row plant spacings of 25-50cm are adequate. For grazing purposes, grasses may be planted between widely spaced leucaena rows to increase total fodder supply (Shelton and Brewbaker 1994).

Forage yield, feeding value and toxicity

In areas with ruminants that lack microbes to break mimosine down, mimosine toxicity can be a problem but this can easily be countered in such a way that intake by the animal is controlled. That is leucaena can be either; (i) cut and fed with other forage material; (ii) grown scattered throughout a grazing camp with major forage component being grass; (iii) used in rotation with camps that do not have leucaena, or (iv) utilized for a limited period of the day. The concentration of mimosine is highest in the young leucaena shoots which cattle like most. It may be as high as 9% in very young leaves, but is usually about 3-4% of forage DM. It is also highest in fast growing plants. Differences in concentration also exist between strains and species of leucaena (Maclaurin *et al.* 1981; Maclaurin *et al.* 1982).

Mimosine is broken down by microbes in the rumen to DHP (3 hydroxy-4-(1H)-pyridone) a goitrogen that is normally broken down further by rumen microorganisms to non-toxic compounds. The microbes are naturally present in ruminants in Indonesia and Hawaii and probably other countries of Southeast Asia and the Pacific where there has been a long history of ruminant animals grazing naturalized leucaena. In some countries, such as Australia, Papua New Guinea and African countries, the appropriate rumen microorganisms are not naturally present leading to an accumulation of DHP which causes goitre that results in listlessness, loss of appetite, excess saliva production, hair loss and loss of weight. However, this effect only occurs if leucaena exceeds 30% of the animal's diet for an extended period of time (Shelton and Brewbaker 1994).

Different forage yields of leucaena have been reported from different parts of the world based on plant type, harvesting interval and frequency, planting density, and fertilizer usage (Maclaurin *et al.* 1981; Maclaurin 1982). Generally, edible forage yields range from 3000-30000 kg DM ha^{-1} yr^{-1} and deep fertile soils receiving more than 1 500mm of well distributed rainfall produce the largest quantities of quality fodder. Yields in the subtropics, where temperature limitations reduce growth rate, may be only 1500-10000 kg of edible fodder ha^{-1} yr^{-1} (Shelton and Brewbaker 1994).

The DM content of leucaena ranges from 22-36% and is affected by environmental conditions, plant age, time of harvesting and the proportion of the particular plant parts that are harvested. Crude protein content is highest in leaf material. It varies from 5-34% of DM but is usually about 24%. Seedpod CP content varies from 12-22%, whilst stems contain only one third as much CP as leaves do. These values indicate a higher CP content in leucaena than in lucerne and *Stylosanthes gracilis* containing 17% and 15%, respectively (Maclaurin *et al.* 1981; Maclaurin *et al.* 1982).

2.4 DISCUSSION AND CONCLUSIONS

Pastures and rangelands, including the uncultivated lands with potential to support grazing and/or browsing, cover 70% of the world's total land area (Singh and Ghosh 1993). Globally, the majority of rangelands support grazing and/or browsing in a variety of systems ranging from privately or communally owned livestock enterprises to subsistence sedentary or nomadic livestock production systems; and any herbivore system on rangeland is dependent on the forage produced by the rangeland itself (Kirkman and de Faccio Carvalho 2003).

However, the current feed supplying potential of rangelands is continuously declining because of increased population growth and other increased anthropogenic influences. The ever-rising population growth forces farmers to expand their croplands into the rangelands and cultivate more lands that are less suited for farming to secure the increased family food demands (Singh and Ghosh 1993; Lekasi *et al.* 2003). As a consequence, there will be increased livestock pressure on the remaining suboptimal rangelands. This will cause deterioration of both crop and rangeland productivity (Singh and Ghosh 1993).

Moreover, the seasonal availability of tropical grasslands, at a lower forage quality, will negatively affect animal performance (Zacharias *et al.* 1991). Despite these limitations, however, animal production from these natural feed resources still plays an important role in the economy of arid zones (Singh and Ghosh 1993). Generally speaking, the whole system of livestock production in arid and semi-arid zones is facing countless problems, creating opportunities for scientific input (Singh and Ghosh 1993).

A long-term soil fertility decline is one of the greatest concerns of land degradation. The increasing cost and environmental concern of inorganic fertilizers is another subject seeking scientific approaches to evaluate locally available organic fertilizers such as crop residues, animal wastes and other forms of organic fertilizers. More interestingly, research has focused on the evaluation of the quality, quantity and ways of utilization of such biological materials (Lekasi *et al.* 2003).

Therefore, as alternatives, the incorporation of forage legumes into grazing pasture/cropland systems; the use of crop residues for animal feed and soil fertility amendment; establishment of legume forage trees (Kirkman and de Faccio Carvalho 2003); and proper application and use of animal wastes can partly substitute and cut the cost of inorganic fertilizers, and as a whole the cost of livestock production systems (Smith *et al.* 2000) and minimize serious environmental instability concerns. In addition, an understanding of the role of grazing animals in moving nutrients from grazing areas and concentrating them in other areas needs to be understood and managed. In particular, the influence of nutrient removal by animals on rangeland productivity is poorly understood. This may possibly make a difference when such strategies are used within the available limited land and other resources.

CHAPTER THREE

STUDY AREA

3.1 THE STUDY AREA

The study was conducted at Ukulinga Research Farm of the University of KwaZulu-Natal, near Pietermaritzburg; and the natural grazing lands of the villages of Zwelitsha and Okhombe located close to the Drakensberg mountains.

Ukulinga is the Research and Training Farm of the University of KwaZulu-Natal located at 29°40'E and 30°24'S, 715m asl. in the "Southern Tall Grassveld" of South Africa with a mean annual precipitation of 782mm falling mostly in summer between October and April (Morris 2002). Mean maximum and minimum temperatures are 25.7 and 8.9 °C, respectively (Morris and du Toit 1998).

Zwelitsha and Okhombe, where the 5th study was located, are two different villages in close proximity to each other close to the Drakensberg mountains of the Republic of South Africa. The region is part of the KwaZulu-Natal province of South Africa in the Bergville district. The villages are situated in a communal rangeland area between the conserved Royal Natal and the Cathedral Peak National Parks. They lie between 28°30'27"S and 29°00'23"E situated 52kms west of the Bergville town in the foothills of the Drakensberg mountain at about 1 200m in the valley to over 1 800m asl. in the hills (Everson *et al.* 1998; von Maltitz 1998). Due to its high altitude and proximity to the Drakensberg the area has moderate summer temperatures with cold winters. The area gets a high rainfall estimated at greater than 800mm per annum, with the higher ground receiving more annual precipitation (Everson *et al.* 1998; von Maltitz 1998). The vegetation is classified as Highland Sourveld[3] (Acocks 1953), or Moist Transitional Tall Grassveld of the Bioresources Groups of KwaZulu-Natal (Camp 1999) which is characterised by low nutritive value during winter.

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[3] "Sourveld" is a word derived from the Afrikaans word "suurveld" meaning a veld/rangeland containing unpalatable plants on reaching maturity, thus allowing the veld to be utilized by stock for only a portion of each year (Booysen 1967).

3.2 METHODS

In these areas five different studies were carried out. Study 1 (planted to *E. tef/M. sativa* intercrop), study 2 (planted to *E. tef/L. leucocephala* intercrop), study 3 (planted to *E. tef* under four different N-fertilizer treatments), study 4 (containing indigenous natural grasses under different grazing systems) and study 5 in the communal grazing systems of Zwelitsha and Okhombe.

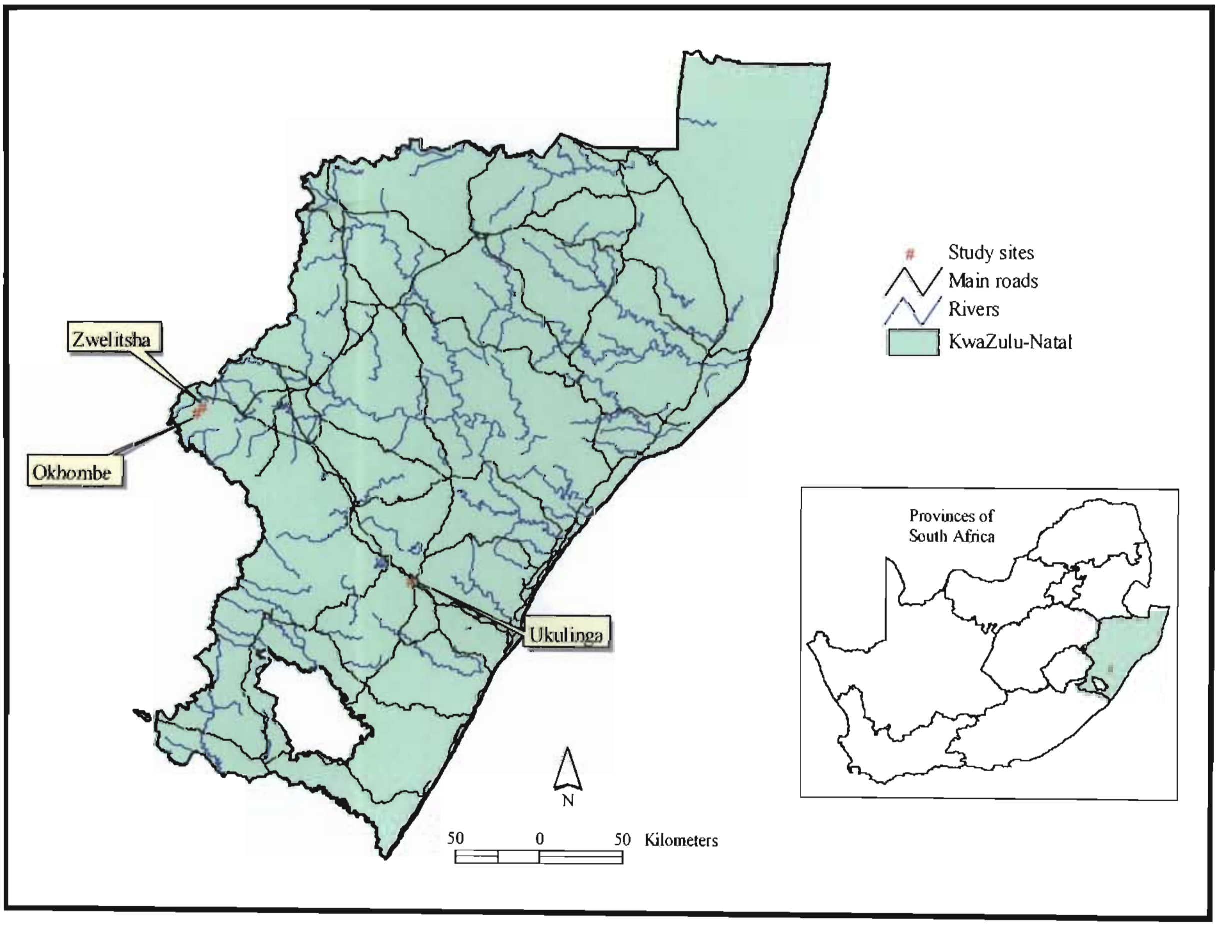

Figure 3.1 Map of KwaZulu-Natal showing main roads, rivers and the indicated study areas.

CHAPTER FOUR

LEGUME-GRASS INTERSPERSING

ABSTRACT

The tropics, sub Saharan Africa in particular, are continuously experiencing a serious soil fertility decline. As a consequence livestock husbandry, especially in the very dry seasons when lack of protein is a challenging problem, require feed production technologies that are locally and economically affordable and environmentally friendly and sustainable. Forage legumes are receiving increased attention as living tools to combat this plant nutrition bottleneck in livestock production systems. For this study lucerne and leucaena were used as the forage legumes with which teff was interspersed as the grass to benefit from the association. Interspersing teff with lucerne reduced teff yield from 1312 kg ha^{-1} in the teff alone plot to 657 kg ha^{-1} in the teff-lucerne interspersed plot in the 75cm row spacing treatment; whereas planting teff with leucaena increased teff DM yield from 887.20 kg ha^{-1} in the teff alone treatment to 1982.89 kg ha^{-1} in the 180cm and 2082.39 kg ha^{-1} in the 120cm row spacing treatment. This is possibly because leucaena had a longer establishment period than lucerne so that this enabled it to develop strong and effective nodules and/or deposit enough organic matter for gradual release of nutrients. The other possible reason is that is lucerne is a herbaceous legume whereas leucaena is a shrub/tree. This difference may have an influence on the amount of organic matter accumulated, the ability of a plant to take nutrients deep in the ground up to the soil surface, nitrogen fixation efficiency difference, and the length of time needed for the plant material to decompose. The faster the decomposition of organic material from legumes the richer will be the soil. Thus, if teff is planted on this nutrient rich soil, possibly the yield will be higher.

Key words: lucerne, leucaena, plant spacing, row spacing, teff, yield

4.1 INTRODUCTION

In the tropics declining soil fertility and the shortage of livestock feeds, particularly the lack of protein during the dry season, are major production shortcomings in many smallholder mixed farming systems (Nyambati and Sollenberger 2003; Mureithi *et al.* 2003). These constraints partly arise from land limitations that lead to continuous cropping and grazing, and partly from inadequate or lack of use of N fertilizers. In recent years, interspersing of legumes has been evaluated in many parts of the tropics where the use of commercial N fertilizers is not economically feasible. The use of forage legumes in smallholder farms in the tropics has generally been low. Thus, for increased adoption, legume-based forage technologies must fit into the overall farming strategy based on food production for human consumption (Nyambati and Sollenberger 2003). Integration of forage legumes into cropping systems may be a strategic intervention for optimising the productivity of a given land area as it may optimise the use of labour and land, and reduce the cost of inputs required for establishing improved forages as well as alleviating livestock feed shortages in mixed farming systems.

Globally grass-legume mixtures are preferred to pure grass forage stands because they usually increase total herbage yield, quality and seasonal distribution of forage (Ta and Faris 1987a; Burity *et al.* 1989). The interest in use of legumes in cropping systems is also renewed by the concerns regarding agricultural sustainability, soil and environmental quality and energy conservation (Mohr *et al.* 1999). Furthermore, grass herbage production is limited largely by the availability of N (Burity *et al.* 1989). Therefore, the nonlegumes can benefit from some of the N fixed by legumes either by direct excretion from the legume nodule system and/or by decomposition of nodule and root debris (Burity *et al.* 1989). Such transfer can represent a considerable part of the nonlegume N budget thereby reducing the need for the expensive input of artificial N fertilizers (Ta and Faris 1987a, b; Lory *et al.* 1992). However, the advantage of growing grass-legume associations depends on several complex genetic constraints (species difference), environmental factors and management systems (Ta and Faris 1987a). Lucerne is a major source of N to grain crops and/or nonlegumes. However, estimates of the amount of N transferred from legumes to nonlegumes are still very controversial issues. For instance, reed canarygrass (*Phalaris arundinacea* L.) received up to 68% of its herbage N from N fixed by lucerne, although values from 20-30% are more typical. According to Lory *et al.* (1992) the amount of N transferred by lucerne to an interspersed nonlegume can also reach up to 20 kg N ha^{-1} yr^{-1}. In other studies (Brophy *et al.* 1987) the N transfer in mixed legume-grass forages, intercrops of grain legumes and nonlegumes range from 26 to 154 kg N ha^{-1} depending upon species composition of the sward, its productivity and duration of crop growth. Therefore, this transfer may partly substitute for N fertilizers in intercrops, pastures, and relay crops consisting of concurrently growing legume-grass associations.

Leucaena leucocephala is one of the most commonly used and known leguminous shrubs/trees in the tropics. Beyond its popularity as a forage legume, there is a great hope that leucaena may provide a considerable amount of N through its ability to access the nutrients deep in the ground and by fixing the non-accessible atmospheric nitrogen that has never directly been used by other plant species which lack this special ability. Using the difference and the ^{15}N dilution methods, Sanginga *et al.* (1989) estimated the nitrogen fixed by leucaena to be 133 and 134 kg N ha^{-1} in six months. The nitrogen fixed by leucaena in their study represented 34-39% of the plant nitrogen required. In another study Hogberg and Kvarnstrom (1982) found the N fixed by leucaena to be 110 ± 30 kg N ha^{-1} and in another study Sanginga *et al.* (1986) found that, in six months, leucaena fixed 224-274 kg N ha^{-1}, which is equivalent to 56% of the plant nitrogen. Thus, from these reports it can be seen that the estimates of the amount of N fixed by leucaena can considerably contribute to the N budget of farming systems and at least cut the costs for the expensive mineral N fertilizers; although the estimates of the amount of N fixed by leucaena varies considerably.

4.2 STUDY 1: TEFF-LUCERNE INTERSPERSING

The objectives of the teff-lucerne interspersing study were to determine the effect of teff-lucerne mixtures on:

1) Dry matter production of teff (with lucerne) compared to teff alone;
2) Teff nutritive value (N and P) when interspersed compared to teff alone;
3) Dry matter production of lucerne when interspersed compared to lucerne alone;
4) Lucerne nutritive value (N and P) when interspersed compared to lucerne alone; and
5) Total productivity and nutritive value of the mixture compared to the components alone.

4.2.1 **Procedure**

Treatments and measurements

Study 1 was carried out on a 30m x 80m area consisting of 30 plots created by the combination of three different within row plant spacings (5, 15, and 25cm) and three different row spacings (75, 125, and 175cm) of *M. sativa* as treatments interspersed with *E. tef.* Teff was broadcast between the lucerne rows. Plots were allocated to three blocks, each block consisting of 10 of the 30 plots including one teff alone plot (control), i.e. each block consisted of 10 plots in total. None of the plots were fertilized with N fertilizer.

The experimental design was a randomised complete block with three replicates of each plot. The planting pattern within each plot consisted of two monospecific rows (75, 125, and 175cm wide plots) of lucerne and teff planted in between the rows. Each lucerne row was a treatment. The field was ploughed before planting for easy plot preparation. After inoculation with suitable Rhizobia, lucerne was hand sown at 20 kg ha^{-1} 10mm deep on September 9, 2002 and teff at 10 kg ha^{-1} on November 21, 2002, after allowing enough time for the lucerne to develop active root nodules. The teff within the plots was hand broadcasted. Then, after growing to 3-4 leaf stage, lucerne rows were thinned to the desired plant spacings. The plots were periodically hand weeded to minimize weed infestation and irrigated to prevent wilting and for good establishment of seedlings. A control teff alone plot was grown in each replication (block). The whole lucerne rows were cut back after teff and lucerne samples were taken to let the lucerne regrow and to avoid shading of teff plants by lucerne plants. However, unlike lucerne, teff was sampled at four different times separated in terms of weeks.

Table 4.1 Monthly rainfall of the 2002-2003 season and long-term mean rainfall at Ukulinga.

Month	Monthly rainfall (mm)	Long-term mean rainfall* (mm)
August	14.5	18.00
September	31	32.57
October	20	53.56
November	53	88.56
December	60	113.75
January	72	93.93
February	107	87.18
March	78.5	63.75
Total	436	551.30

*It is the mean of eight seasons of each month (1996/97-2003/04).

Sampling

Using a hand clipper a one metre lucerne herbage regrowth strip from within each lucerne row was harvested on December 27, 2002; January 9, 2003; January 29, 2003; and February 13 2003 at a height of 5cm. Similar strips of teff were also taken from within each plot on the same day of harvest to that of lucerne four weeks after planting teff. In each graph, the weeks 4, 6, 8, and 10 represent cutting times when plant samples were taken. So they will be used as cut 4 weeks, cut 6 weeks, cut 8 weeks and cut 10 weeks throughout. Both lucerne and teff plant samples were fresh weighed in the field and sub-sampled. Both subsamples of lucerne and teff were oven dried at 60 °C for 48 hours, separately weighed to calculate dry matter (DM) content and finely ground to pass through a 1mm screen in preparation for forage quality analysis.

Soil samples were collected to 15cm depth using a soil auger and then air-dried and sieved through 2mm screen for further chemical analysis purposes. They were collected at the end of the last plant sample harvest.

