SCREENING OF INDIGENOUS FORAGE LEGUMES AS POTENTIAL FODDER CROPS AND PROTEIN SOURCE FOR LIVESTOCK IN CENTRAL NAMIBIA

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ABSTRACT

The objective of the study was to screen indigenous forage legumes found in central Namibia and evaluate their potential as fodder and protein source for livestock. The growth rate, biomass yield and nutritional value of four indigenous legumes (*Otoptera burchellii*, *Vigna lobatifolia*, *Crotalaria argyraea* and *Cullen tomentosum*) and four improved legumes (*Lablab purpureus*, *Medicago sativa*, *Canavalia ensiformis* and *Vigna unguiculata*) were evaluated in a split-plot design with Single superphosphate at varying levels (0, 60, 80 and 100 kg P/ha). Fertilizer application up to 80 kg P/ha increased biomass and 100-seed weight; responses for *O. burchellii* were however inconsistent. The legumes differed ($P < 0.05$) in biomass yield; least square means (tons/ha) were: *L. purpureus* (8.9 ± 0.3), *V. lobatifolia* (1.5 ± 0.4), *O. burchellii* (2.5 ± 0.3), *V. unguiculata* (4.4 ± 0.3), *C. tomentosum* (5.1 ± 0.4), *C. ensiformis* (4.0 ± 0.3) and *M. sativa* (4.7 ± 0.3). The 100-seed weight increased as P fertilizer level increased. The CP, ADF, NDF, ash and calcium differed ($P < 0.05$). The least square means for CP (% DM) at bloom stage were: *L. purpureus* (21.9± 0.3), *V. lobatifolia* (18.9± 0.4), *O. burchellii* (21.3± 0.3), *V. unguiculata* (18.9±0.3), *C. tomentosum* (20.9±0.3), *C. ensiformis* (20.4±0.3) and *M. sativa* (26.9±0.3). NDF ranged from 30.5 ± 1.6 to 42.4 ± 1.8 % DM. Phosphorus content was similar ($P > 0.05$) among legumes. *L. Purpureus* and the indigenous legumes *O. burchellii* and *V. lobatifolia* have potential as fodder and protein source *ipso facto* could contribute substantially to improving nutrition of ruminants in central Namibia.

Key words: Forage legumes, biomass, ruminants, fodder, rangeland, indigenous

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DEDICATION

This work is dedicated to my wife Beata Ndahafa Kaholongo for keeping up the family while I was away for studies. To my sons, Tuure Utshona Kaholongo (Junior) and Kalapuse Hafeni Kaholongo you are a source of inspiration. I extend this dedication to my late father Tuure Utshona Kaholongo (Senior) who passed away on the 19th July 2013. Father, you made a difference in my life.

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To my family, thank you for your uncountable support. May God bless!

DECLARATION

I, Lukas Tegelela Kaholongo, hereby declare that this study is a true reflection of my own research, and that this work has not been submitted for a degree in any other institution of higher education.

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.... Date: 17/06/2016

Lukas T. Kaholongo

CHAPTER 1

INTRODUCTION

1.1 Background information

Although the agricultural sector contributes about 5 % to the Gross Domestic Product (NPC, 2012), about 70% of Namibia's population is directly or indirectly dependent on agriculture for their livelihood (Mendelsohn, El Obeid, de Klerk& Vigne, 2006). Livestock production contributes 76% of the overall agricultural output value. Some 70% of this amount comes from commercial areas and 6% from communal areas (NPC, 2012). Almost the whole of Namibia receives a long term average rainfall of less than 500 mm per annum and can therefore be classified as semi-arid and arid rangelands. The low and often unpredictable rainfall makes the planning and execution of sustainable animal production models extremely difficult and management in such environments is often driven by short-term decisions in a "reactive" mode (NNFU, 2008) rather than a proactive approach. Management decisions are often driven by short-term weather patterns and fodder flow management is very difficult (Rothauge, 2000). Off-take of beef cattle from the commercial farms is about 24.4%, but is only 6 % in the communal areas. The lower off-take from the communal areas is mainly due to irregular calving and high mortality (NNFU, 2008).The problem is more pronounced in the drier months of the year when the grazing is so scarce, and in areas where it is available, it is characterized by poor quality; protein and energy are the main constraints on feed quality. Crop residues which are available in large quantities can play a role in