All plant and soil samples, prior to chemical analysis, were subjected to a sulphuric acid-hydrogen peroxide digestion of the Kjeldahl method using a high (360 °C) temperature controlled digestion block (Tomas *et al.* 1967). Then the digests were analysed for total N using automated colorimetry (Technicon Autoanalyzer II, Technicon Industrial Systems 1978). Plant samples were also analysed for total phosphorus content using the same Autoanalyzer machine.

Statistical analysis

Ten different lucerne plant row and plant spacing combinations were used as treatments. The analysis of variance (ANOVA) was used to determine the effects of these treatments on dry matter (DM) yield and nutritive quality of teff and lucerne (Appendices 1-5). Differences between means ($P<0.05$) were assessed using the least significant differences (LSD). The statistical analysis was performed using Genstat 6.1 software (McConway *et al.* 1999).

4.2.2 **Results**

Teff herbage yield response to teff-lucerne interspersing

There was no statistically significant ($P<0.05$) effect of lucerne plant spacing on teff DM yield when lucerne plant spacing treatment was tested against the teff alone treatment (Appendix 1a). However, compared to the teff alone (no lucerne interspersed with teff) treatment yield, the DM yield of teff grown in mixture with lucerne has shown significant ($P<0.05$) effects of row spacing, particularly at the 75cm row spacing treatment. Teff DM yield was reduced from 1312 kg ha^{-1} in the teff alone treatment plot to 657 kg ha^{-1} in the 75cm lucerne plant row spacing treatment plot. When the three different lucerne row spacing treatments were compared, there were statistically significant ($P<0.05$) differences between the 75cm and the 125cm lucerne row spacing treatments, and between the 75cm and 175cm lucerne row spacing treatments but the 125cm and 175cm lucerne row spacing treatments did not show ($P<0.05$) statistical difference on their effect on teff DM yield, showing that it was not necessary to increase lucerne row spacing from 125cm to 175cm. In this study neither of the lucerne row spacing treatments produced more than the teff alone treatment plots (Figure 4.1a).

When the effect of the four different cutting weeks on teff DM yield were compared among each other, teff DM yield was higher for the cut 6 weeks both in the teff alone treatment and teff-lucerne interspersing treatment plots and dropped at the cut 8 weeks. Yield started to increase for the cut 10 weeks. All cutting weeks, except the 6 and 10 weeks, were statistically (P<0.05) different one from the other. That is the DM yields of teff obtained from the teff-lucerne treatment plots of both cuts done in the 6th and 10th weeks are almost similar (Figure 4.1b).

The interaction between row spacing (RS) and cut, when compared to that of the teff alone treatment, has shown a significant effect (P<0.05) on teff dry matter production. That is to say, interspersing teff with lucerne reduced teff DM yield. However, yield has shown a consistent increase especially for cuts 2 and 3 when row spacing was increased from 75cm to 175cm (Table 4.2).

Table 4.2 Teff dry matter yield (kg ha^{-1}) when planted alone and interspersed with lucerne.

Lucerne plant RS (cm)	Cut after				Total
	4 weeks	6 weeks	8 weeks	10 weeks	
Teff alone	**99[a]**	**437[b]**	**374[b]**	**402[b]**	**1312[a]**
75	19[a]	199[a]	143[a]	296[b]	657[b]
125	104[a]	389[b]	250[b]	429[b]	1172[c]
175	81[a]	434[b]	304[b]	349[b]	1168[c]
RS mean	75.75	364.75	192.60	369	1077.25

Within a column, values followed by the same letter do not differ significantly (P<0.05) from each other.
RS = lucerne plant row spacing.

In a similar fashion to that of teff DM yield, teff nitrogen (N) content was lower (P<0.05) when teff was interspersed with lucerne than when growing alone. The reduction was 63% at the 75cm lucerne plant row spacing treatment plot. However, the decline in teff N content was minimized to 33% when teff was planted in between two lucerne rows planted at 125cm inter-row spacing. Increasing lucerne row spacing to 175cm brought N content to only 13% less than the nitrogen content of the teff alone treatment (Figure 4.2a).

Except at the 75cm lucerne row spacing treatment where the phosphorus content of teff herbage was lower for the first and cut 8 weeks than the P yield of its respective teff alone treatment, the phosphorus content of teff herbage interspersed with lucerne was significantly higher (P<0.05) than that of the teff alone treatment (Figure 4.3a and b). Phosphorus content increased substantially when row spacing was increased from 75cm to 175cm. Thus both the 125cm and 175cm row spacing treatments had higher P contents than the teff alone treatment. In terms of teff DM yield, the highest production was obtained for the cut 10 weeks (Table 4.2). However, cut 4 weeks of teff growth period has produced maximum value of teff N and P (Figures 4.2b and 4.3b) for both row spacing treatments. As can be shown in Figure 4.1b, the total teff N yield obtained from plots with teff-lucerne interspersed was less than the N yield of teff obtained from the teff alone plot. However, the total teff N content of the 125cm and 175cm lucerne row spacing treatments was almost similar to that of the teff alone treatment plot (Figure 4.2b). The total P content of teff obtained from the above two lucerne row spacing treatments was also higher as compared to the P content of teff obtained from the teff alone treatment plot (Figure 4.3b).

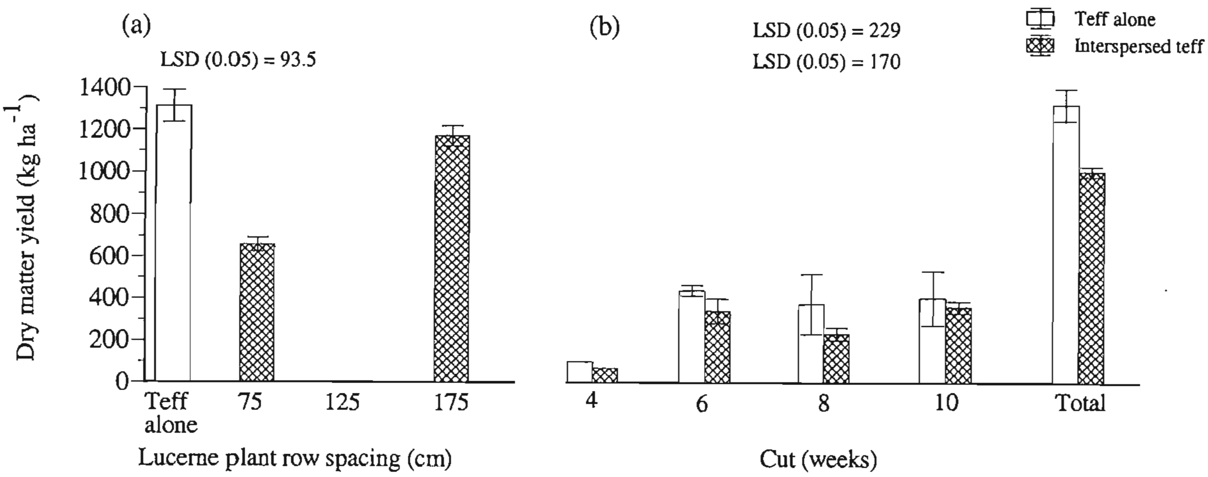

Figure 4.1 Effect of lucerne row spacing (a) and cutting time (b) on teff DM yield compared to teff alone DM yield at three different row spacings.

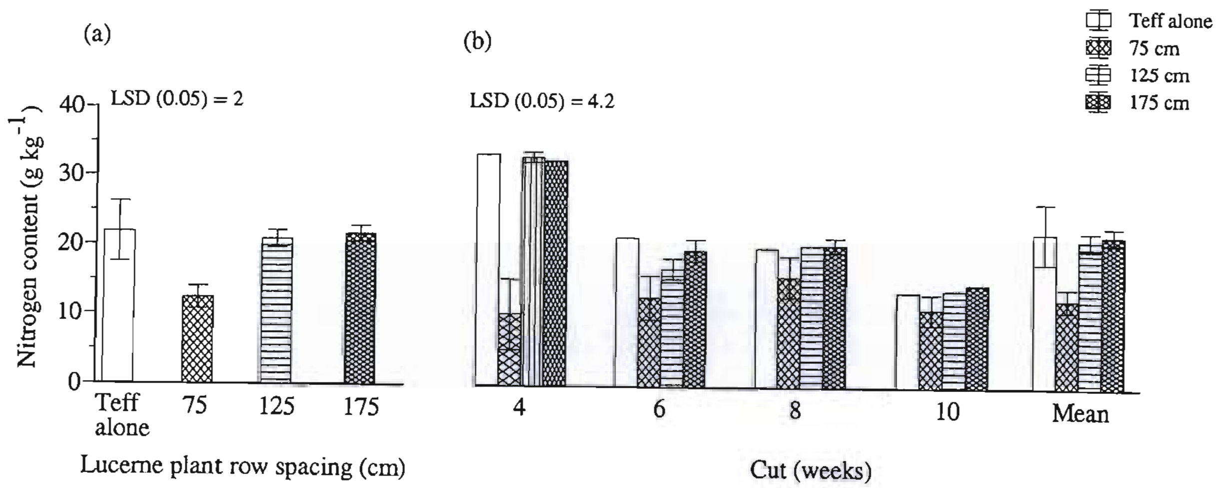

Figure 4.2 Comparison of the N content of teff obtained from teff interspersed with lucerne at three different row spacings (a) and N content of teff obtained at four different cuttings (b) to teff alone N content.

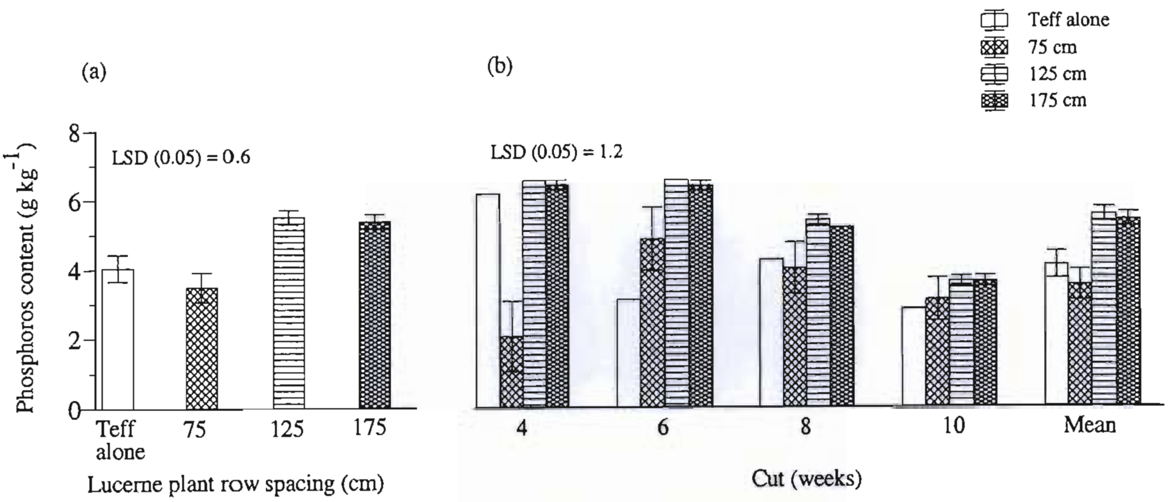

Figure 4.3 Comparison of the P content of teff obtained from teff interspersed with lucerne at three different row spacings (a) and P content of teff obtained at four different cuttings (b) to teff alone P content.

Lucerne herbage yield response to teff-lucerne interspersing

All treatments (lucerne plant spacing, lucerne row spacing, and cutting time) had a statistically significant ($P<0.05$) effect on lucerne DM yield (Appendix 2a). Here only the effects of both lucerne row spacing and cutting time will be considered. As it is shown in Figure 4.4a the total lucerne DM yield of the four cut weeks was higher for the 75cm row spacing treatment and the lucerne alone treatment produced less than the other three lucerne row spacing treatments. This shows that planting lucerne in rows, instead of broadcasting, is more effective for efficient DM production. Yield was higher for the 75cm row spacing treatment and lower as lucerne row spacing increased. Dry matter yield was lower both for the lucerne alone and interspersed (lucerne interspersed with teff) lucerne for the cut 4 weeks (Figure 4.4b). The diagram also shows that DM yield was directly related to stage of plant growth. The yields of both the lucerne alone and interspersed lucerne treatments were almost similar both for the cut 6 weeks and cut 8 weeks.

The N concentration of lucerne was almost similar for the lucerne alone, 75, 125 and 175cm row spacing treatments. They produced 38.7, 39, 39.7 and 38.9 g kg^{-1}, respectively (Figure 4.5a) for the cut 6 weeks. On the other hand, similar to the DM yield of lucerne the 75cm row spacing treatment produced slightly higher, 37 g kg^{-1} N than the other treatments and the 125cm row spacing treatment produced the lowest, 32.7 g kg^{-1} (Figure 4.5a). For the cut 8 weeks, except the 125cm row spacing treatment, the lucerne alone, 75 and 175cm treatments produced almost similar amounts of nitrogen. Their N yields were 35, 34.8 and 35.3 g kg^{-1}

respectively (Figure 4.5b). This has shown that the integration of lucerne with teff had little effect on lucerne N content.

For lucerne P content the interspersing of the two plant species had a statistically significant effect (P<0.05). Figure 4.6a and b showed that the lucerne alone treatment produced more than the other three treatments. This implies that teff competed for P with lucerne and this reduced the lucerne P content by 176% and 166% in the 75 and 175cm row spacing treatments respectively for the cut 8 weeks. When comparing the 75, 125 and 175cm row spacing treatments, the 125cm produced more P for the cuts 6 weeks, cut 8 weeks and cut 10 weeks but produced less than the 175cm row spacing treatment for the cut 4 weeks. For all four cut weeks the 75cm row spacing treatment produced less P than the other two cut weeks treatments (Figure 4.6b).

The total dry matter yield of lucerne obtained from the teff-lucerne mixture plots was much higher than that obtained from the lucerne alone plot (Figure 4.4b) and the total N content of lucerne (Figure 4.5b) was higher for the 75cm lucerne row spacing treatment and almost similar to that obtained from the lucerne alone plot in the 175cm lucerne row spacing treatment plot. However, the total P content of lucerne obtained from the teff-lucerne mixture plots was much lower than the total P obtained from the lucerne alone plot (Figure 4.6b).

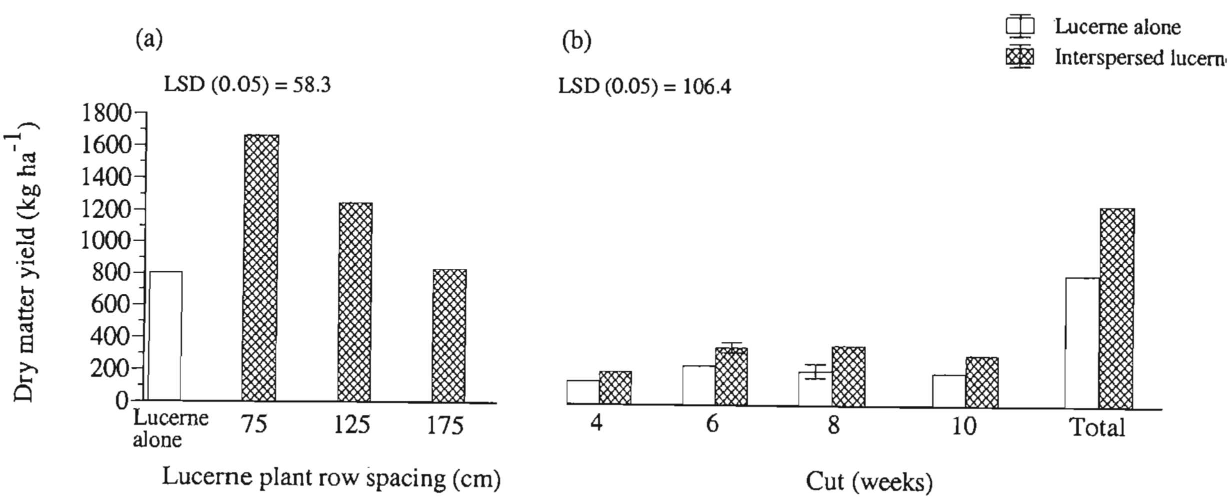

Figure 4.4 Effect of lucerne row spacing (a) and cutting time (b) on lucerne DM yield compared to lucerne alone DM yield at three different lucerne row spacings.

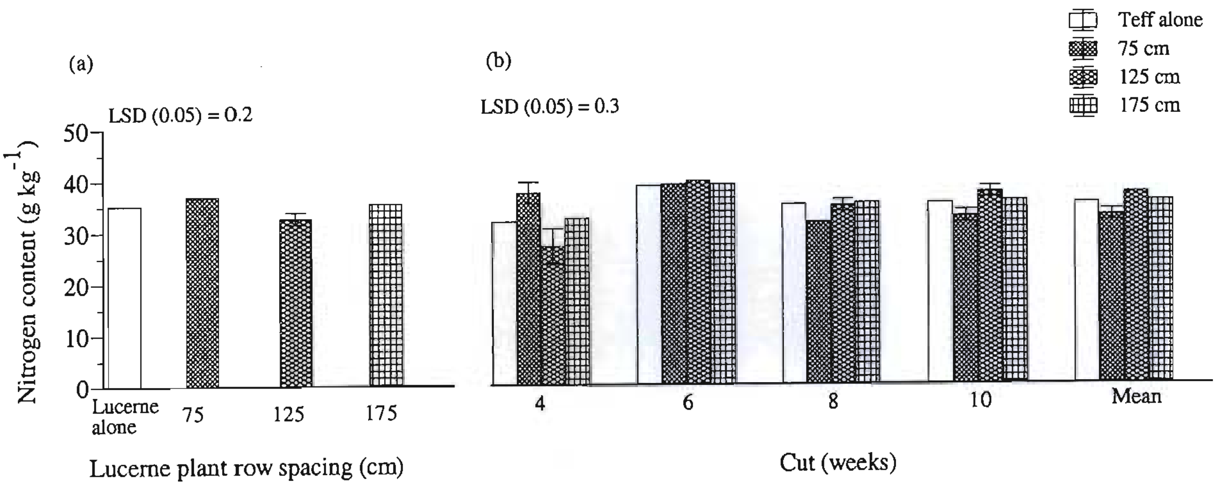

Figure 4.5 Comparison of the N content of lucerne obtained from lucerne interspersed with teff at three different lucerne row spacings (a) and N content of lucerne obtained at four different cuttings (b) to lucerne alone N content.

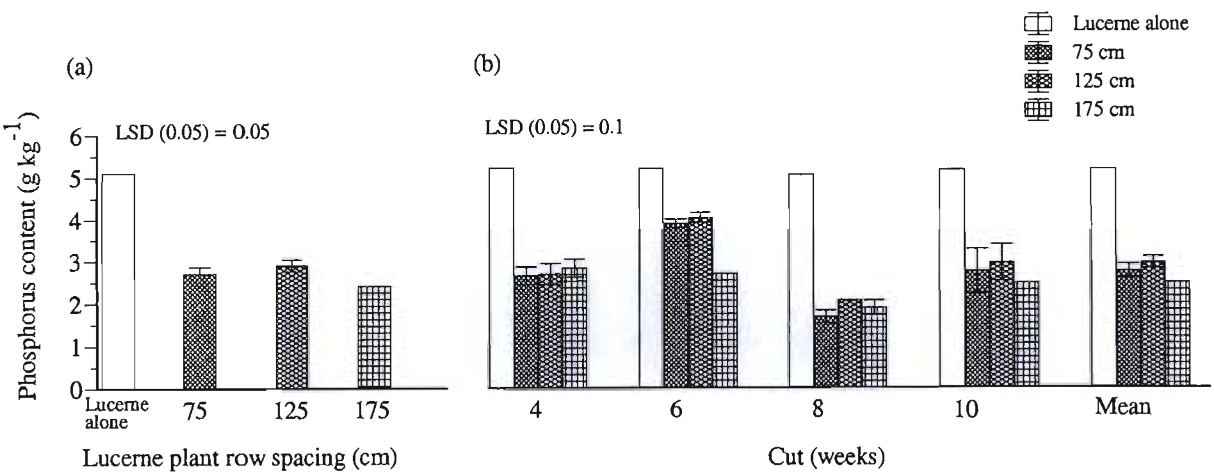

Figure 4.6 Comparison of the P content of lucerne obtained from lucerne interspersed with teff at three different row spacings (a) and P content of lucerne obtained at four different cuttings (b) to lucerne alone P content.

Teff-lucerne stand yield response to teff-lucerne interspersing

Lucerne plant row spacing significantly (P<0.05) affected the teff-lucerne mixture DM yield (Appendix 3). Total DM yield was much higher for the teff-lucerne (5468 kg ha^{-1}) mixture than for the teff alone (1312 kg ha^{-1}) or lucerne alone (806.5 kg ha^{-1}) stands (Figure 4.7a). When each stand composition was tested for DM yield at different cutting times, the DM yield of the teff-lucerne produced 318, 643, 480 and 560 kg ha^{-1} for cuts 4, 6, 8 and 10 weeks respectively. The teff-lucerne mixture DM yield was low for the cut 4 weeks. The DM yield of the teff-lucerne mixture fluctuated across the different cutting times. The DM yield for the teff alone was 99, 437, 374 and 402 kg ha^{-1} for cuts 4, 6, 8 and 10 weeks respectively. The lucerne alone stand gave 147, 243, 215 and 202 kg ha^{-1} for cut 4, 6, 8 and 10 weeks respectively. The teff alone stand produced more DM than the lucerne alone stand for the cuts 6, 8 and 10 weeks and less for the cut 4 weeks. Both the teff alone and lucerne alone stands had different DM yields for all cutting weeks. i.e. there was no similarity in DM production between the two for the mentioned cutting weeks (Figure 4.7b).

The N content of the teff-lucerne mixture was also significantly higher ($P<0.05$) than that of the teff alone and lucerne alone stands (Appendix 4). Except for the cut 4 weeks, unlike the DM yield, the N content of the lucerne alone stand was higher than that of the teff alone stand. Compared at different cutting intervals, the teff-lucerne mixture was higher in N content than the teff alone for all the four cuts (Figures 4.8a and b).

The P content had a similar response to that of the N content for the three stands. Phosphorus content was higher for the teff-lucerne mixture followed by the lucerne alone and was lowest for the teff alone stand (Figure 4.9a). For the cuts 4, 6, 8 and 10 weeks, the P content of the teff-lucerne mixture was higher. Except for the cut 4 weeks, teff P content was higher in the teff-lucerne stand compared to the teff alone. Teff P content was similar both for the second and cut 10 weeks (Figure 4.9b).

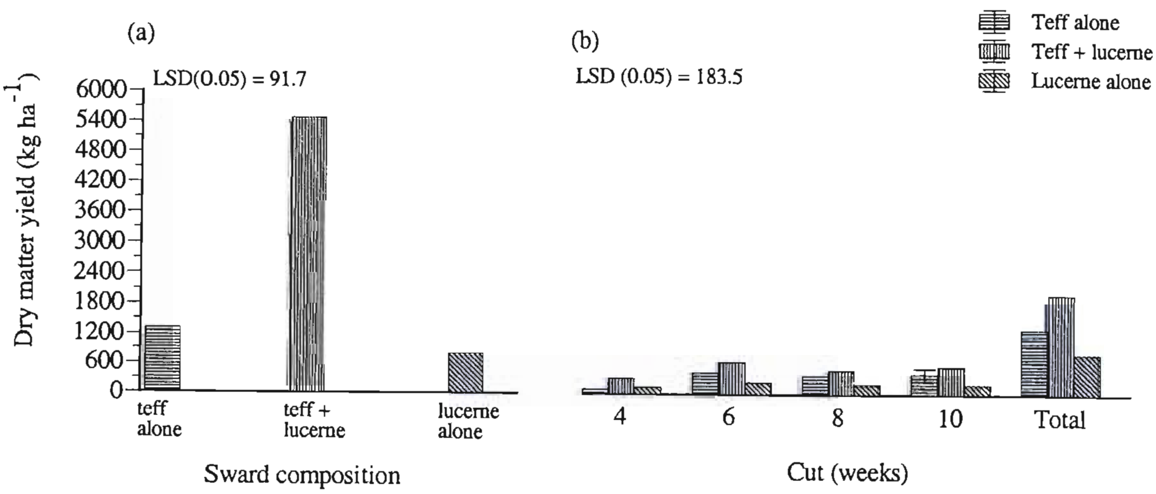

Figure 4.7 Comparison of DM yield of mixed and pure stands between different stand compositions (a) and between the different stand compositions at different cuttings (b).

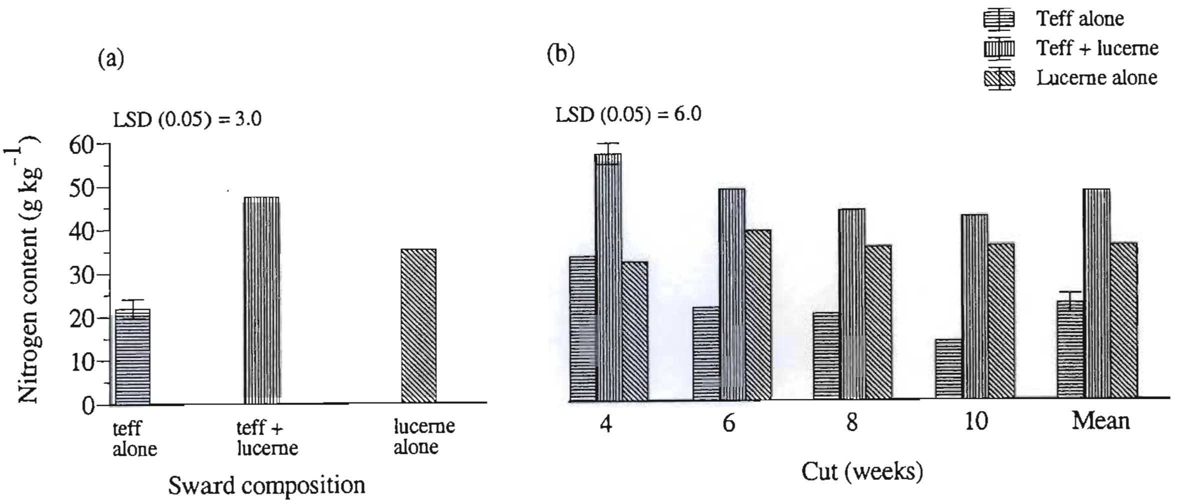

Figure 4.8 Comparison of N content of mixed and pure stands between different stand compositions (a) and between the different stand compositions at different cuttings (b).

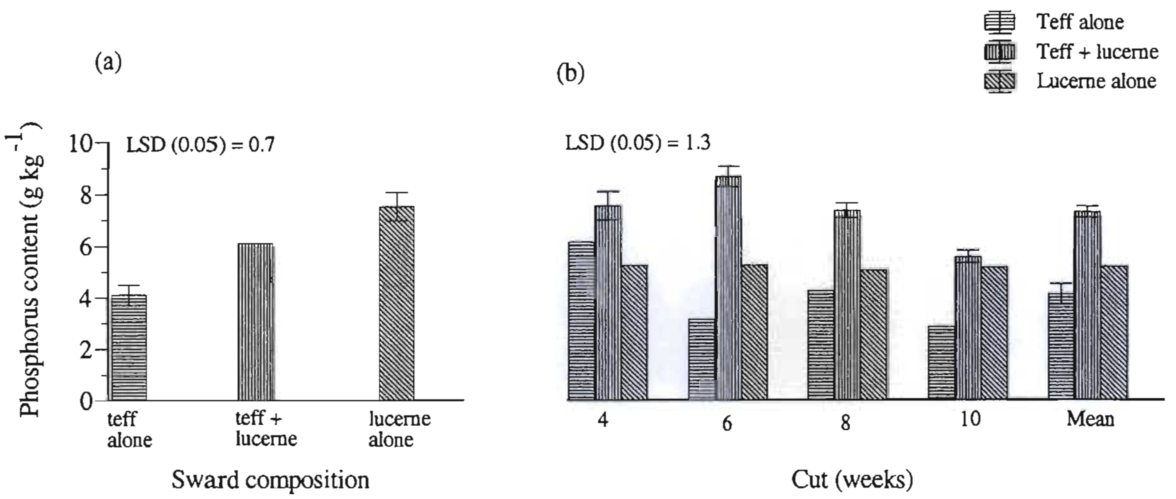

Figure 4.9 Comparison of P content of mixed and pure stands between different stand compositions (a) and between the different stand compositions at different cuttings (b).

Soil nutrient content status

After finishing plant sampling, soil samples were taken from each plot for soil N content evaluation. The plots containing teff-lucerne stands contained significantly greater ($P<0.05$) soil N levels than the teff alone plot and the highest soil N content was obtained at the 15cm x 125cm plot (Table 4.3).

Table 4.3 Comparison of soil N content (g kg^{-1}) of plots containing teff-lucerne mixture to teff alone plot soil N content.

	Lucerne row spacing (cm)			
Lucerne plant spacing (cm)	0	75	125	175
0	1.21^{a}	-	-	-
5	-	1.49^{b}	1.57^{c}	1.30^{d}
15	-	1.40^{ab}	1.81^{ac}	1.36^{ad}
25	-	1.27^{ba}	1.39^{bb}	1.71^{bc}
LSD(0.05) 0.017				

Values in a column with different letters significantly differ from each other.

4.2.3 **Discussion**

The objectives of this study were to determine the effects of teff-lucerne interspersing on teff DM yield and nutritive quality compared to its teff alone results; and on lucerne DM yield and nutritive quality in relation to its lucerne alone stand. The DM yield of the interspersed teff at the 75cm row spacing treatment was only 657 kg ha^{-1} and it was 49% lower compared to its teff alone DM yield of 1312 kg ha^{-1} resulting in a yield ratio of only 0.5:1 compared to the minimum desired ratio of 1:1. Also the other row spacing treatments produced less than the teff alone treatment (Table 4.2). Thus, teff DM yield was reduced by interspersing. This might be due to competition for light between lucerne and teff plants rather than a failure of lucerne to contribute N, because in most plots after lucerne reaches more than 50-60cm tall, it covers a substantial area especially in the 75cm lucerne plant row spacing treatment plot. Liebenberg (1997) found a reduced plant dry matter yield by interspersing beans with maize and he suggested that the plant competition for light to be a possible reason for the reduced plant DM yield. Although they did not specify for which growth requirement their experimental plants competed for, Ta and Faris (1987a) found a reduced DM yield of timothy grass interspersed with lucerne when they increased the proportion of lucerne plants. Dry matter yield was 5900 kg ha^{-1} at the 1:1 ratio and 5400 kg ha^{-1} at the 1:2 ratio. This can also be seen from Figures 4.1a, 4.2a and 4.3a where yield increased when row spacing was increased. The other possible reason is that the amount of N fixed by lucerne might have not been exceeding lucerne N requirement. A third possible aspect might be competition from weeds, particularly the broad leaved weeds that were a threat to the growth of teff which needed a regular weeding of plots.

Table 4.2 also shows that the total teff DM production of all three row spacing treatments was lower than the DM yield of the 'teff alone' treatment.

There was a significant decrease in the N concentration of teff grown in mixture with lucerne over teff alone from the four cuts. Total N concentration was 21.85 g kg^{-1} of DM in the teff alone stand and 18.22 g kg^{-1} of DM in the teff lucerne interspersed stand. This is a common occurrence experienced in most grass-legume mixtures in the first establishment year. This is probably because the lucerne is still competing with teff for the available N and the N it has produced. Brophy *et al.* (1987) also suggested that low grass N content in rows most surrounded by lucerne was probably due to early competition from lucerne with less vigorous grass. So to evaluate such associations, results should include data from the season after establishment of grass-legume growths.

Lucerne DM yield increased for the cuts 6 and 8 weeks and nitrogen level increased for the three row spacing treatments for the cut 6 weeks and almost all treatments yielded more than their respective lucerne alone treatments with the exception of the 125cm row spacing which produced more for cut 6 weeks (Figures 4.4). The total DM yield of lucerne obtained from the teff-lucerne stand was 3739.5 kg ha^{-1} compared to the 806.1 kg ha^{-1} obtained from lucerne alone stand. This is possibly because the competition for resources from teff was less compared to the competition between lucerne plants. Total DM yield of the four cut weeks was 1662.8 kg ha^{-1} for the 75cm lucerne plant row spacing treatment and started to decline (1244.5 kg ha^{-1}) for the 125cm row spacing treatment and became slightly higher (832.2 kg ha^{-1}) than the lucerne alone (806.1 kg ha^{-1}) treatment for the 175cm row spacing treatment (Figure 4.4a). When each treatment for each cutting time was tested separately and compared to its respective lucerne alone treatment, all treatments produced more than the lucerne alone treatment. The diagram also has shown that yield increased as cutting weeks increased from 4 weeks to 8 weeks of lucerne plant growth period and started to decline under the fourth or cut 10 weeks (Figure 4.4b). Bittman *et al.* (1991) found greater yield (2590 kg ha^{-1}) under a two-cut system than under multiple cut. Ta and Faris (1987a) found an increased lucerne DM yield than lucerne alone when lucerne was planted with timothy grass. They attributed this to lucerne intraspecies competition. Lucerne planted alone produced 35.2 g N kg^{-1} dry weight and 35 g N kg^{-1} dry weight when it was planted with teff. Ta and Faris (1987b) obtained a similar result by planting lucerne with timothy grass.

The teff-lucerne stand was promising for integrating legumes and grasses in farming systems. It produced a higher DM than that of teff or lucerne alone (Figure 4.7a). From any cut teff-lucerne stand produced a higher DM than did teff and/or lucerne alone. This result agreed with results reported by Dilz and Mulder (1962), Hamilton *et al.* (1969), and Ta and Faris (1987). Generally, the greatest DM yield and N concentration were obtained from the teff-lucerne mixture, followed by lucerne alone and the least result was obtained from the teff alone.

Herbaceous forage legumes have been and are playing an important role in the low input farming systems as sources of soil nutrients and contributors to the protein requirement of animal feed. The other important group of forage legumes, the shrub/tree forage legumes, which have similar advantages to the herbaceous forage legumes but are also known for their additional advantages such a source of fuel, shade, controlling water runoff in sloppy areas will be discussed in the next study.

4.3 STUDY 2: TEFF-LEUCAENA INTERSPERSING

The objectives of this study are similar to that of the first study. Here the intention was to:

1) Determine the influence of teff-leucaena interspersing on teff DM production as compared to teff alone;
2) Compare the nutritive quality of teff grown interspersed with leucaena to teff alone; and
3) Determine the influence of teff-leucaena interspersing on leucaena DM production and nutritive quality.

4.3.1 **Procedure**

Treatments and measurements

This second study was previously planted to *L. leucocephala* (cultivar Cunningham and variety Spectra) hedgerows on a silt-loam soil 0.5-0.75m deep, for research purposes, spaced at 30cm x 180cm and 30cm x 120cm (Morris and du Toit 1998). In between the rows *E. tef* was interspersed. Six plots of leucaena hedgerows spaced at 180cm (3 plots) and at 120cm (3 plots) were used as replications for each row spacing. The experimental design was a completely randomised design.

Before planting teff, plots were sprayed with Glyphosate (a nonselective herbicide) to remove existing vegetation between leucaena rows to avoid possible competition and for a better establishment of teff seedlings. Existing leucaena plants were trimmed to 30cm height to minimize shading of teff plants. Teff was planted at 10 kg ha^{-1} on the same day as that of study one (November 21, 2002) to have the same seeding rate and harvesting time. Throughout the growth period, similar to that of study one, plots were hand weeded to reduce possible weed infestation.

Sampling

Using a hand clipper, a one-metre edible (the leaves plus the softer most upper stems) leucaena plant strip from within each leucaena row was taken on December 27, 2002; January 9, 2003; January 29, 2003; and February 13 2003. A 100cm x 180cm and 100cm x 120cm strip of teff herbage was also taken, on the same days as the leucaena harvest, at a height of 5cm from within each plot starting four weeks after planting teff. Samples were fresh weighed in the field then subsampled. Subsamples were oven dried at 60 °C for 48 hours, weighed to calculate DM yield and finely ground to pass through a 1mm screen in preparation for forage quality analysis.

Soil samples were collected at a depth of 15cm and then air-dried for chemical analysis. They were collected after the final harvest. The chemical analysis of both soil and plant samples of this study were done in the same place using the same equipment and technique to that of samples of study one.

Statistical analysis

The treatments were two row spacings (180cm and 120cm) of leucaena plant of two different establishment times, 25 and 4 years respectively. The analysis of variance (ANOVA) was then used to determine the effects of these treatments on DM yield and nutritive quality of teff and leucaena herbage samples (Appendices 6a-10c). Differences between means ($P<0.05$)

were assessed using the least significant differences (LSD). The statistical analysis was carried out using Genstat 6.1 software (McConway *et al.* 1999).

4.3.2 **Results**

Teff herbage yield response to teff-leucaena interspersing

For the cut 4 weeks teff DM yield was significantly lower ($P<0.05$) in the 180cm treatment than in the teff alone and the 120cm row spacing treatments. The 120cm row spacing treatment produced lower than both the teff alone the 180cm row spacing treatments on the cut 6 weeks. For the cuts 8 and 10 weeks both leucaena row spacing treatments produced considerably higher DM than their respective teff alone treatments. For the cut 10 weeks both treatments produced almost similar amounts of dry matter (Figure 4.10). Both the teff alone and the 180cm treatments showed a fluctuating trend in DM yield production. The DM yield of the 120cm row spacing treatment kept increasing up to the cut 8 weeks after which it maintained a DM of 2500 kg ha^{-1} that was significantly higher than the 180cm treatment for the cut 10 weeks of 2000 kg ha^{-1}.

The nitrogen production on all three treatments followed a different trend to the DM yield trend. The nitrogen yield of the 180cm row spacing treatment was higher than its teff alone treatment for all four cut weeks and started to decrease consistently for the next cut weeks. The 120cm row spacing treatment followed a different trend to the N yield trends of the 180cm row spacing treatment. Teff N content continued to decrease up to the cut 10 weeks and compared to its respective teff alone treatment mean, the N yield of the 120cm row spacing treatment was lower for all four cuts (Figures 4.11).

The P production of the teff alone and the 120cm row spacing treatments followed a similar trend to nitrogen content with the exception of the teff alone treatment or cut 10 weeks where yield was extremely low. The P yield of the 180cm row spacing treatment was higher for the cuts 4, 8 and 10 weeks than its teff alone treatment. The P yield of both the 180cm and 120cm row spacing treatments was significantly higher ($P<0.05$) than the teff alone treatment for the cut 10 weeks (Figure 4.12).

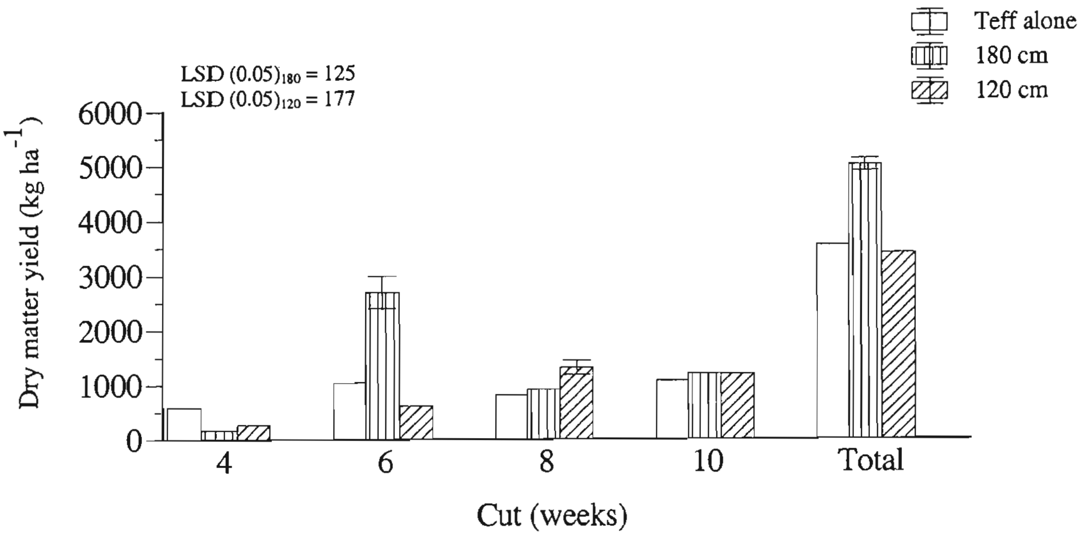

Figure 4.10 The effect of leucaena row spacing on teff DM yield at four cuttings.