filling this gap. However, they are of low nutritive value due to their low digestibility and their inability to provide the rumen micro-organisms and the host animal with all the nutrients required (Woyengo, Gachuiri, Wahome & Mbugua, 2004). Animals have to rely predominantly on such high-fiber feeds which are deficient in nutrients such as nitrogen, phosphorus, and other minerals essential for microbial fermentation (Khalil, Osuji, Umunna& Crosses, 1994).

The problems associated with low protein and mineral deficiencies can be addressed by supplementation. In many cases low protein can be alleviated by non-protein nitrogen to sustain animals on a maintenance level. Such supplements, however, will rarely promote satisfactory levels of production unless energy sources are also added in substantial quantities (Zemmelink, 2000). Often the option of using well-adapted cultivated grass species alone or in conjunction with leguminous pasture or browse species, with or without irrigation, is economically sounder. Re-seeding rangelands with indigenous legumes is also expected to improve nutrition of ruminants because of their ability to fix atmospheric nitrogen into soils, hence increasing herbage yield, crude protein in the diet and digestibility (Richardson and Smith, 2006). Namibia is endowed with a lot of indigenous forage legumes that could be exploited in improving the productivity of rangelands. Forage legumes are important components of herbivores nutrition because of their high percentage of crude protein. However, there is limited information on the potential of indigenous forage legumes in feeding livestock.

There have been efforts in the Ministry of Agriculture, Water and Forestry to promote exotic species, for example, over-sowing of flooded areas such as pans or

Oshanas with exotic legumes like *Centrosema pascuorum*, *Stylosanthes hamata* and *Aeschynomene americana*. They were tried in the common flooded areas of North-Central Division (NDC), Namibia, by the Northern Regions Livestock Development Project (NOLIDEP) during the 1996/1997 rainy season. However, results were rather disappointing due to late planting, quick and deep flooding of the sites and poor adaptability of these fodder species to Namibian conditions (Mukulu & Sweet, 1997). On the contrary, native legumes are well adapted to many of the harsh environmental conditions that currently limit the growth of exotic perennial legumes (Megan, 2003). In particular, they can cope with low and irregular rainfall and as such, are likely to have deep roots and the ability to use water both from deep in profile all year-round (Megan, 2003). Thus current research should be geared towards characterizing and selecting promising forage legumes in terms of biomass production, nitrogen fixation and soil improvement (Anikwe & Atuma, 2003). In agreement, MAWF (1997) recommended that research using exotic species needed to be revisited with a focus on legume species found locally or in neighboring countries. It is worth noting that the Namibia Development Plan (NDP4) and its Agricultural Sector Execution plan together with the MAWF Strategic Plan (2014-2017) have identified Conservation Agriculture (CA) as an important practice for improved food security. Promoting the utilization of indigenous forage legumes for soil improvement and feeding of livestock fits in well with this intervention.

1.2 Statement of the problem

In spite of abundant rangelands in Namibia, livestock production is constrained by many factors including fluctuations in feed quality and quantity, diseases and parasites and heat stress. Compounding these problems is rangeland degradation due to over grazing and bush encroachment, leading to a decline in available grazing, ruminant livestock productivity and a reduction in off-take rates. The constraints lead to reduced growth rates; impaired reproduction, increased mortality and increased production costs for instance through purchased feed during the dry season. This reduces competitiveness of the livestock sector and threatens sustainability of livestock production and livelihoods in the semi-arid areas of the country for example central Namibia.

With respect to nutrition, crude protein content of grasses declines during the dry season to below the minimum threshold of 6-7% required for rumen microbial activity (Gebreyowhans & Gebremeskel, 2014). Legumes are high in crude protein and supplementation of basal grass diets with legumes has been shown to improve intake, digestibility and animal performance (Owens, Sapienza & Hassen, 2010).Therefore, this research was geared towards addressing this problem by characterizing selected promising indigenous forage legumes in terms of growth rate, biomass production and nutritional values. Indigenous forage legumes in this research referred to forage legumes that occur naturally in Namibia rangelands. Improved forage legumes refer to forage legumes which have undergone extensive research leading to increased

performance in terms of biomass yield, adaptability and persistence. These forage legumes could be used as fodder during the dry season.