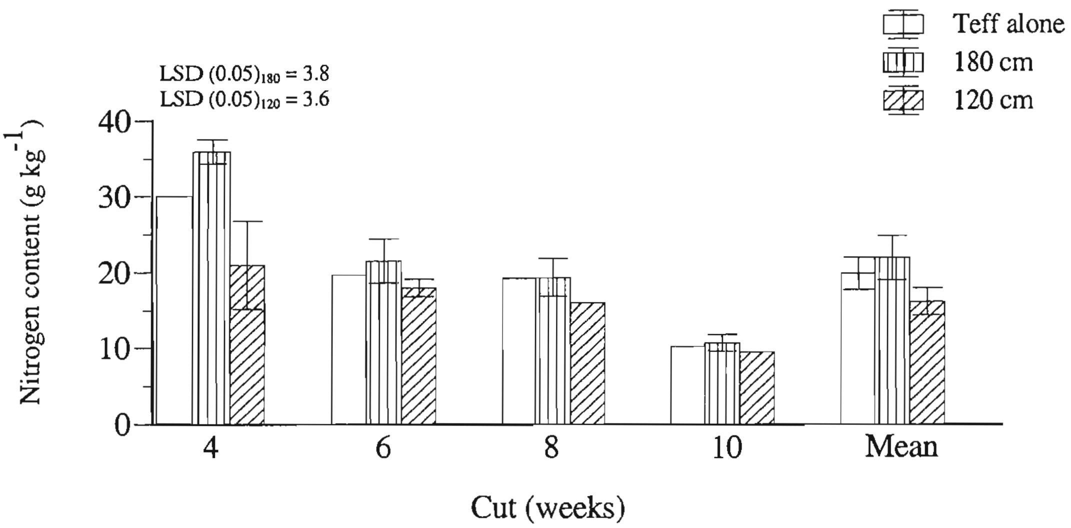

Figure 4.11 The effect of leucaena row spacing on teff N content at four cuttings.

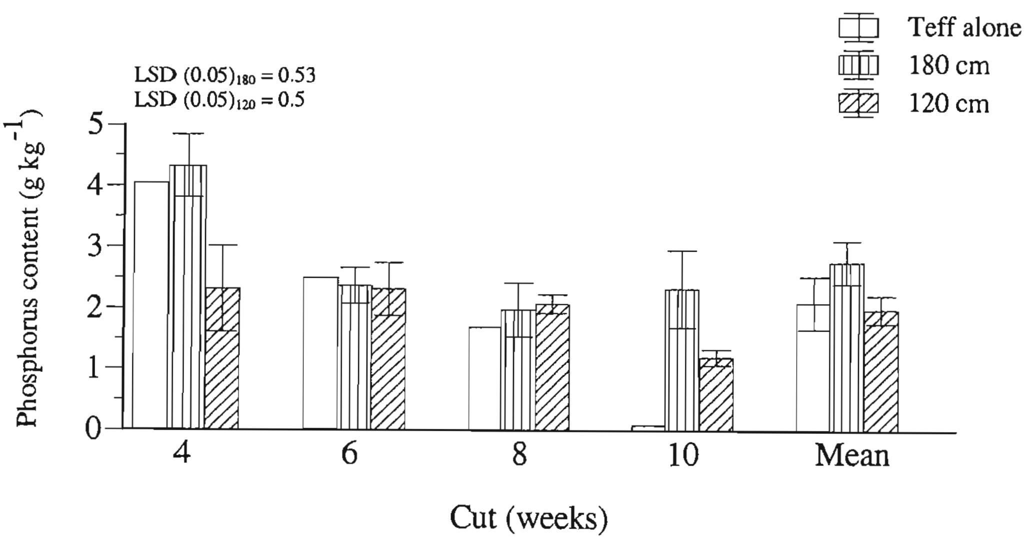

Figure 4.12 The effect of leucaena row spacing on teff P content at four cuttings.

Leucaena herbage yield response to teff-leucaena interspersing

In all four cuts the 120cm row spacing treatment produced more than the 180cm row spacing (Figure 4.13). The 180cm row spacing treatment gave the lowest yield for the cut 6 weeks and the 120cm row spacing treatment produced the highest for the cut 4 weeks. The DM yield for the 120cm treatment was decreasing slightly for the next two cut weeks. However, the change in DM yield was more noticeable in the 180cm treatment. This was especially apparent between the cuts 4 and 6 weeks as well as between cut weeks 4 and 8. The DM yield for cut 8 weeks was slightly higher than cut 10 weeks (Figure 4.13). The total DM yield was higher for the 120cm row spacing treatment than for the 180cm row spacing treatment.

In terms of leucaena nutritive quality, the 180cm row spacing treatment produced higher levels of N and P than the 120cm row spacing treatment for all cut weeks. For the cuts 4 and 8 weeks the N yield of the 180cm row spacing treatment was significantly higher than that of the 120cm as compared to the yield obtained in the cut 6 weeks. The N yield of the 120cm row spacing treatment was almost the same for the cut 8 and 10 weeks as it was the case for the 180cm row spacing treatment. Both treatments produced more N for the cut 6 weeks and less for the cut 4 weeks (Figures 4.14 and 4.15).

The highest and lowest leucaena P contents were obtained for the cut 4 weeks of the 180cm row spacing and the 120cm row spacing treatments, respectively. For the 120cm row spacing treatment leucaena P content was higher for the cut 6 weeks but both the 8 and 10 cut weeks produced almost the same amount. In the 180cm row spacing treatment leucaena P content was almost similar both for the cuts 6 and 8 weeks (Figure 4.15).

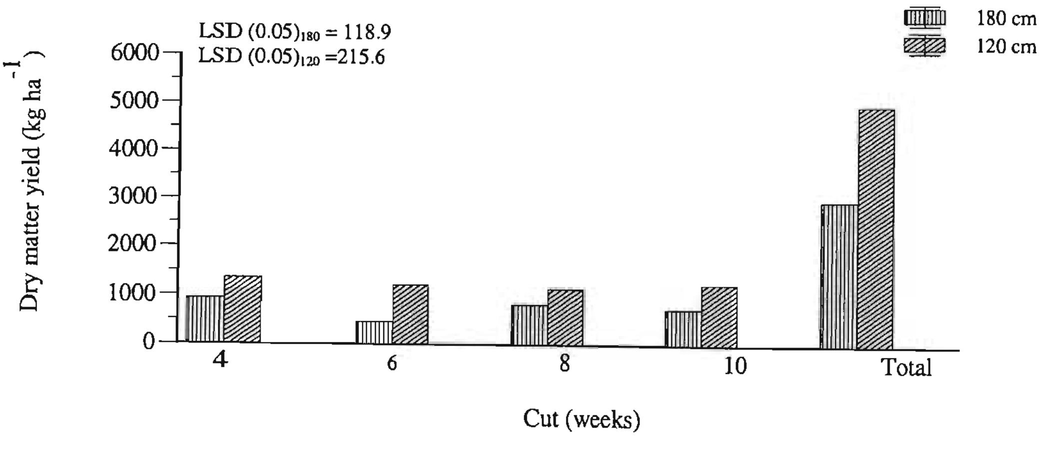

Figure 4.13 The effect of leucaena row spacing on leucaena DM yield at four cuttings.

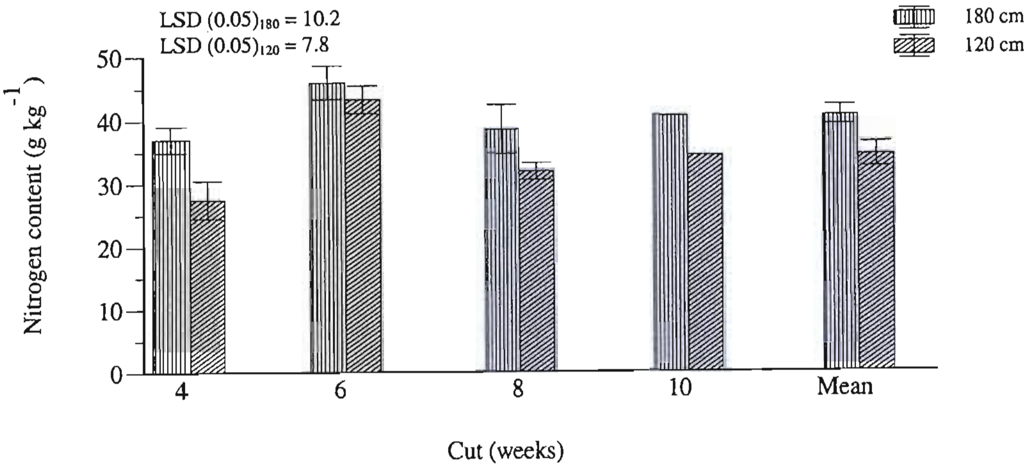

Figure 4.14 The effect of leucaena row spacing on leucaena N content at four cuttings.

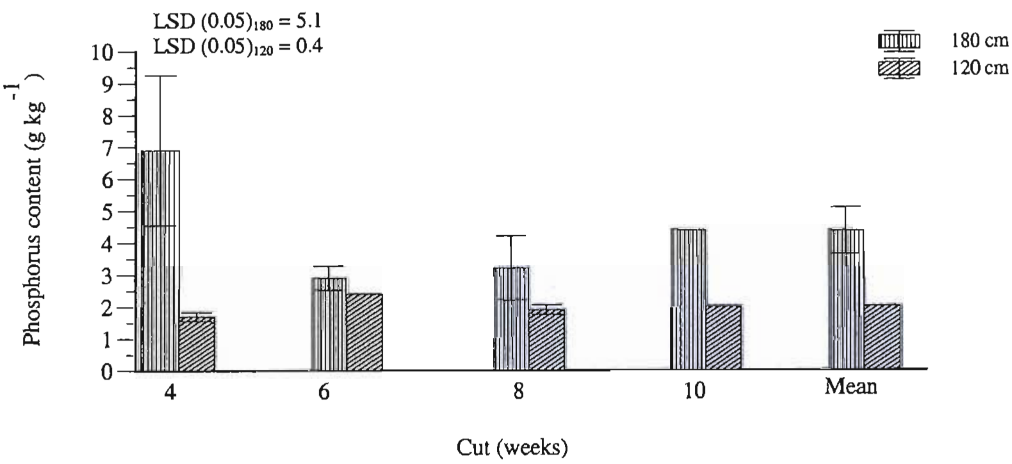

Figure 4.15 The effect of leucaena row spacing on leucaena P content at four cuttings.

Teff-leucaena stand yield response to teff-leucaena interspersing

Growing teff mixed with leucaena significantly increased ($P<0.05$) the teff DM yield of the sward (Appendices 6a and 9a). Dry matter yield of the teff-leucaena stand of the 180cm row spacing treatment was highest for the cut 6 weeks and lowest for the cuts 4 and 8 weeks. For the cut 8 weeks the teff-leucaena stand DM yield of the 120cm leucaena row spacing treatment was higher than the teff alone and 180cm row spacing treatment teff-leucaena stand DM yield. The DM yield of the teff-leucaena stand of the 120cm treatment in the cut 4 weeks and 180cm row spacing treatment in the cut 10 weeks. The teff alone stand produced almost the same amount of DM for the cuts 6 and 10 weeks. The teff-leucaena stand of the 120cm row spacing for the cut 6 weeks and the 180cm row spacing treatment for the cut 8 weeks produced similar amount of teff DM (Figure 4.16).

The N content of the teff-leucaena stand of both row spacing treatments was significantly increased ($P<0.05$) (Appendices 6b and 9b). In all four cuts the N yield of both the 120cm and 180cm row spacing treatments was different but more than the teff alone stand. The N content of the 180cm row spacing teff-leucaena stand was highest (72.90 g kg^{-1}) for the cut 4 weeks. Nitrogen yield of the two row spacing treatments was lowest for the cut 10 weeks which was 51.03 and 43.7 g kg^{-1} respectively (Figure 4.17).

The P content of the mixed stand was significantly ($P<0.05$) increased except for the cut 4 weeks of the 120cm row spacing (Appendix 8c and 11c). Phosphorus yield of the teff-leucaena stand of the 180cm row spacing treatment was highest (11.24 g kg^{-1}) for the cut 4 weeks but it was almost the same for the cuts 6 (5.29 g kg^{-1}) and 8 weeks (5.2 g kg^{-1}) and was 6.66 g kg^{-1} for the cut 10 weeks. The 120cm row spacing produced the lowest amount (3.17 g kg^{-1}) of P for the cut 10 weeks (Figure 4.18).

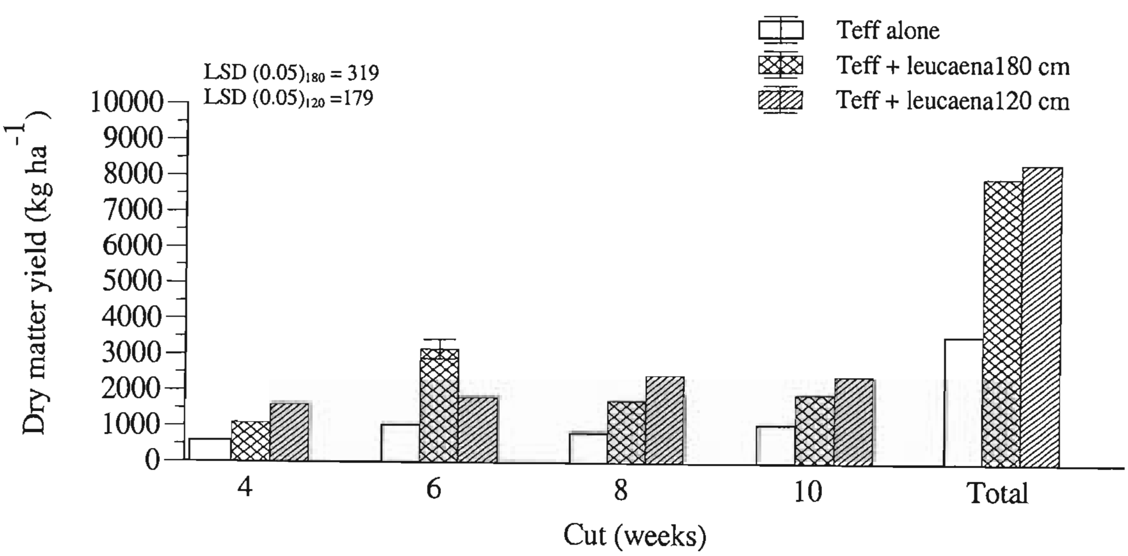

Figure 4.16 Comparison of DM yield of teff-leucaena mixed stands and pure teff stands at four cuts and their totals.

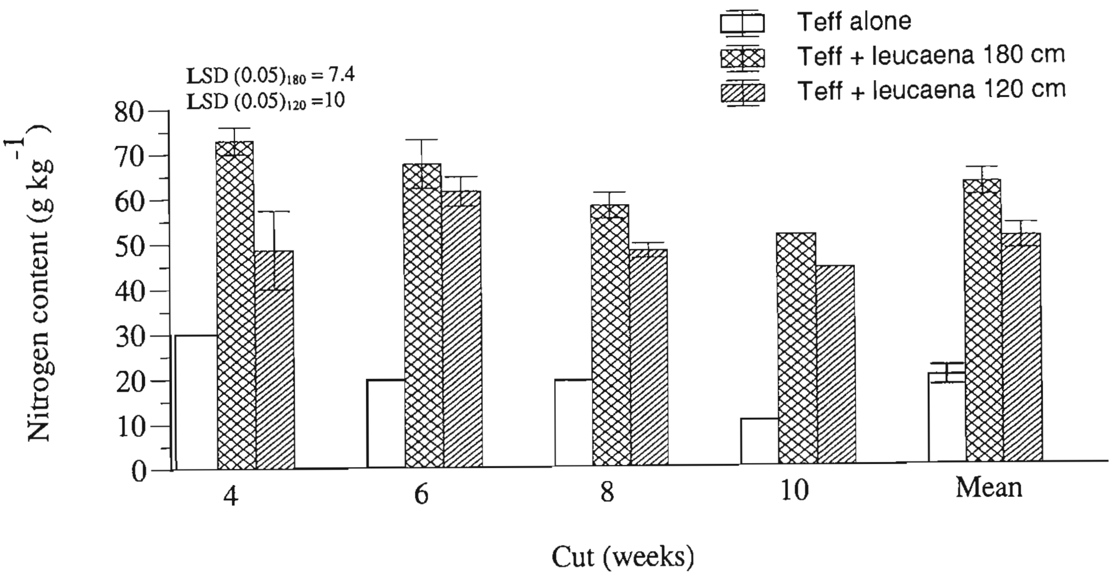

Figure 4.17 Comparison of N content of teff-leucaena mixed stands and pure teff stands at four cuts and their totals.

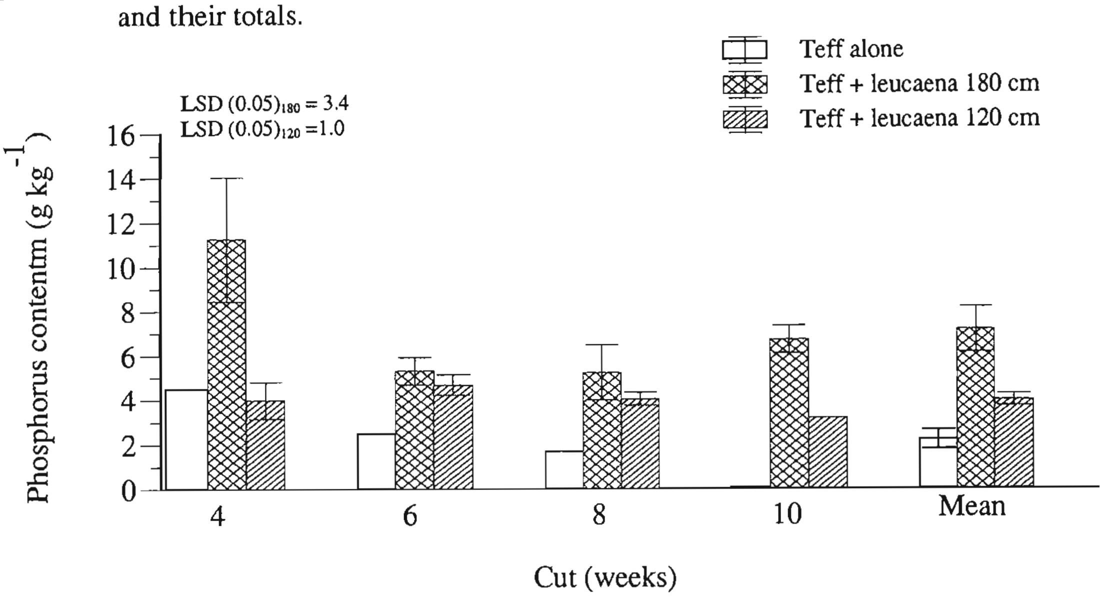

Figure 4.18 Comparison of P content of teff-leucaena mixed stands and pure teff stands at four cuts and their totals.

Soil N content

There was significant difference between plots ($P<0.05$), the soil of the teff alone plot contained more N (1.91 g kg^{-1}) than the teff-leucaena plots (Table 4.4). Comparing the two different leucaena row spacing treatments, the 180cm row spacing plot contained higher level of soil N than the 120cm row spacing. The teff alone plot had almost twice the amount of N per kg of soil than the 120cm plot (Table 4.4).

Table 4.4 Comparison of soil N content of teff-leucaena stand plots at two different leucaena row spacings to teff alone plot soil N content.

Leucaena row spacing (cm)	Soil N content (g kg^{-1})
Teff	1.91[a]
180	1.48[b]
120	1.00[c]
LSD (0.05) 0.42	

Values with different letters differ from each other

4.3.3 **Discussion**

Monoculture systems in rainfed areas do not always meet expectations for food and fodder, nor make optimal use of available land, labour and finance. Thus, interspersing trees with annual crops might meet the needs of the farming community and increase yield in small land holdings (Mittal and Singh 1989).

In this study, the means of teff DM in both row spacings and, N and P from teff-leucaena interspersed plots, except for the 120cm, were higher than their respective teff alone treatment means. For the 120cm row spacing treatment, teff DM yield and teff P content were lower for the cuts 4 and 8 weeks and higher for the cuts 6 and 10 weeks. Mean teff N yields from teff-leucaena interspersed plots were lower than the yields of their counter teff alone treatments for all four cut weeks (Figures 4.14).

The DM yield and nutritive quality differences between teff yields obtained from the two different leucaena plant row spacing treatments are possibly because the longer establishment period for leucaena plants in the 180cm row spacing treatment plots has enabled soil to accumulate enough organic matter for slow release of nutrients, or the ability of longer leucaena roots to extract underground nutrients up to the soil surface.

At the cut 10 weeks the DM yield and nutritive qualities of teff obtained from the interspersing were higher than the yields obtained from their respective teff alone treatments. This indicates that the herbage yields obtained from legume-grass intercrops are better, in terms of quality and quantity, than herbages from pure grass swards.

Tree legumes are often planted specifically for forage, from pastoral point of view, both in extensive grazing systems and in association with crops as a principal source of high quality forage used to supplement low quality roughages such as crop residues (Gutteridge and Shelton 1994). Here leucaena was planted with teff at two different plant row spacings. For the 180cm row spacing the DM yield was 244 kg ha^{-1} and 411 kg ha^{-1} for the 120cm row spacing. Their total herbage N concentration was 40.4 and 34.2 g kg^{-1} of dry matter of leucaena, respectively. Phosphorus content of leucaena of both leucaena row spacings was generally low. The 180cm row spacing produced the highest (2.4 g kg^{-1}) for the cut 4 weeks.

In this teff-leucaena interspersing trial the total teff-leucaena stand DM yield from all cuts was higher than the teff alone stand. The highest yield was obtained in the 180cm row spacing treatment for the cut 6 weeks. Both species produced similar amount of DM for the cuts 4 and 10 weeks.

The teff-leucaena stand from all four cuts in both the 180cm and 120cm row spacing treatments produced the same amount of N and N concentration was higher in the teff-leucaena stand than the teff alone stand. As Mittal and Singh (1989) have reported usually farming systems in which trees are intercropped with annual field crops might meet the needs of the farming community and increase yield in small land. Kang *et al.* (1981) have also reported that interspersing of forage tree legumes such as leucaena is an alternative as part of efforts to replace or improve the traditional fallowing system with a more productive and stable system.

CHAPTER FIVE

STUDY 3: EFFECT OF NITROGEN FERTILIZER ON TEFF DRY MATTER YIELD AND NUTRITIVE QUALITY

ABSTRACT

The study of teff (cultivar SA Brown) herbage response to the nitrogen fertilizer application rate conducted over one growing season of four consecutive cuts showed that maximum teff herbage DM yield and N content were obtained at the N fertilizer application rate of 100 kg ha^{-1}. There was significant effect of N fertilizer application on total teff herbage production and N content. The results showed an increase in herbage yield as rate of N application increased. However, when the results for the four different cutting weeks were compared the highest yield of teff DM and N contents were obtained for the cut 4 weeks. The N application rates were 0, 50, 100 and 150 kg N ha^{-1}. The teff herbage DM yields of the 50 and 100 kg N fertilizer application rates were higher by 11.0 and 27.9% respectively than the control (0 kg N ha^{-1}) plot.

Key words: nitrogen fertilizer, fertilizer application rates, cutting regime, teff, yield

5.1 INTRODUCTION

The primary use of teff in countries such as Eritrea is as a grain crop for human consumption unlike its use for hay production in the other regions of the world and Africa such as the Republic of South Africa. Although there are few documented reports on its herbage contribution to the livestock sector in the countries where teff is known more for its grain yield, there is no doubt that its use as a good source of animal feed is not less than the other sources of straw that are used to over-winter animals. As a result most available reports on the crop's response to N fertilization and N fertilizer recommendations are usually related to its grain yield only. Moreover, most of the reports on teff response to N fertilization and N fertilizer recommendations focus on a single locality, its centre of origin Ethiopia. Although important, such limited and localized reports may have little relevance to its growth in different environmental conditions due to the geographical differences between different regions (Jones 1988; Kassier 2002).

Different authors and agricultural organizations recommended different N levels. In Ethiopia, based on soil type, Bechere (1995) recommended 40 and 60 kg N ha^{-1} for light and black soils respectively. As a general or blanket recommendation, a N fertilizer rate of 32 kg ha^{-1} is given by Ketema (1993). Although teff does respond considerably to mineral fertilizers, in Ethiopia farmers still grow teff in the absence of added N fertilizers (Jones 1988). He also recommended for the development and use of cultivars that are highly responsive to artificial fertilizers and Kassier (2002) found that the two different teff cultivars, SA Brown (3250 kg ha^{-1}) and TEF 373 (3100 kg ha^{-1}), obtained their highest DM yield at two different N fertilizer application rates, at 75 and 150 kg N ha^{-1} respectively implying that different cultivars of teff have different N fertilization requirements. However, excessive application of N fertilizer (Kassier 2002) may cause teff lodging through luxurious growth. Thus, it may be better not to fertilize fields that have been well fertilized for previous crops.

According to Kassier (2002), recommendations for N application rates have limited use on a universal scale and hence it would be necessary to determine the response of teff to N fertilization. He added that the variation in available soil N from season to season and from site to site makes it difficult to give a blanket/general N fertilizer requirement to be used as standard for all locations.

5.2 OBJECTIVES

The major objectives of this study include:

1) Determination of DM yield and nutritive quality of teff for the four different N fertilizer application rates; and
2) Both DM yield and nutritive quality results of teff from sub-studies one and two are evaluated against results obtained from this study.

5.3 PROCEDURE

Treatments and measurements

Here the treatments comprised of 0, 50, 100, and 150 kg N ha^{-1} applied in a 20m x 40m field subdivided into plots of each 2m x 20m. Each treatment was replicated three times. Then the four different treatments (12 when replicated 3 times each) were randomly assigned so that each treatment had an equal chance of being allocated to either of the plots.

Teff was hand sown at 10 kg ha^{-1} on November 21, 2002, then periodically hand weeded to avoid weed infestation and hence to minimize intraspecific competition for the available soil nutrient resources and possibly minimize shading of teff plants by weeds growing over them.

Sampling

Using a hand clipper, a one-metre strip of teff herbage from within each plot at a height of 5cm was separately harvested on December 27, 2002; January 9, 2003; January 29, 2003; and February 13, 2003. Samples were fresh weighed in the field then sub-sampled. Sub-samples were oven dried at 60 °C for 48 hours, weighed to calculate dry matter yield and finely ground to pass through a 1mm screen in preparation for forage quality analysis. Using a soil auger, soil samples were collected from each plot at a depth of 15cm and then air-dried for chemical analysis. Samples were collected after the last plant sample harvest. The sulphuric acid-hydrogen peroxide digestion of the Kjeldahl method at a controlled temperature digestion, using the same technique and machine which were used in the above two sub-studies were also implemented for this study to analyse the chemical content of both soil and plant samples.

Statistical analysis

The analysis of variance (ANOVA) was used to determine the effects of the four different nitrogen fertilizer application rates on DM yield results and nutritive quality of teff herbage samples. Differences between means ($P<0.05$) were assessed using the least significant differences (LSD). The statistical analysis was carried out using Genstat 6.1 software (McConway *et al.* 1999).

5.4 RESULTS

Teff herbage yield response to N fertilizer application rates

In this study teff was cut four times. As in the previous sub-studies the cut 4 weeks (cut 4 weeks) was done four weeks after planting teff. Here there were four N fertilizer application rates (0, 50, 100 and 150 kg N ha^{-1}) as treatments. Compared to the control treatment, the 50 and 150 kg N fertilizer application rates produced a higher teff DM (Figure 5.1). They were 11.0 and 27.9% higher than the control treatment DM yield (800 kg ha^{-1}). This showed that the use of mineral N fertilizer was significant ($P<0.05$) to increase teff DM; on the contrary the N fertilizer application rate of 150 kg ha^{-1} produced lower teff DM yield than the control treatment and was 35% lower (Figure 5.1a).

For the cut 4 weeks the 0, 50 and 150 kg N treatments teff DM yield significantly declined ($P<0.05$), as nitrogen application rate increased from 0 to 150 kg N ha^{-1} but it was higher (198 and 275 kg ha^{-1}) for the 100 kg N ha^{-1} application rate at the cuts 4 and 8 weeks respectively. For the cut 6 weeks, there were significant differences ($P<0.05$) between the N application rate treatments. The 50 and 100 kg N application treatments produced 400 and 350 kg ha^{-1} of teff compared to the 241 kg ha^{-1} obtained from the control treatment. For the cuts 8 and 10 weeks there was no significant difference between treatments (Figure 5.1b).

Herbage quality was determined for this study. Similar to their effect on DM yield almost all the N fertilizer application treatments increased N more than their respective control treatment. For the total N yield there was a significantly positive ($P<0.05$) effect of treatments on herbage N content (Figure 5.2a). For the cut 4 weeks, in a similar fashion to the teff DM yield, teff N content of the 50, 100 and 150 kg N treatments was 15, 13.53 and 18.37 g kg^{-1}

which were higher than that of the control treatment which was only 10.20 g kg^{-1}. For the cut 6 weeks the 50 and 100 kg N treatments produced 5.3 and 4.2 g kg^{-1} higher than the control. The 50 and 150 kg N treatments produced 4.8 and 1.73 g kg^{-1} lower than the control treatment for the cut 8 weeks, however, the 100 kg N treatment produced 4.8 g kg^{-1} higher than the control treatment. For the cut 10 weeks, unlike in the teff DM yield, the all three N fertilizer treatments produced more N than the control (Figure 5.2b).

The 50 and 100 kg ha^{-1} N fertilizer treatments produced more P than the control (Figure 5.3a). For the cut 4 weeks both the 50 and 100 kg ha^{-1} N fertilizer application treatments produced a higher teff P content than the control. For the cut 6 weeks, however, the control treatment produced a higher amount of P than the other N fertilizer application treatments. The only significant treatment for the cut 8 weeks was the 100 N fertilizer treatment which produced 3.31 g kg^{-1} more P than the other treatments. Eventually, in the cut 10 weeks, the control produced only 0.08 g kg^{-1} which was significantly lower than the other N fertilizer application treatments (Figure 5.3b).

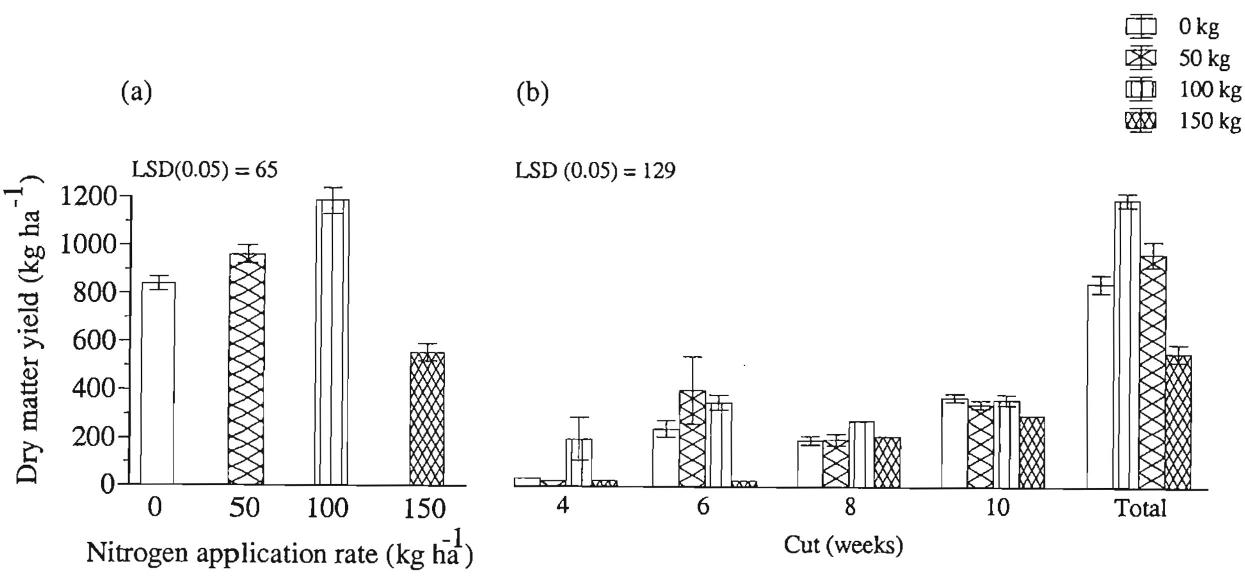

Figure 5.1 Effect of rate of application of nitrogen fertilizer on teff total DM yield (a) and teff dry matter yield at four different cuttings (b).

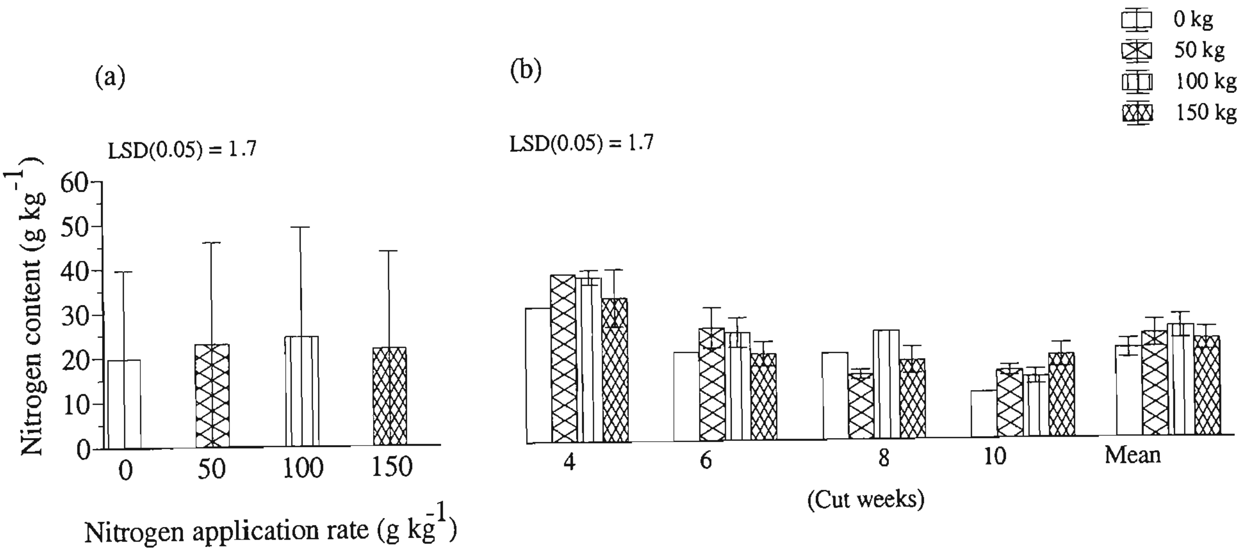

Figure 5.2 Effect of rate of application of nitrogen fertilizer on teff total N content (a) teff N content at four different cuttings (b).

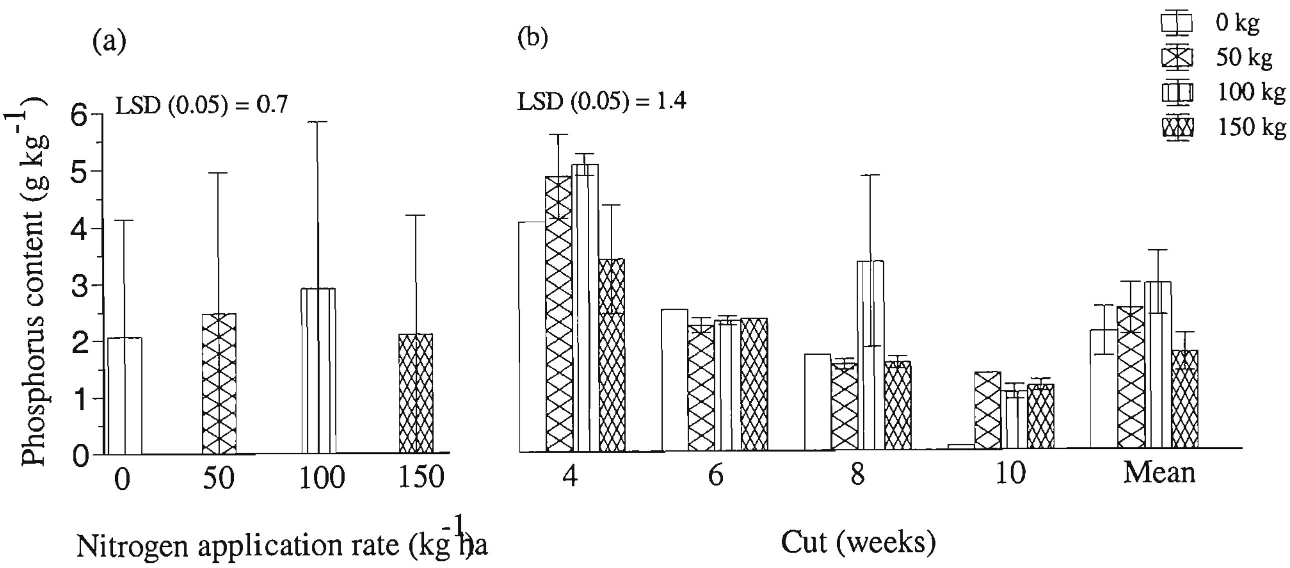

Figure 5.3 Effect of rate of application of nitrogen fertilizer on teff total P content (a) teff P content at four different cuttings (b).

Effect of N fertilizer on soil N content

The control plot produced the lowest amount of soil N compared to the other three N fertilizer application rates. Similar to the teff DM yield and nutritive quality, the plot that received 100 kg N ha^{-1} had the highest soil N content compared to the control and the other two N fertilizer application rates. On the other hand, unlike the teff DM yield and nutritive quality, the plot dressed with 150 kg N ha^{-1} had a higher soil N content than the control plot (Table 5.1). As it was reported by Balík *et al.* (2003), this might be because the application of mineral nitrogen fertilizers possibly increased the mineralization of soil or organic matter in the soil. On the contrary, Černý *et al.* (2003), found lower soil N content in treatments with N fertilizer applications compared to the control.

Table 5.1 Comparison of soil N content of plots subjected to four different N fertilizer rates.

Treatment	Applied N fertilizer (kg ha^{-1})	Soil N content (g kg^{-1})
1	0	1.56^{a}
2	50	1.77^{a}
3	100	2.23^{b}
4	150	1.93^{a}
LSD(0.05) 0.58		

Values with the same letter do not significantly differ from each other.

5.5 DISCUSSION

According to the results obtained, this study has shown a positive response of teff DM production to the 50 and 100 kg N fertilizer application rates (Figure 5.1a). Possibly, the inherent high N status of the soil might have contributed to the teff N requirements (Kassier 2002). However, the addition of N fertilizer might have also contributed in the increment of teff DM production as it was shown at the 50 and 100 kg N ha^{-1} application rates (Figure 5.1a). According to the nutrient and lime recommendations by the KwaZulu-Natal Department of Agriculture and Environmental Affairs for this particular area, the recommended amount of fertilizer N to produce 6000 kg ha^{-1} of any tropical grass per hectare was 110 kg N ha^{-1}. If the amount of fertilizer N required to produce the teff DM yields obtained in this study was calculated based on this recommendation, the rates of fertilizer N used in this study were even in excess. Stevenson (1982) cited by Kassier (2002) reported that there are not only differences in N requirements between species but also between selections within species. Kassier (2002) found that TEF373 had a higher requirement compared to the SA Brown. Based on the results obtained in this study and the suggestions given by Kassier (2002), the rates of N fertilizer used in this study might have been in excess of the SA Brown N requirement. According to reports by Schroeder *et al.* (1985), these in excess rates of N fertilizer might have reduced the SA Brown herbage production responses at the 150 kg ha^{-1} N fertilizer application rate as can be seen in Figure 5.2a.