1.3 Objectives of the study

1.3.1 Overall objective:

The main objective of this research was to screen and identify indigenous forage legumes found in central Namibia and evaluate their potential as fodder and protein source for livestock.

1.3.2 Specific objectives

The specific objectives of this study were to:

(i) Screen, identify and determine growth characteristics of four (4) indigenous forage legumes and four (4) improved forage legumes in Namibia;

(ii) determine the optimum phosphorus (P) fertilizer requirements for the legumes;

(iii) determine biomass production of the four (4) indigenous and four (4) improved forage legumes;

(iv) determine the nutritional value of four (4) indigenous and four (4) improved forage legumes;

(v) Determine the effect of ensiling on the silage characteristics (fermentation quality, DM concentration and nutritional composition) of five (5) of the forage legumes (i.e. *Lablab purpureus*, *Canavalia ensiformis*, *Medicago sativa*, *Cullen tomentosum* and *Otoptera burchellii*).

1.3.3 Hypotheses of the study

(i) Growth characteristics of the four (4) indigenous forage legumes and the four (4) improved legumes are not significantly different.

(ii) Optimal phosphorous (P) fertilizer requirements are similar for the eight (8) forage legumes.

(iii) Biomass production of the four (4) indigenous forage legumes and four (4) improved legumes are not significantly different.

(iv) Nutritional values of the four (4) indigenous forage legumes and four (4) improved forage legumes are not significantly different.

(v) There is no significant difference in the ensiling characteristics of the five (5) forage legumes (*Lablab purpureus*, *Canavalia ensiformis*, *Medicago sativa*, *Cullen tomentosum* and *Otoptera burchellii*).

1.4 Significance of the study

The results of this study may allow a re-visit of the potential of locally adapted legumes for livestock use in central Namibia even more than in the past. Incorporating legumes in pastures has always been a challenge, particularly in grazing systems as intense grazing and inadequate fertilization for example with Phosphorous leads to poor persistence. Although persistence was not directly addressed in this study, the preliminary information gathered may shed light on areas that warrant investigation in future studies.

Legumes also play an important role in amelioration of poor soils due to the Biological Nitrogen Fixation (BNF).For crop farmers, the indigenous legumes identified, could contribute to improvement of soil fertility and hence yield improvements.

In terms of livestock production, this study could provide alternative feed supplements for livestock during the dry season and also alternative feed ingredients for feedlot operators in Namibia. The study might provide useful information that could contribute to the possible domestication of indigenous forage legumes in Namibia. It might also enable the documentation of useful indigenous forage legume species in Namibia. Forage legumes with desirable characteristics could be useful for over-sowing natural pastures and improve nutrition of ruminants because of their ability to fix atmospheric nitrogen into soils, hence increasing herbage yield, crude protein in the diet and digestibility, thus contributing positively to livestock production.

1.5 Limitation of the study

Although there are a number of forage legumes in Namibia, only a limited sample, four (4) indigenous forage legumes and four (4) improved legumes were studied due to time, availability of planting materials and financial constraints.

CHAPTER 2

LITERATURE REVIEW

2.1 Livestock farming

The vegetation in Namibia, in regions with rainfall lower than 250 mm, can only support small ruminants such as sheep and goats (Kruger & Lammerts-Imbuwa, 2008). The areas receiving between 250 and 400 mm allow cattle farming, and consequently mixed livestock farming based on ruminants. In areas with rainfall in excess of 400mm, cattle farming is predominant but dry-land crop production can be initiated (NNFU, 2006). Livestock contribute 70% to the agricultural output (NPC, 2012), and serve various roles to communities including cash, wealth, sustenance and food security, draught power, manure, employment, skins, dowry, ecosystem health and exchange for other farm produce. Owing to climate, soil types and evapotranspiration rates, Namibia is better adapted to livestock-based as opposed to arable agriculture.