N content of teff was determined in this study. There was a significant difference ($P<0.05$) between N fertilizer treatments for the nutritive quality of teff herbage (Figure 5.2a). However, herbage quality especially that of teff N content, was positively affected by the N fertilizer treatments. Except for cut 8 weeks at N rates of 50 and 150 kg ha^{-1}, all results for teff herbage and N content of all three cut weeks were above the control teff N content (Figures 5.2b). When comparing the N content response to N fertilizer application rates, it was lower at the highest rate, at the 150 kg N ha^{-1}.

For the teff P content the 50 and 100 kg N fertilizer application levels produced more than the teff alone treatment (Figure 5.3a). However, teff P content was reduced as teff cutting time increased and eventually teff P content of the teff alone treatment was well below the other N fertilizer application treatments at the cut 10 weeks (Figure 5.3b).

Although the data can not be used as a general reference and the response of teff DM production and nutritive quality differed between the N fertilizer application rates, the broad recommendation for N fertilization of teff is between 50 and 100 kg ha^{-1} for this particular season and site because as Kassier (2002) has mentioned the available soil N status of a particular site differs from season to season and spatially.

Possibly, these results may give a clue for Eritrea's farmers and farmers as a whole on how teff DM production, N content and P content can be influenced by N fertilizer application. Compared to other crops, teff has a short growing period, if affordable; farmers need to first assess the soil N status of their field, as teff is able to grow with N mineralised from the organic materials.

CHAPTER SIX

STUDY 4: EFFECT OF DIFFERENT GRASSLAND MANAGEMENT TECHNIQUES ON NUTRIENT CYCLING

ABSTRACT

Grasslands need to be managed properly so that they can provide the uses that are expected from them. The grasses they produce should be used in such a way that they regenerate for the next grazing. If they are underutilized, the old material should be removed so that young shoots are not chocked, are able to grow up and replace the removed dead material. Different burning, grazing and mowing techniques are used to manage grasslands and grasses. This study assessed some of these management methods like burning, grazing and mowing/cutting on grass DM yield, nutritive quality and nutrient cycling. All grassland management techniques produced different amounts of grass DM and N contents. Their DM yield was in the following order: grazing 3852, burning 4380, and mowing 4097 kg ha^{-1}, respectively. Their effect was significant on grass N concentration and it was in the following order: 8.10, 10.13 and 7.80 g kg^{-1} of dry matter. They had no significant effect on grass phosphorus concentration.

Key words: management technique, grass, dry matter, nitrogen concentration, phosphorus concentration

6.1 INTRODUCTION

Numerous and different management techniques have been developed to maintain grassland productivity. Some of these practices include burning, mowing and various grazing systems. Fire has had a major impact on ecosystem structuring and functioning, the most obvious effect being the removal of old, dead vegetation. According to Van de Vijver (*et al.* 1999), burning increases post-burn vegetation nutrient concentration possibly due to enhanced soil nutrient supply through ash or increased mineralisation; renewal and related changes of plant tissue composition; and relocation of nutrients from roots to shoot. It is also a factor in modifying the grass species richness of an area through plant community composition and diversity improvement by affecting the competitive interaction, dominance and vigour of the available vegetation (Van de Vijver *et al.* 1999; Fynn *et al.* 2004). In the study by Fynn *et al.* (2004) grass species richness declined by greater than 50% in the absence of burning.

Although it has been shown to reduce the intensity of competition for a limiting resource, burning may also increase the availability of light (Fynn *et al.* 2004). On the contrary, burning may result in a decrease of the availability of other limiting resources such as soil moisture and nitrogen. Consequently, in low productivity habitats, such as on infertile well-drained soils, burning may increase competition for a limiting soil resource. Thus, although burning may be an important requirement for species coexistence, the intensity of burning required for the coexistence of the maximum number of species should vary with habitat productivity (Van de Vijver *et al.* 1999; Fynn *et al.* 2004).

While it is well established that infrequent and low intensity defoliation results in low quality pasture (McKenzie and Tainton 1996), cutting trials can not accommodate the effects of grazing which include treading, selection and excretion. It is, therefore, important to undertake grazing trials that evaluate the effects of defoliation management under conditions that ultimately apply at the farm level to evaluate the impact of grazing on nutrient cycling and distribution in the dung and urine of animals (McKenzie and Tainton 1996). Manure is a valuable farm resource and should be treated as an asset. Recycling manure to the soil through a precise manure management plan is efficient and practical because this optimises the nutrient value of the manure while minimizing potential environmental hazards. Therefore, the consideration of nutrient cycling within soil-plant-animal grazing systems is of great importance in grazing land ecosystems (Taddesse *et al.* 2003). In their study Taddesse and his colleagues reported decreased biomass production, lower plant species richness and low water infiltration rate on plots which did not receive manure than on the manured plots.

6.2 OBJECTIVES

The aims of this study were:

1) To determine the effect of grazing, burning and mowing on grass dry matter yield;
2) To measure the nutritive value of grass for the different management regimes; and
3) To compare the effect of the three different management regimes on soil fertility.

6.3 PROCEDURE

Treatments and measurements

Study 4 (native pasture) was conducted on a flat grassland on a deep (>1m) clay-loam soil dominated by *Themeda triandra* (62%) and *Cyperaceae* spp. (17%) including few other grasses such as *Tristachya leucothix*, *Setaria nigrirostris*, and *Eragrostis capensis* 5%, 4%, and 4%, respectively. *Themeda triandra* was selected as an indicator species to evaluate plant nutrient status across all treatments. This study had three plots, approximately one hectare each, subjected to three different grassland management regimes. The first plot was grazed at least for the last 30 years on a regular basis. The second plot was a burning trial established in 1950 to determine the interactive effect of different type, season and frequency of disturbances on species richness. The site was burnt and mown annually in summer for hay Fynn *et al.* (2004) (Burning). It was burnt at least for 54 years. The third one (Mowing) was mown for hay twice per year but not grazed. The first mowing was done every December and the second every April or May (du Toit, Person. Com)[4]. It was mown for more than 50 years.

Sampling

Plant samples from study 4 were harvested on March 24, 2003. As mentioned in the section 6.2 this study had three different plots that have received different management regimes. Each plot was divided into three longitudinal lines of equal distance from each other and from the peripheries of a camp. Eight samples were collected along each longitudinal line (24

[4] Grassland Science, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa.

replicates in total). Samples of *T. triandra* were harvested at a stubble height of 5cm using a 30cm x 30cm quadrat. Then from each of the three bulked samples a subsample was taken and dried at 60 °C for 48 hours to constant weight in an oven. Oven dried samples were ground to pass through a 1mm stainless steel sieve in preparation for DM content estimation and nutritive quality analysis.

Twenty four soil samples were collected at the same locations and date as the plant samples. Samples were taken at a depth of 15cm using a soil auger and then air-dried for further chemical analysis.

Similar to the plant and soil samples of sub-studies 1 to 4, all plant and soil samples of this study, prior to chemical analysis, were subjected to a sulphuric acid-hydrogen peroxide digestion of the Kjeldahl method. Then chemical analysis was done using the automated colorimetry technique using the Technicon Autoanalyzer II machine.

Statistical analysis

The three management regimes were taken as treatments. Analysis of variance (ANOVA) was used to determine the effects of these treatments on DM yield (Appendix 13a) and nutritive quality (Appendices 13b and 13c) of *T. triandra* herbage samples. ANOVA was also used to determine soil N and P content. Differences between means ($P<0.05$) were assessed using the least significant differences (LSD). The statistical analysis was done using Genstat 6.1 software (McConway *et al.* 1999).

6.4 RESULTS

The effect of all three management strategies was not significant ($P<0.05$) on herbage DM yield (Figure 6.1 and Appendix 13a) and P content (Figure 6.3 and Appendix 13c). However, their effect was significant on the N content of the herbage. The burning treatment had a greater effect on herbage N content followed by the grazing and then by the mowing (Figure 6.2). The grazing and the mowing treatments produced almost similar amount of herbage N concentration (Figures 6.2).

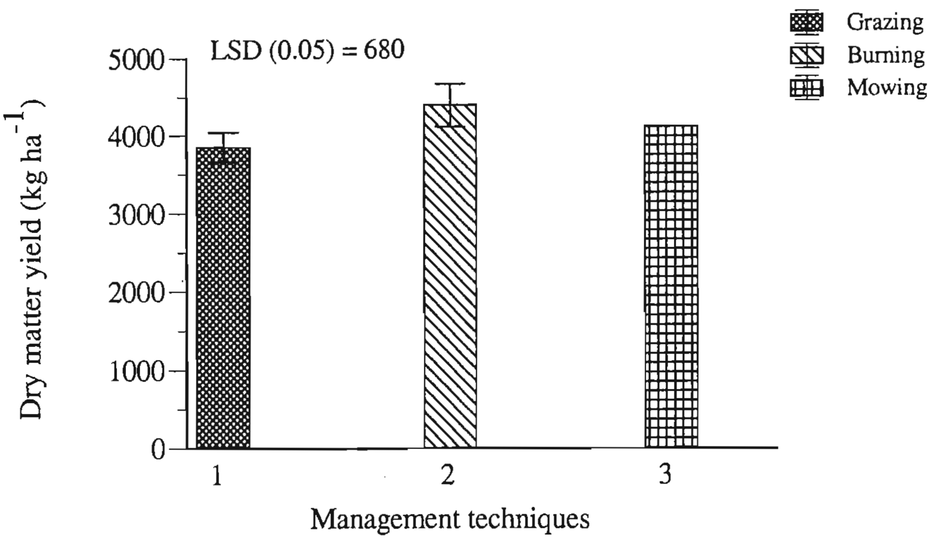

Figure 6.1 Comparison of three different management techniques on *T. triandra* DM yield.

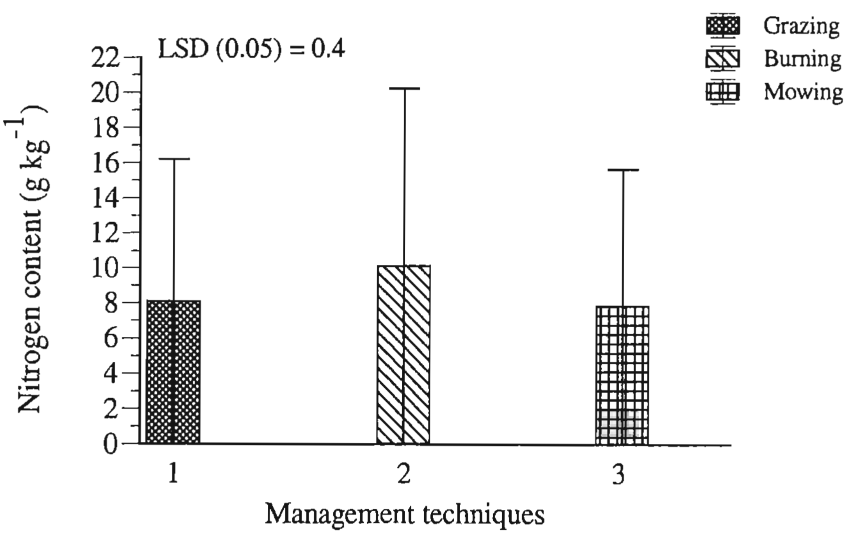

Figure 6.2 Comparison of three different management techniques on *T. triandra* N content.

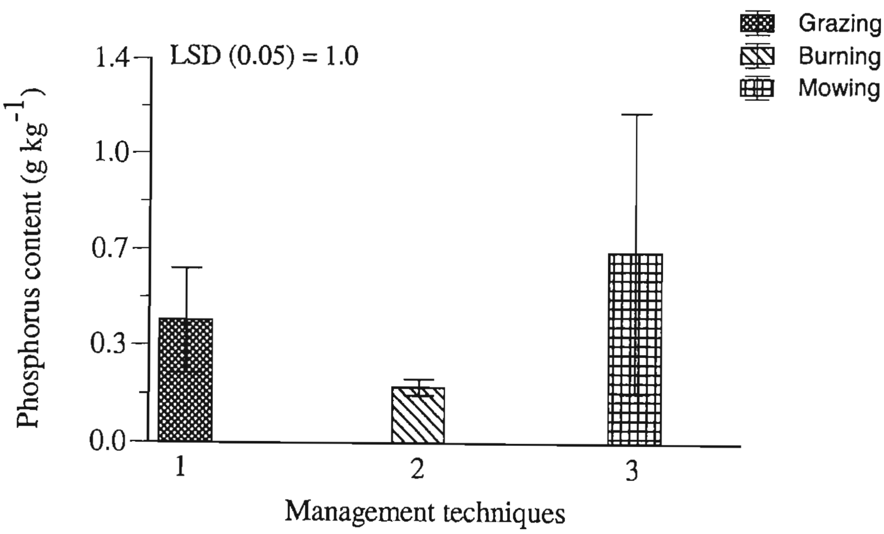

Figure 6.3 Comparison of three different management techniques on *T. triandra* P content.

Soil N content

Grazing had a significant (P<0.05) effect on the soil N content of the plots (Table 6.1) when compared to burning and mowing treatments. This higher value from grazing is possibly because of the returning of nutrients by grazing animals through their excreta, and the reduced soil N content from the mown plot is probably because of the removal of most of the plant material from the field.

Table 6.1 Comparison of three different grassland management techniques on soil N content.

Treatment	Management technique	Soil N content (g kg^{-1})
1	Grazing	2.54^{a}
2	Burning	2.36^{b}
3	Mowing	2.33^{b}
LSD(0.05) 0.068		

Values with the same letter do not significantly differ from each other

6.5 DISCUSSION

The grass DM yield results obtained for the three different management strategies did not significantly differ from each other (Appendix 13a). The burning treatment produced the greatest DM yield, followed by the mowing treatment then the grazing treatment (Figure 6.1). In their study Van de Vijver *et al.* (1999) found no difference between burned and mown treatments on aboveground biomass. Furthermore, biomass removal through burning and mowing did not affect nutrient availability or soil organic matter.

Nitrogen concentration of grass was significantly affected by the different management techniques. It was higher in the burning plot as it was for the DM yield. Van de Vijver *et al.* (1999) reported that burning increased leaf:stem ratio which in turn increased the live grass N concentration. The grass N content values of mowing and grazing treatments were almost similar, 8.10 and 7.80 g kg^{-1} respectively. Phosphorus concentration was highest in the mowing treatment, the rest of the treatments contained lower concentrations.

Although the effect of grazing on grass dry matter yield was not more than the burning and mowing treatments, grazing had similar effect on grass N content to the mowing treatment and a greater effect on grass phosphorus content compared to the burning treatment (Figures 6.2 and 6.3). Furthermore, the grass DM yield obtained from the grazed plots was not significantly different from those obtained from the burnt and mown plots. This shows that grazing animals can play a great role in nutrient movement and distribution temporally and spatially. As Patra *et al.* (2000) have mentioned, organic materials such as manure hold great promise due to their local availability as a source of multiple nutrients and ability to improve soil characteristics. The cycling of nutrients through livestock has also been an important factor in the nutrient cycling processes (Powell *et al.* 1998).

Results obtained from this study have shown that:

- Recycling of nutrients through animals did not result in increased dry matter yields relative to mowing and burning.
- Recycling of nutrients did not result in greater N and P levels in the herbage relative to mowing and burning.
- Burning had a greater influence on N and P levels of grass than grazing or mowing.

Over the timescales under consideration, removal of nutrients in the form of hay did not appear to negatively affect veld grass production or nutrient content.

CHAPTER SEVEN

STUDY 5: EFFECT OF ANIMAL EXCRETA ON NUTRIENT CYCLING IN EXTENSIVE GRAZING SYSTEMS

ABSTRACT

Grazing animals play an important role in the ecology of pastures and rangelands. From their positive effects the distribution and recycling of soil nutrients through their excreta (dung and urine) are some of the advantages that should be taken into consideration in livestock production systems. However, the spatial and temporal distribution and recycling of these organic nutrients still require attention for effective distribution and recycling management. Monitoring and using different grazing systems is one of those ways of influencing nutrient cycling in animal farming systems. In this study extensive grazing systems in the communal grazing areas have shown that herbage samples from around homesteads had higher DM yield and nutrient content than samples obtained away from the homesteads. The descending order of DM yield for Okhombe was 3422, 2308, 1735 and 1216 kg ha^{-1} at 0, 10, 20 and 30m away from the homestead. For Zwelitsha it was 2637, 2105, 1901, 1688, 1415 and 949 kg ha^{-1} at 0, 10, 20, 30, 40 and 50m. This is an indication that grazing animals do carry nutrients from grazing areas to areas were they rest.

Key words: homestead, manure, distance, DM yield, grass quality

7.1 INTRODUCTION

Livestock excrement is a valuable source of soil nutrients for pasture (Murphy 1986) because 60-95% of the nutrients consumed by grazing livestock pass through the digestive tract (Peterson and Gerrish 1995). Although the actual amounts retained depend on the type of animal and its stage of development, only a small fraction of the nutrients is ingested. High yielding animals remove more than low yielding animals (Murphy 1986; Owen-Smith 2000).

Understanding the effects of different grazing management systems on nutrient resources is important to sustain long-term productivity and to minimise environmental impacts of potential nutrient losses on grazing ecosystems. One of such grazing systems is the communal grazing system where grazing lands are used all the villagers as common property and grazed by livestock of the community. Different grazing management systems affect both nutrient stocks (the quantity of a nutrient present at a site and its distribution between different ecosystem pools) and nutrient fluxes (nutrients movement between different ecosystem pools) in the landscape. Under some grazing systems nutrients may become more vulnerable to loss from the landscape due their redistribution and concentration in pools that are more labile and/or more subject to disturbance processes which increase nutrient mobility and flux rates. The vulnerability of particular nutrients to loss under different grazing regimes will depend on the size of the nutrient pools and on their spatial and temporal distribution across the landscape, the fluxes between these pools, and how all of these are influenced by specific management practices. Communal extensive grazing systems are still major grazing systems in different parts so need to be dealt with.

The main organic fertilizer used by smallholder farmers is cattle manure. Its application will increase soil nutrients, increase soil organic matter, soil biological activities, improve soil structure, water infiltration, soil water holding capacity, decrease soil surface crusting, minimize soil bulk density reducing resistance to root penetration, and reduce risks to soil erosion by wind and water. Cattle manure is also regarded as the fertilizer of choice for most farmers in the communal areas because it bears the least risk for crop failures (Murphy 1986; van Straaten 1999).

Grazing animals play an important role in the ecology of pastures. They consume nutrients in the form of forages and use them to reproduce, produce and grow. However, most of the nutrients are excreted back in the form of faeces and urine to the pastures as long as the animals are in the grazing areas. A portion of the excreted nutrients is taken up by the pasture and recycled back to the pasture if the grazing animals consume the plants again (Powell *et al.* 1998; White *et al.* 2001). White *et al.* (2001) suggested that the distribution of nutrients within the pasture system would mainly depend on the location of water sources, shade, and topography. They have reported also that, proportional to the time cattle stay on pastures, manure handling and storage management requirements were smaller and less-expensive compared with confinement farms and manure on the pasture was evenly distributed except around the water troughs during warm weather grazing.

The homestead is one of those areas where most animal excreta and thereby plant nutrients from animal excrements are concentrated. It is also believed that grazing animals carry nutrients in the forage from the grazing lands and concentrate them in limited areas such as under trees' shade and watering points. To assess this, soil and plant samples were taken from extensive communal grazing systems starting at the base (fence) of the homestead then moving away a regular distance of 10 m from each sampling spot.

7.2 OBJECTIVES

The goals of this study were:

1) To determine the effect of animal excreta on grass dry matter with increasing distance from the homestead;
2) To estimate the nutritive value of grass with increasing distance from the homestead; and
3) To compare the DM yield and nutritive quality of grasses obtained at different distances from the homestead.

7.3 PROCEDURE

Treatments and measurements

Study 5 was conducted on the communal grazing lands (where all livestock of the community graze the common grazing lands without temporal and spatial restrictions) of the villages of Zwelitsha and Okhombe. Animals graze out in the fields, approximately, from 9h00 to 16h00 and are kept in the homesteads in the late afternoons, evenings and early mornings to avoid thefts. The distances the animals move away from the homestead for grazing depends on the size of land a particular community owns and concern of livestock theft. Dung is normally collected under unprotected areas and applied to crop field, if the farmers need to apply. There were two sampling areas each covering 50m x 50m and 60m x 30m, respectively. Both homesteads were surrounded with a fence. Here, plant samples, starting at the fence of the homestead then after each 10m, were collected from a systematically placed 30cm x 30cm quadrat. The spot (at the base of the fence) where the first sample was taken was considered as a zero distance from the homestead. Then the next sampling spot radiated at 10m interval from the previous sampling point. For Zwelitsha the total number of samples was 24; 6 to the north, 6 to the south, 6 to the east and 6 to the west. For Okhombe the samples were 12 in total; 4 to the west, 4 to the east and 4 to the south. A sample to the north was not taken, because all the houses occupied all of the northern side of the site. That is each sampling spot (sample) was replicated 6 times for Zwelitsha and 4 times for Okhombe, respectively.