2.2 Rainfall and its influence on livestock production

Namibia is the most arid country in sub-Saharan Africa with naturally low agricultural productivity. Rainfall is low and highly variable with the occurrence of drought as a natural phenomenon (Kruger & Lammerts-Imbuwa, 2008). Drought in Namibia is generally not a question of few weeks without rain, but normally a case of one or more years with very little rain (Hemstetter & McKee, 1995). Fodder crops can be helpful to keep animals in a fair condition for a period of time until the opportunity arises to sell rather than to feed animals (especially cattle) until enough grazing is available on the veld again (JPC, 2008). Drought in Namibia is never predictable in

terms of when it will occur and the duration thereof (Stehn, 2008). From this point of view, it is doubtful (especially for cattle) whether a build-up of hay would serve its purpose (Rothauge, 2001). As a fodder bank for drought, baling of grass can be considered or silage produced (Stehn, 2008).

The combination of low average annual rainfall and high rainfall variability limit agriculture in Namibia to extensive livestock farming. Almost the whole of Namibia receives a long term average rainfall of less than 400 mm per annum and can therefore, be classified as semi-arid and arid rangelands. Extensive small stock farming is the main agricultural activity in areas receiving less than 200mm per annum, while large-stock farming is prominent in areas where average annual rainfall exceeds 300mm. Mixed large- and small stock farming is practiced in the rainfall zone falling in the 200-300mm category (Kruger & Lammerts-Imbuwa, 2008).

2.3 Farmers survival strategies against drought

To alleviate feed shortage in the dry season, small-holder farmers collect crop residues and store them for later use in stall feeding. Sorghum and millet are the major cereal crops in tropical and sub-tropical Africa. Their stover can only meet the maintenance energy requirements of sheep and cattle, if large amounts are offered, allowing selective consumption (Woyengo et al., 2004). For production and draft animals, higher quality supplements are needed (Zemmelink, 2000).Suitable supplements include residues of legume crops and industrial by-products. Use of cultivated forages by small holders is limited, due to the shortage of land and high costs of inputs. Use of agro-industrial by-products is also low, as they are often exported or

not accessible to farmers due to poor infrastructure and marketing costs, and high prices. Forage legumes such as Lucerne (*Medicago sativa*) and red clover (*Trifolium pretense*) have been shown to have high intake potential and high protein contents compared to grass (Fraser, Haresign & Speijers, 2004). According to Gous, Nesamvuri, Raphulu & Tshovhote (2003), *Vigna* species are important grain legumes in the tropical and subtropical regions where the shortages of animal protein sources are experienced. They can be an excellent source of dietary protein in animal nutrition especially where proteins are in short supply and expensive. Therefore, there is a need to study these species to determine their potential as fodder crops and protein source for ruminants.

As droughts in Namibia are unpredictable in terms of when they will occur and how long they will carry on, it is seldom wise to invest in feeding programs. Good veld management and conservative stocking rate is the best possible drought management practice (Stehn, 2008). It is a common practice among farmers to collect and include pods (especially camel thorn and prosopis) in licks and feeds to cope with drought (Kruger & Lammerts-Imbuwa, 2008). As a survival strategy in Namibia, buildup of a fodder reserve of rested veld (10-33% of ranch), dryland cultivated pastures of indigenous grasses (5% of ranch), plantations of drought-resistant fodder crops (5% of ranch) and opportunistically-made hay (from valleys and roadside reserves) create biological buffer against the impact of drought (Rothauge, 2001). For the 2015 drought, government provided drought relief to the tune of more than N$359 million, which included the implementation of the Livestock Marketing Incentive Scheme as well as

the Lease of Grazing and Transport Scheme (Drought: ministry urges farmers, 2015, p.1).

2.4 Forages

Forage is defined as edible parts of plants, other than separated grain, that can provide feed for animals, or that can be harvested for feeding (Leep, Dietz &Min, 2002).Generally the term refers to such material as pasturage, hay, silage, and green chop, in contrast to less digestible material known as roughage (Leep et al., 2002). In practice, however, the concept is often extended to woody plants producing succulent growth and indeed in the tropics some shrubs and trees are of considerable importance in this respect. Forage crops may be used in pastures or may be cut and carried to the animals that are expected to eat them. Forages have always been an extremely important source of nutrients in livestock rations. Additionally, they provide fiber in the ration which enhances proper digestion in forage-consuming animals. Through their conversion into milk and meat products, forages continue to be one of the primary sources of nourishment in the human diet (Schroeder, 2004).

The most important forage plants are the grasses, which comprise about 75% of the forage consumed in the tropics. The family of grasses, Graminae, includes about 620 genera and 10,000 species. While the number of cultivated grasses reaches 350 or more, only a relatively small number of grasses predominate and can be considered principal forage species. A second major group of forages is the legumes. The family Leguminosae is one of the largest of flowering plants with an estimated 700 genera and 14,000 species (Martin, 1993).

Feed costs represent the single largest expense in most livestock operations. Producing and properly preserving high-quality forages can help reduce the costs associated with feeding concentrates and supplements (Schroeder, 2004).

2.5 Leguminosae as a good fit

The Fabaceae are mostly herbs but include also shrubs and trees found in both temperate and tropical areas. They comprise one of the largest families of flowering plants, numbering some 400 genera and 10, 000 species. The leaves are stipulate, nearly always alternate, and range from pinnately or palmately compound to simple (Grubben & Denton, 2004).

The principal unifying feature of the family is the fruit, a pod, technically known as a legume. The family is usually divided into three sub-families: Papilionoideae, Caesalpinoideae and Mimosoideae. The three subfamilies are generally identifiable by their flowers. Papilionoideae are easily recognized by their characteristic papilionoideae (butterfly-like) flowers. The flower is irregular (zygomorphic) and is made up of five petals, and two petals partially fused together to form a boat-shaped keel. This group contains most of the important leguminous crop species such as soya bean (*Glycine max*), common pea (*Pisum sativum*), cowpeas (*Vigna unguiculata*), beans (*Phaseolus vulgaris*) and peanut (*Arachis hypogea*) (Zomlefer, 1994; Sprent, 2001).

Legumes are second only to the grasses (cereals) in providing food crops for world agriculture. In comparison to cereal grains, the seeds of the legumes are rich in high quality protein, providing man and animals with a highly nutritional food resource

(ILDIS, 2006). The leaves and grains are not only used as high-protein diet, but also as high protein fodder for livestock (Sprent, 2001).

The leguminosae (Pule-Meuelenberg & Dakora, 2007) are unique in their ability to form N_2 fixing symbioses (BNF) with members of the Rhizobiaceae (or rhizobia, namely, *Rhizobium*, *Brady rhizobium*, *Sino rhizobium*, *Mesorhizobium*, *Azorhizobium* and *Allorhizobium*). Inside root nodules, these rhizobial bacterial are able to reduce atmospheric N_2 into NH_2 via the GS/GOGAT (glutamine synthetase/glutamate-oxoglutarate aminotransferase) pathway and exchange this nitrogenous solute for photosynthate from the host plant (Dakora, 2003). Soil nutrient availability is a primary factor driving nitrogen fixation and legume establishment (Giller, 2001; O'Hara, 2001).

Legume-rhizobium symbiosis is often limited by phosphorus, molybdenum (Mo), sulphur (S) and zinc (Zn) deficiencies in soils. Calcium is important for root infection and nodule formation in legume BNF, while cobalt is required by N_2 fixing bacteria for electron transport (Tauro, 2009).

This mutually beneficial relationship between the Leguminosae and the Rhizobiaceae forms the basis for the ecological importance of legumes in natural and agricultural ecosystem in promoting increased crop yields and livestock production (Pule-Meuelenberg & Dakora, 2007).

2.6 Importance of legumes in animal production as a reason for investigating their potential

Legumes can contribute improved nutritive value and sustainability to warm-season, subtropical and tropical pastures and rangelands substantially (Muir, Pitman, Dubeux and Foster, 2014). They are characterized as plants with high protein content, and with relatively low cell wall matter content. Legumes can fix nitrogen availing it to neighboring grasses via nodule decay where grasses otherwise exhibit chlorosis; provide ruminants with digestive proteins and soluble carbohydrates when grasses often fail to provide the minimum nitrogen (N) or energy concentrations animals require to maintain weight (Humphreys, 1994).