Sampling

Plant samples were taken on March 26, 2003 starting at the base of the fence of the homestead (designated as zero distance) and then radiating 10m away from the previous sample. All plants within the 30cm x 30cm quadrat were cut using a hand clipper to a stubble height of 5cm and subsampled. Subsamples were then oven dried at 60 °C for 48 hours to a constant weight for DM yield estimation and then passed through a 1mm sieve for plant nutritive value analysis.

Soil samples were collected exactly from the same spot where the plant samples were taken from. In a similar manner to all other soil samples, soil samples of this study were air dried and sieved to pass through 2mm screen for nutrient content analysis.

Statistical analysis

Plant samples were taken from two different homesteads. The aim was to assess the effect of animal manure on the DM and nutritive quality of herbage samples as one moves away from the place where nutrients in animal manure are concentrated (i.e. the homesteads). The fence of the homestead was used as reference point from which herbage samples were taken so that the next sample is 10m away from the preceding one. Linear regression analysis was used to determine the effects of nutrients in animal manure on DM yield and nutritive quality of plant herbage samples. The statistical analysis was performed using Genstat 6.1 software (McConway *et al.* 1999).

7.4 RESULTS

Herbage DM yield decreased with increasing distance from the homestead (Figures 7.1 and 7.4). The DM yield means at each distance differed significantly from each other. Distance had also an effect on the nutritive quality of the herbage (Figures 7.2, 7.3, 7.5, and 7.6). For Okhombe the N content of the herbage decreased significantly from 24 g kg^{-1} to 10 g kg^{-1} respectively as distance from the homestead increased. At the 20m and 30m distance yield was almost constant showing that nutrients from animal excrements are more concentrated near homesteads where livestock spend their night time re-chewing their cuds, defecating and urinating more (Figures 7.1 and 7.2). For Zwelitsha nutritive quality yield was declining till the 20m distance after which it started to increase at the 30m distance. This shows the pattern how grazing animals distribute nutrients according to their selective behaviour of feeding. As they spend more time feeding on more selected forages they may defecate and urinate more and it might be that is why the trend of the herbage nutritive quality yield is variable (Figures 7.2, 7.3, 7.5 and 7.6).

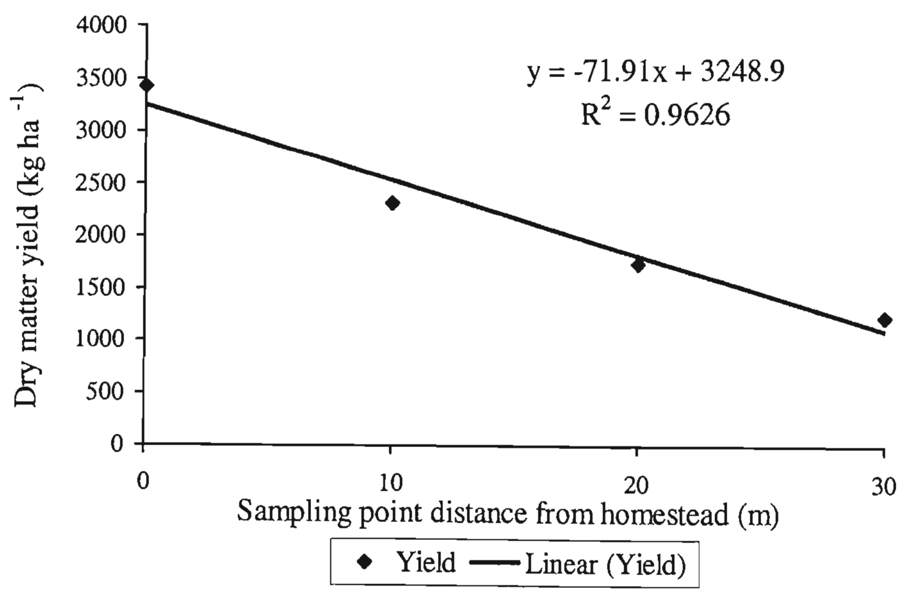

Figure 7.1 The effect of distance from homestead on herbage DM yield (Okhombe).

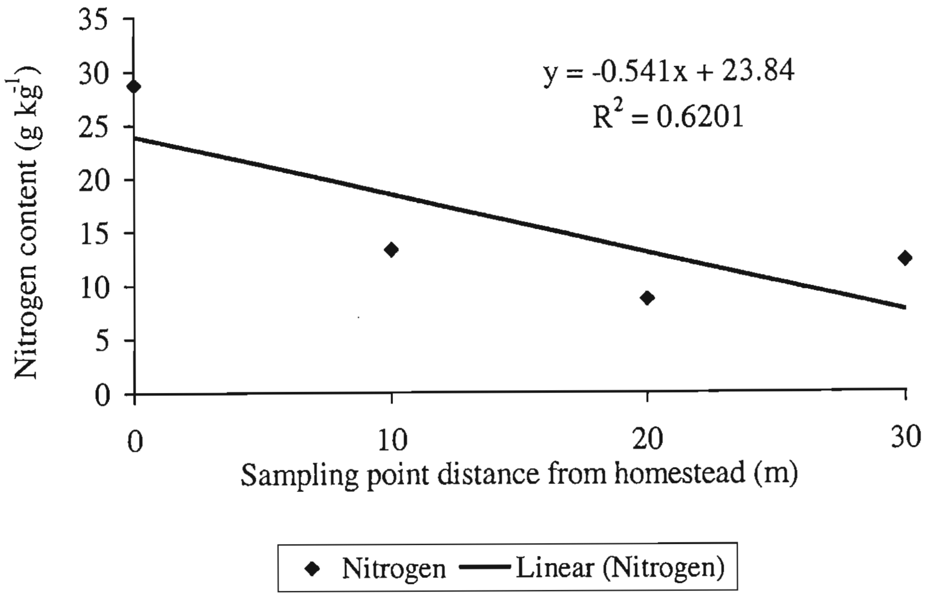

Figure 7.2 The effect of distance from homestead on herbage N content (Okhombe).

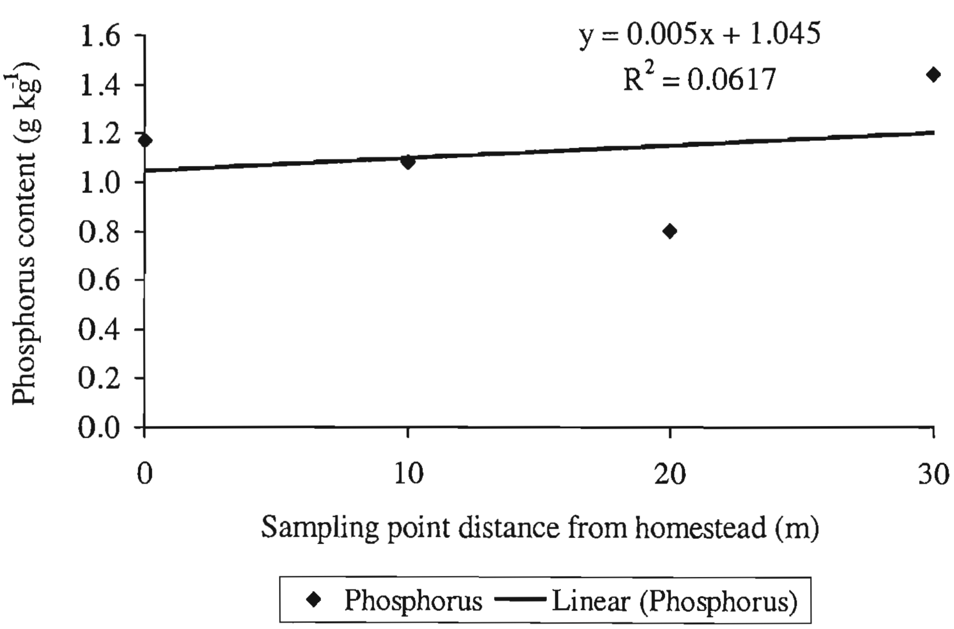

Figure 7.3 The effect of distance from homestead on herbage P content (Okhombe).

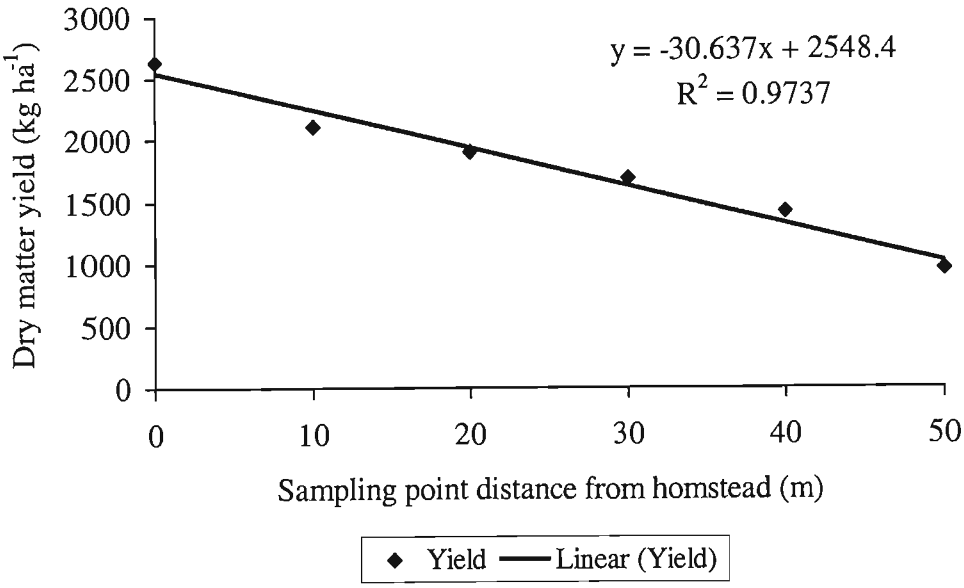

Figure 7.4 The effect of distance from homestead on herbage DM yield (Zwelitsha).

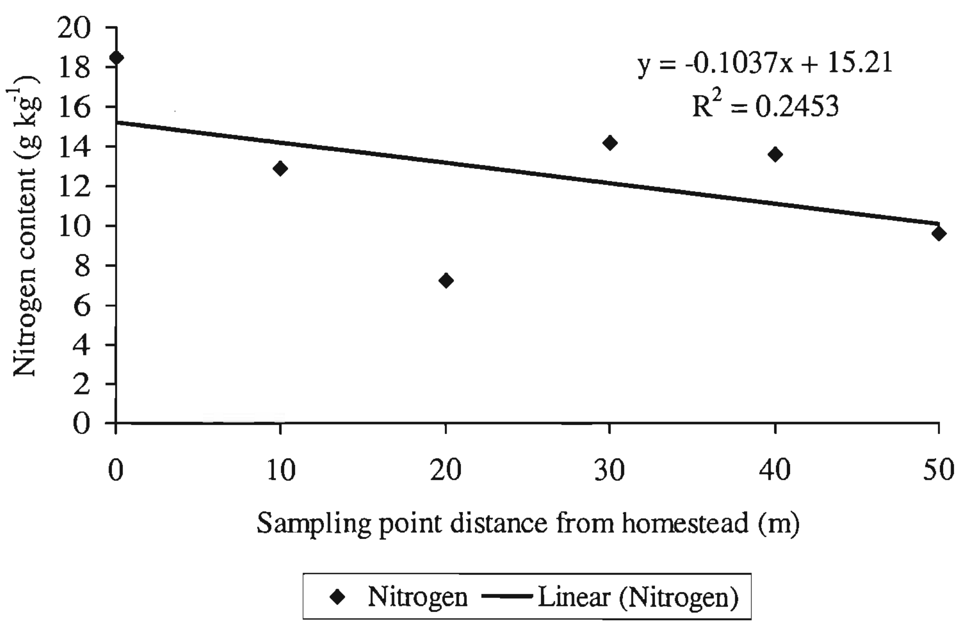

Figure 7.5 The effect of distance from homestead on herbage N content (Zwelitsha).

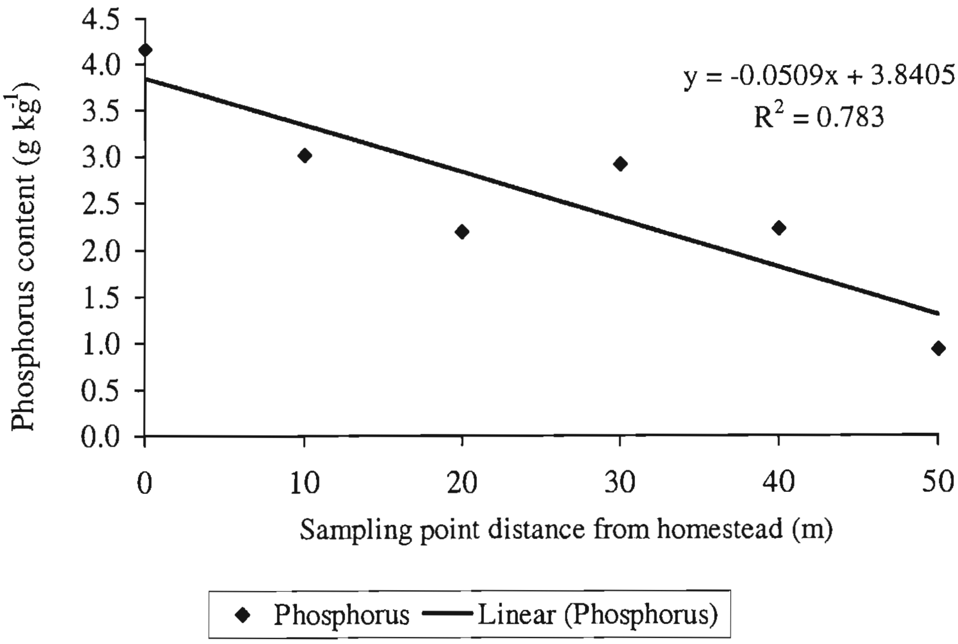

Figure 7.6 The effect of distance from homestead on herbage P content (Zwelitsha).

Effect of grazing animals' excreta on soil N content

For both sites soil N content decreased as distance from homestead increased (Table 7.1). Possibly grazing livestock might had a role in moving soil nutrients from grazing fields in the vegetation they consume in the form of urine and faeces and concentrated them in the homesteads.

Table 7.1 Comparison of soil N content at different distances from the homestead.

Treatment	Distance (m)	Soil N content (g kg^{-1})
Okhombe		
1	0	2.71^{a}
2	10	1.91^{ab}
3	20	1.41^{b}
4	30	1.20^{b}
LSD(0.05) 1.24		
Zwelitsha		
1	0	3.46^{a}
2	10	2.20^{ab}
3	20	1.73^{b}
4	30	1.66^{b}
5	40	1.29^{b}
6	50	0.98^{b}
LSD(0.05) 1.4		

Values with the same letter do not significantly differ from each other

7.5 DISCUSSION

Grazing animals play an important role in the ecology of rangelands and pastures because their excrement is a valuable source of soil nutrients for the pasture (Murphy 1986; Peterson and Gerrish 1995; Powell *et al.* 1998; White *et al.* 2001). However, although animal excreta may increase primary productivity by accelerating energy and matter recycling, the area selective behaviour of grazing by animals causes soil-related or grazing-induced variation in species composition, herbage quality and productivity (Morris 2002). Although it was not part of the study, rate of decomposition of animal dung might also increase the turn-over times for organically bound nutrients which is influenced by management and weather conditions. For example, it took 1.4 years for buried and 5 years for surface dung samples to decompose (Milton and Dean 1996).

In this study distance from the homestead was used as a parameter to assess the effect of animal manure on herbage DM yield and nutritive quality as distance increases from the homestead. The enclosure (the homestead) is one of those places where livestock concentrate their excrements and thereby the nutrients they gathered from grazing lands. Here the intention was to assess if herbage DM and nutritive quality trend will vary as the geographical distance from the homestead increases or decreases. From the results obtained in this study it can be clearly seen that herbage quantity and quality decreased as the distance from the homestead increased. This may imply that soil nutrients are being carried by grazing animals from different areas of the grazing ecosystems. Murphy (1986) suggested that some sources of nutrient removal are transfer of nutrients in dung and urine from the grazing area to yards. In addition, this illustrated that grazing animals have their own role in the distribution of soil nutrients through their dung and urine. Hence, they could be one of the means to be manipulated so that the uniform distribution of soil nutrients in the ecosystem is managed if these important vectors of the grazing ecosystem are managed in such a way that they will be able to return what nutrients they harvested back to their origin. Otherwise, the nutrient pools of grazing systems would deteriorate to the extent that their nutrients are harvested frequently and dumped into very small areas such as the homestead.

In most rural communities livestock are kept in the enclosures during the night and during the day they are led to grazing areas, as it was the case for the two villages, Okhombe and Zwelitsha. Investigations on the distribution of excreta under free-grazing conditions have shown a considerable concentration on camps, the small areas where the animals rest, especially at night (Hilder 1966). Animals commonly defecate more than half of their faeces and urine into the enclosures. The rest is not recoverable, as it is lost along the way to and in the grazing areas. Usually most enclosures in rural communities do not have roofs and the floors are not covered thus excretions accumulate on the unprotected soil (van Straaten 1999; Owen-Smith 2000). Thus this will require new methods of nutrient capture and transfer and improved land management to avoid nutrient losses, decreases in agricultural production and environmental degradation (Powell *et al.* 1998).

The farmers transport the manure to the field and leave it there for several weeks or months. Eventually, it is incorporated into the soil shortly before the onset of the rainy season when the manure is completely dry and low in nutrients (van Straaten 1999). This and other management problems make the use of manure as organic fertilizer ineffective. Van Straaten (1999) also found that dark grey to black, compacted and with higher moisture content manure to have higher nitrogen content. He further reported that the chemical composition of manure is dependent on age and condition of the animal, kind and amount of feed consumed, nature and amount of litter, construction aspects of cattle pen and the storage of manures.

CHAPTER EIGHT

GENERAL DISCUSSION AND CONCLUSION

To make management systems optimise herbage and nutrient production from rangelands and pasture, it is crucial to know the response of forage plants to different management inputs. Some of these management inputs are the deliberate interventions of human to rehabilitate and/or modify grazing systems. This includes the introduction of preferred forage plants, use of different fertilizers, disturbance of existing vegetation such as burning, mowing and using different grazing routines.

The over all purpose of interspersing grasses and legumes is to optimize forage quality and increase forage quantity. In the first study, teff DM yield was lower for the teff herbage obtained from teff grown interspersed with lucerne compared to the DM of teff obtained from the teff-alone plot. However, the overall DM yield of the teff-lucerne mixture was significantly higher than that obtained from the teff-alone plot. This applied also to the N and P content of the mixture planting of teff and lucerne. Both DM yield and nutritive quality of teff and the teff-leucaena stands, in the second study, were higher for the stands obtained from teff-leucaena stands compared to the teff-alone one. Most of these results were comparable if not more than the ones obtained from the third study by applying inorganic N fertilizer.

In the fourth study most results did not show significant differences among each other. However, there is no doubt that different management techniques such as burning, mowing and controlled rotational grazing, most of the time, will have a positive effect on the sustainable utilization of grazing areas and their vegetative systems. In the fifth study the nutritional value of forage decreased as distance from homestead increased. This might possibly show that grazing animals drop most of their manure around these areas and transport nutrients to smaller areas.

Nevertheless, there is no doubt that grazing and/or croplands of developing countries are declining because of the mismanagement of resources. In most of the developing countries and sub-Saharan Africa the productivity of grazing lands, croplands and livestock are linked and inseparable. Whatever livestock production system or crop/plant production method is used, the products and/or the by-products of one are useable by the other. For example, crop residues can be used as feed by animals. In return, animal wastes can be used as sources of nutrients for crops and other plants. Moreover, as population pressure pushes cropping lands to the rangelands, it becomes necessary to use crop residues and/or grow animal feed side by side to crops as the extensive invasion of rangelands could reduce the availability of grazing lands for livestock. This implies developing increasingly intensive livestock production systems. Unless they are used, the by-products of both sectors such as the animal manure will become wastage and an agroecological threat. This is particularly a serious problem in intensive livestock production systems where animals are confined and their wastes need proper disposal and storage. Livestock are the chief vectors of nutrient transfer across the landscape. They graze the rangelands and crop residues. In mixed farming systems, crop residues provide vital feeds during the 6-8 months dry season and manure from the grazing animals enhances soil fertility for crop production. The grazing lands provide feeds during the grazing/manuring period, resulting in a net nutrient transfer from rangelands to croplands. Sustainable feed and livestock production systems, however, depend on the continuous maintenance and enhancement of both rangelands and croplands because excessive removal of vegetation depletes soil nutrient reserves and increases the risk of soil erosion and environmental degradation (Murphy 1986; Powell *et al.* 1998).

As illustrated in Figure 8.1, allowing animals to graze natural pastures during the day and manure cropland at night results in a net transfer of nutrients from rangelands to croplands (b). However, the change from extensive livestock grazing management to semi-intensive stall feeding confinements (where animals are kept in a house and fed by cutting and carrying feed) of livestock production systems (because of shortage of land due to expansion of cropping lands) will require more feed of high quality and improved feed harvesting and storage techniques aimed at minimizing the competition between livestock and soil conservation for the use of crop residues. Thus, improved methods of capturing and recycling the nutrients contained in feed refusals (the feed which is left and mixed with the faeces and urine) and manure are also needed for all integrated farming systems (Powell *et al.* 1998). That is to say all the litter feed and manure should be collected and kept in a place where there can be a minimum loss of nutrients.

Therefore, the integration of forage legumes and browse trees into croplands can play an important role in reducing the pressure on rangelands and in sustaining the productivity of both crops and livestock because forage legumes can improve animal feed supply and quality, suppress weed growth, accelerate nutrient cycling, and improve soil moisture conservation (Powell *et al.* 1998; Kirkman and de Faccio Carvalho 2003). In most rural areas land and labour are usually used in efficiently. Thus, integrating forage legumes into croplands may have an advantage in that the labour, land, finance and other management practices which were meant for growing only crops might be further extended to the cultivation of the included legumes without or little increase of labour and other management requirements (Mittal and Singh 1989). This might encourage farmers because in addition to growing their crops, they are using their available resources to grow other animal feed sources without or little additional inputs.

In this study teff yield of the first study was reduced in the teff-lucerne mixture while the lucerne yield increased, the yield response of lucerne and interspersed teff-lucerne mixture stands gave a positive response to legume forage grass integrated associations. The lucerne and the teff in mixture with lucerne might have benefited from the N produced by lucerne. In the second study teff, leucaena and interspersed teff-leucaena mixture stands were significantly and positively affected by the integration. When comparing the total DM yield of teff grown in mixture with forage legumes and in N fertilizer treated plots, teff DM yield obtained from both teff-lucerne and teff-leucaena mixtures was higher than that obtained from N fertilized fields. It was 8000-8050 kg ha^{-1} for the teff grown with leucaena, 1000 kg ha^{-1} with lucerne, and 900-1200 kg ha^{-1} when grown with N fertilizer applications. Thus, these natural sources of nutrients may have an advantage over mineral fertilizers in that they may have a slow release of their soil nutrients and less environmental hazards compared to the synthetic inorganic fertilizers which in recent times are causing environmental concerns to many agricultural and environmental ecosystems.

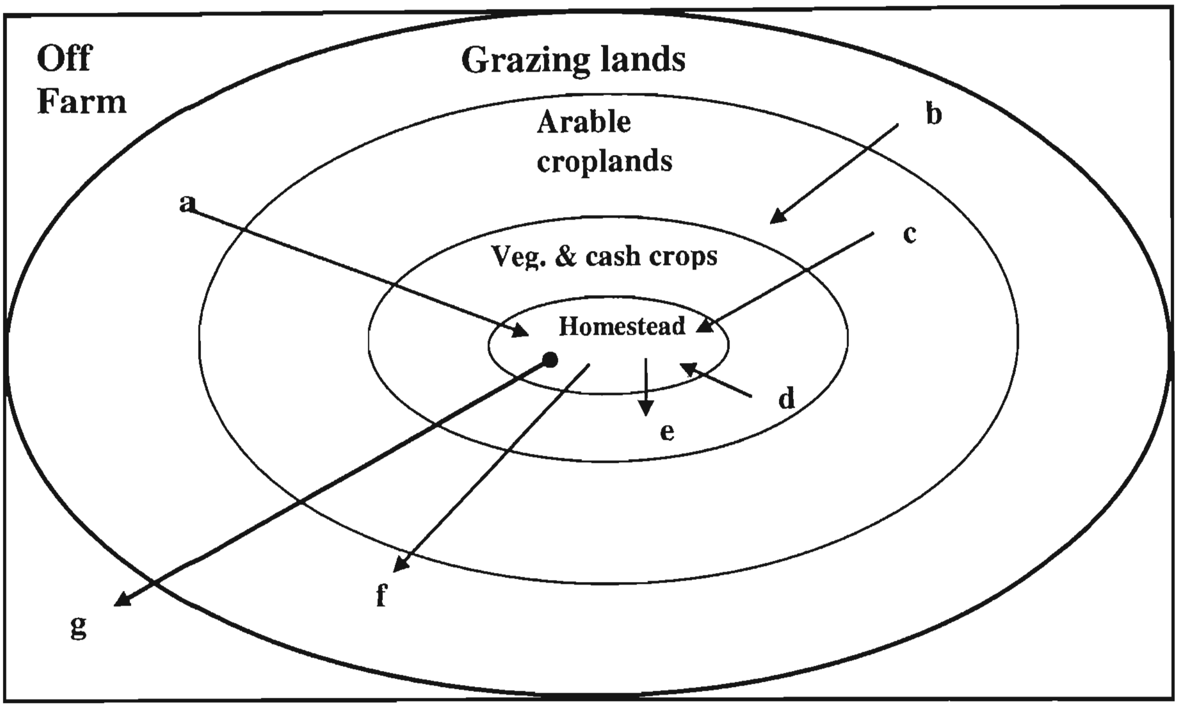

Figure 8.1 The fate of returning nutrients accumulated in the homesteads back to the grazing lands.

a. Grazing animals bring nutrients from the grazing lands to the homestead as manure or meat and milk.

b. Grazing animals transfer nutrients from rangeland to cropland.

c. Nutrients from the arable croplands are also brought to the homestead in the form of food crops, crop by-products and fuel. Animals may also graze this land periodically.

d. Vegetables and cash crops are consumed by the household and their by-products by the animals.

e. The majority of manure from animals is used on vegetable and cash crop lands close to the homestead.

f. Animals corralled and fed in the homestead at night may transport some nutrients back to the grazing lands in the form of manure during the day.

g. Generally nutrients that are continuously carried to the homestead are subject to loss through:

1. The sale of cash crops and vegetables;
2. The burning of manure and crop by-products for fuel
3. Non-return of human waste to the land

NB: When geographical distance increases intensity of grazing lands management decreases with distance from the homestead.

The biological merit of integrating forage with grasses and/or crops makes it an important conservation farming practice for smallholders and resource-poor farmers and with minor modifications, it could also be adapted to the broader farming systems of the world. Possibly the use of deep rooted legumes such as leucaena may exploit moisture and nutrients deep in the soil profile; permit nutrient cycling; improve soil structure; provide good soil erosion control and reduce the need for chemical fertilizers. Competition for light, especially with tree forage legumes such as leucaena, can be eliminated by regular pruning of the tree species. This was observed in that the plats close to leucaena plants where thin and weak. Many benefits are claimed for forage legumes. The sown perennial pasture legumes prevent soil erosion; provide high quality feed to supplement diets of crop residues; and leguminous forage contributes to the nitrogen budget of the system and maintains soil fertility. However, no single species delivers all stated benefits, and no single species is suited to the whole array of environmental circumstances.

Grasses are the major sources of animal feed. Many management techniques have been developed to maintain the quality and productivity of grasslands. However, their use will differ from place to place depending on current environmental conditions of a locality.

Throughout the history of man livestock and crops coexisted and exist inseparably. Moreover, man is still using them as major sources of living but giving priority to crops and expanding croplands to rangelands. More attention needs to be placed on animal feed to prevent a degraded and unsustainable environment. Therefore, the possible solution could be the integration of the two sectors because crop residues can be good sources of animal feed and nutrient cycling through the grazing animal could play a very important part in the productivity of pastures.

The integration of grasses and legumes is also another alternative of maintaining the sustainability of grazing and croplands. Thus, the rotation/integration of teff with leguminous crops and animal manure might be an alternative to the mineral fertilizer sources.

Although this study has tried to show some of the advantages of grass/legume interspersing in comparison to the use of inorganic fertilizers; the role of different grassland management systems and the influence of grazing animals on grazing lands, the final user of most agricultural researches is the farmer. Therefore, all these intervention approaches should be tested in an on-farm setting under the management of the farmer supported by the scientist so that their applicability is realized.

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APPENDICES

Appendix 1 Analysis of variance: effect of teff-lucerne interspersing on teff DM yield (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Rep stratum	2	15999	
Stand	1	65862	0.072
Stand.Plant space	2	9037	0.636
Stand.Row space	2	197614	<.001
Stand.Cut	6	275740	<.001
Stand.Plant space.Row space	4	37489	0.121
Stand.Plant space.Cut	6	7694	0.885
Stand.Row space.Cut	6	20174	0.421
Stand.Plant space.Row space.Cut	12	12890	0.794
Residual	78	19865	
Total	119		

b) Nitrogen

Sources of variation	DF	MS	F
Rep stratum	2	174.24	
Stand	1	142.57	0.026
Stand.Plant space	2	177.19	0.003
Stand.Row space	2	947.93	<.001
Stand.Cut	6	448.60	<.001
Stand.Plant space.Row space	4	82.77	0.023
Stand.Plant space.Cut	6	30.26	0.371
Stand.Row space.Cut	6	248.51	<.001
Stand.Plant space.Row space.Cut	12	6.92	0.994
Residual	78	27.55	
Total	119		

c) Phosphorus

Sources of variation	DF	MS	F
Rep stratum	2	8.065	
Stand	1	5.607	0.037
Stand.Plant space	2	15.850	<.001
Stand.Row space	2	46.215	<.001
Stand.Cut	6	17.642	<.001
Stand.Plant space.Row space	4	10.276	<.001
Stand.Plant space.Cut	6	1.341	0.384
Stand.Row space.Cut	6	8.697	<.001
Stand.Plant space.Row space.Cut	12	1.446	0.326
Residual	78	1.246	
Total	119		

Appendix 2 Analysis of variance: effect of teff-lucerne interspersing on lucerne DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Rep stratum	2	20591	
Stand	1	130931	<.001
Stand.Plant space	2	8566	0.332
Stand.Row space	2	388181	<.001
Stand.Cut	6	116953	<.001
Stand.Plant space.Row space	4	7531	0.422
Stand.Plant space.Cut	6	10864	0.238
Stand.Row space.Cut	6	17090	0.079
Stand.Plant space.Row space.Cut	12	1440	0.992
Residual	78	7632	
Total	119		

b) Nitrogen

Sources of variation	DF	MS	F
Rep stratum	2	0.02857	
Stand	1	0.02876	0.516
Stand.Plant space	2	0.09295	0.259
Stand.Row space	2	181.16274	<.001
Stand.Cut	6	199.35769	<.001
Stand.Plant space.Row space	4	166.91897	<.001
Stand.Plant space.Cut	6	37.06557	<.001
Stand.Row space.Cut	6	74.48629	<.001
Stand.Plant space.Row space.Cut	12	88.53569	<.001
Residual	78	0.06719	
Total	119		

c) Phosphorus

Sources of variation	DF	MS	F
Rep stratum	2	0.007071	
Stand	1	47.751962	<.001
Stand.Plant space	2	1.046579	<.001
Stand.Row space	2	1.417379	<.001
Stand.Cut	6	9.175173	<.001
Stand.Plant space.Row space	4	0.894453	<.001
Stand.Plant space.Cut	6	0.484986	<.001
Stand.Row space.Cut	6	1.913286	<.001
Stand.Plant space.Row space.Cut	12	1.628955	<.001
Residual	78	0.005875	
Total	119		

Appendix 3 Analysis of variance: effect of lucerne plant and row spacing on DM production of teff alone, teff-lucerne mix and lucerne alone stands.

Sources of variation	DF	MS	F
Rep stratum	2	49758	
Stand	2	592742	<.001
Stand.Plant space	2	446389	<.001
Stand.Row space	2	96105	0.019
Stand.Cut	9	222393	<.001
Stand.Plant space.Row space	4	308719	<.001
Stand.Plant space.Cut	6	38785	0.134
Stand.Row space.Cut	6	81132	0.004
Stand.Plant space.Row space.Cut	12	38908	0.083
Residual	86	22979	
Total	131		

Appendix 4 Analysis of variance: effect of lucerne plant and row spacing on N content of teff alone, teff-lucerne mix and lucerne alone stands.

Sources of variation	DF	MS	F
Rep stratum	2	167.84	
Stand	2	4071.65	<.001
Stand.Plant space	2	2735.39	<.001
Stand.Row space	2	224.63	<.001
Stand.Cut	9	528.32	<.001
Stand.Plant space.Row space	4	1371.97	<.001
Stand.Plant space.Cut	6	226.91	<.001
Stand.Row space.Cut	6	837.86	<.001
Stand.Plant space.Row space.Cut	12	141.08	<.001
Residual	86	25.87	
Total	131		

Appendix 5 Analysis of variance: effect of lucerne plant and row spacing on P content of teff alone, teff-lucerne mix and lucerne alone stands.

Sources of variation	DF	MS	F
Rep stratum	2	8.051	
Stand	2	71.536	<.001
Stand.Plant space	2	13.441	<.001
Stand.Row space	2	5.121	0.015
Stand.Cut	9	19.946	<.001
Stand.Plant space.Row space	4	18.482	<.001
Stand.Plant space.Cut	6	3.548	0.010
Stand.Row space.Cut	6	11.838	<.001
Stand.Plant space.Row space.Cut	12	5.128	<.001
Residual	86	1.168	
Total	131		

Appendix 6 Analysis of variance: effect of leucaena plant row spacing (180cm) on teff DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Stand	1	119	0.881
Stand.Cut	6	51466	<.001
Residual	16	5190	
Total	23		

b) Nitrogen

Sources of variation	DF	MS	F
Stand	1	25.420	0.073
Stand.Cut	6	263.685	<.001
Residual	16	6.909	
Total	23		

c) Phosphorus

Sources of variation	DF	MS	F
Stand	1	2.6136	0.015
Stand.Cut	6	5.8312	<.001
Residual	16	0.3503	
Total	23		

Appendix 7 Analysis of variance: effect of leucaena plant row spacing (180cm) on leucaena DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Cut	3	19708	0.043
Residual	8	3542	
Total	11		

b) Nitrogen

Sources of variation	DF	MS	F
Cut	3	69.60	0.147
Residual	8	25.97	
Total	11		

c) Phosphorus

Sources of variation	DF	MS	F
Cut	3	14.722	0.191
Residual	8	6.654	
Total	11		

Appendix 8 Analysis of variance: effect of leucaena plant row spacing (180cm) on teff-leucaena and teff alone stand DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Stand	1	800314	<.001
Cut	3	181953	0.010
Stand.Cut	3	81297	0.107
Residual	16	34078	
Total	23		

b) Nitrogen

Sources of variation	DF	MS	F
Stand	1	10829.00	<.001
Cut	3	460.04	<.001
Stand.Cut	3	22.99	0.323
Residual	16	18.32	
Total	23		

c) Phosphorus

Sources of variation	DF	MS	F
Stand	1	151.253	<.001
Cut	3	25.258	0.004
Stand.Cut	3	7.146	0.174
Residual	16	3.803	
Total	23		

Appendix 9 Analysis of variance: effect of leucaena plant row spacing (120cm) on teff DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Stand	1	914	0.772
Stand.Cut	6	49179	0.006
Residual	16	10532	
Total	23		

b) Nitrogen

Sources of variation	DF	MS	F
Stand	1	82.14	0.024
Stand.Cut	6	133.82	<.001
Residual	16	13.20	
Total	23		

c) Phosphorus

Sources of variation	DF	MS	F
Stand	1	0.0759	0.600
Stand.Cut	6	4.5319	<.001
Residual	16	0.2654	
Total	23		

Appendix 10 Analysis of variance: effect of leucaena plant row spacing (120cm) on leucaena DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Cut	2	4047	0.720
Residual	6	11640	
Total	8		

b) Nitrogen

Sources of variation	DF	MS	F
Cut	2	197.95	0.007
Residual	6	15.54	
Total	8		

c) Phosphorus

Sources of variation	DF	MS	F
Cut	2	0.35634	0.018
Residual	6	0.04186	
Total	8		

Appendix 11 Analysis of variance: effect of leucaena plant row spacing (120cm) on teff-leucaena and leucaena alone stand DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
Stand	1	952272	<.001
Cut	3	53609	0.012
Stand.Cut	3	22917	0.134
Residual	16	10668	
Total	23		

b) Nitrogen

Sources of variation	DF	MS	F
Stand	1	5575.40	<.001
Cut	3	230.11	0.003
Stand.Cut	3	138.53	0.023
Residual	16	33.33	
Total	23		

c) Phosphorus

Sources of variation	DF	MS	F
Stand	1	21.2440	<.001
Cut	3	6.5674	<.001
Stand.Cut	3	2.7631	0.003
Residual	16	0.3787	
Total	23		

Appendix 12 Analysis of variance: effect of rate of N fertilizer (kg ha^{-1}) application on teff DM production (a), N content (b), and P content (c).

a) Dry matter

Sources of variation	DF	MS	F
NF	3	51781	<.001
NF.Cut	12	53741	<.001
Residual	32	5932	
Total	47		

b) Nitrogen

Sources of variation	DF	MS	F
NF	3	47.79	0.082
NF.Cut	12	237.78	<.001
Residual	32	19.55	
Total	47		

c) Phosphorus

Sources of variation	DF	MS	F
NF	3	1.8701	0.065
NF.Cut	12	6.9154	<.001
Residual	32	0.7039	
Total	47		

Appendix 13 Analysis of variance: effect of different management techniques on *T. triandra* DM production (a), N content (b), and P content (c).

a) Dry matter

Source of variation	DF	MS	F
Mgt. Tech.	2	209662	0.243
Residual	6	116006	
Total	8		

b) Nitrogen

Source of variation	DF	MS	F
Mgt. Tech.	2	4.83444	<.001
Residual	6	0.04528	
Total	8		

c) Phosphorus

Source of variation	DF	MS	F
Mgt. Tech.	2	0.1752	0.850
Residual	6	0.2937	
Total	8		

Appendix 14 Regression analysis: difference on herbage DM production (a), N content (b), and P content (c) when moving away from homesteads in Okhombe.

a) Dry matter

Source of variation	DF	MS	F
Distance	3	2687495	<.001
Residual	8	115712	
Total	11	817107	

b) Nitrogen

Source of variation	DF	MS	F
Distance	3	236.48	0.015
Residual	8	35.99	
Total	11	90.67	

c) Phosphorus

Source of variation	DF	MS	F
Distance	3	0.2074	0.785
Residual	8	0.5800	
Total	11	0.4784	

Appendix 15 Regression analysis: difference on herbage DM production (a), N content (b), and P content (c) when moving away from homesteads in Zwelitsha.

a) Dry matter

Source of variation	DF	MS	F
Distance	5	1350347	<.001
Residual	18	16354	
Total	23	306352	

b) Nitrogen

Source of variation	DF	MS	F
Distance	5	60.90	0.349
Residual	18	50.79	
Total	23	52.99	

c) Phosphorus

Source of variation	DF	MS	F
Distance	5	0.2809	0.577
Residual	18	0.3598	
Total	23	0.3426	