The effect of the legume is two-fold. First, the quality of feed is improved especially in the dry season when the protein content in mature grass is extremely low (Dewhurst, Delaby, Moloney, Boland & Lewis, 2009). Even a small proportion of legume at any growth stage can increase animal performance. The nitrogen content and digestibility of tropical legumes do not decline as rapidly with age as is the case in tropical grasses and dietary nitrogen can be maintained above the critical level of 7 % for allowing optimum intake of herbage. Second, legumes can make a valuable contribution to the nitrogen economy of pastures (Muir et al., 2014). In most countries, the cost of nitrogen fertilizers prohibits their widespread use on pastures. Depending on environmental conditions, legumes can fix between 45 and 290 kg N/ha per year in grazed pastures (Bayer & Waters-Bayer, 1998).

Although they contain alkaloids, tannins and estrogens, these factors are considered to be of secondary importance. Van Soest (1994) has reported that moderate tannin content may even improve the protein utilization in the rumen of the ruminants. In the growth period, the digestibility of legumes decreases more slowly than that of grasses, and the optimum time for silage preparation is longer (Kaldmae & Vadi, 2000). For example, the digestibility of red clover decreased by 0.15% a day, whereas that of rye grass decreased by 0.5% a day (Kaldmae & Vadi, 2000). Whilst the crude protein content of grass with moderate levels of N fertilizer is often relatively close to animal requirements (130 to 170 g/kg DM), legumes often contain much higher levels (180 to 300 g/kg of DM), much in excess of requirements (Dewhurst et al., 2009). Most of the tropical pastures have crude protein contents ranging from 7 to 12% for the grasses and more for legumes. The crude protein content of legumes is about 25% and it is higher than that of grasses at similar ages and stages of growth and shows little fluctuation during growing process (Aminah and Chen, 1991).

Apart from higher nitrogen content, tropical legumes generally maintain higher sulphur (0.07-0.21%) and calcium (1.13-1.93%) as compared to that of grass (0.09-0.15% and 0.17-0.41%, respectively. Similarly, the values of phosphorus in legumes are expected to be higher than grasses despite great variability between species and plant age. The additional role of legumes in increasing the mineral content of pastures has an additive effect on animal nutrition and production. As indicated earlier, the protein content of tropical pastures decreases rapidly as growth progresses. As a general guide, 10% crude protein on a dry matter basis is adequate for fattening cattle but above 15%

crude protein is required for high producing milking cows (Ayisi et al., 2002). Fraser, Speijers, Theobald, Fychan and Jones (2004) stated that forage legumes such as Lucerne (*Medicago sativa*) and red clover (*Trifolium pratense*) have been shown to have high intake potential and high protein content compared to grass.

In general, crude protein contents of at least 200g per kg dry matter are found in young leafy plants of legumes and for a large part of the year the plant maintains concentrations above the threshold for ruminant productivity of 70g per kg dry matter (Mokoboki, Ndlovu & Ayisi, 2002). This characteristic alone makes tropical legumes superior to most of the tropical grasses which invariably start with a lower crude protein content and declines to 30g or less per kg dry matter during the dry season. Forage legumes therefore are considered to be special feeds, which may be used as either alternatives to protein concentrates such as oilseed cakes or protein - rich supplements, to improve nutritive value of low quality roughages and mature standing herbage.

Legume forages generally lead to higher intakes and animal production than grass silages of comparable digestibility (Dewhurst et al., 2009). Increases in the intake of the diet when a forage legume is included have been widely reported but the response varied considerably between experiments. In terms of production, Boitumelo and Mahabile (1992) have reported a two-fold increase in milk production when 20% of the cows' diet is made up of legume hay.

In an experiment to evaluate Lablab hay and Paprika calyx as protein sources in diets for lactating indigenous Mashona cows in Zimbabwe, Murungweni, Mabuku and Manyawu (2004) found that Lablab hay and Paprika calyx compared well to

commercial dairy meal. Given the cost of commercial concentrates and the relatively poor milk yield response of Mashona cows to supplementation, it is uneconomic to feed bought-in concentrates. It is also highlighted that Mucuna and Lablab hay can substitute for the common commercial feed (14.5% CP) commonly used by most commercial farmers for pen fattening (Murungweni et al., 2004).

In Botswana, feeding high protein *Lablab purpureus* during the dry season has been a significant intervention in small dairy farms (Boitumelo & Mahabile, 1992). Chemical analysis showed that Lablab contained 2.6 times more crude protein (CP) than sorghum stovers (16.4% vs.6.4%) (Boitumelo & Mahabile, 1992). Therefore, the use of Lablab as a protein supplement in cereal crop stover based diets is a practical approach for the dry season feeding of lactating and in-calf cows.

2.7 The latent attributes of indigenous forage legumes

Indigenous forage legumes are well adapted to many of the harsh environmental conditions that currently limit the growth of exotic perennial legumes such as Lucerne (Megan, 2003). In particular they can cope with low and irregular rainfall and as such, are likely to have deep roots and the ability to use water both from deep in the soil profile all year-round. Depending on their natural environment they also could be adapted to highly acidic or saline soils and low soil fertility. Domesticating native species can provide other benefits such as avoidance of the quarantine restrictions associated with importing exotics while providing biodiversity benefits (Megan, 2003).

Furthermore, mixing species in fallows provides a better risk management strategy through compensatory biomass and nutrient production gains obtained from the strongly

competing species (Gathumbi, Cadisch & Giller, 2004). For example, indigenous legumes in sole stands were found to contribute about 3-17 % of the total biomass which could translate to < 5 kg N ha^{-1}, while mixing species could increase contribution up to 40 % of total biomass, translating into potential N inputs of 6-53 kg N ha^{-1} (Mapfumo, Mtambanengwe, Giller and Mpepereki, 2005). Mixing species also enhances the uptake of soil water and nutrients within the soil profiles due to differences in rooting depth and ability to exploit resources (Farley & Fitter, 1999; Nordin, Hogberg & Nasholim, 2001). These attributes underscore the need to pursue research on legumes indigenous to central Namibia.

2.8 Choosing which forage legumes to grow as prospective fodder crops

Not all forage legume species are suited to any climate and growing season, nor are all species adapted to grazing by animals. To be productive in a pasture system, a plant needs to be able to withstand frequent defoliation, provide re-growth quickly throughout the growing season, and provide sufficient yields of high-quality forage (Majewski, 2007).Naturally, good forage should be palatable to the animals for which it is grown and this palatability should extend throughout the year (Franklin, 1993). When the forage is used through cutting or pasturing, it should regenerate rapidly. The overall yield should be high, and this depends in part on previously mentioned factors. Other attributes could be compatibility, diseases and pest free. Finally, nutritive quality ought to be high. Height of forage is an important characteristic, since tall forages are easy to cut but difficult to graze (Franklin, 1993).

Aganga and Tshwenyane (2003) stressed that if forage cultivation is being introduced into an area, species suitable for the local ecological conditions and farming system have to be selected. Appropriate species can be selected only if the purpose of forage cultivation is clear, for example to increase the amount of forage available during a particular season and to increase the quality of the ration for a specific production aim (Bayer &Waters – Bayer, 1998).The new forage plants must bring significant advantages in at least one characteristic in comparison with existing forage – husbandry practices and/or species.

Tainton (2000) stated that it is important to appreciate that veld and pastures can play complementary roles in providing fodder to livestock. Before pastures are introduced into any system an assessment should be made of the extent to which productivity among other attributes as listed, is likely to be increased, the amount of capital needed, the livestock system which is envisaged, the availability of labor and management expertise, and perhaps most important of all, the attitude of each individual farmer to pasture development (Tainton, 2000).

2.9 Influence of nutritional content of the feed on livestock production

The level of animal production achieved in any environment is related to quality, quantity and continuity of supply of feed throughout the year. These are in turn related to rainfall, temperature and soil type and fertility (Ayisi et al, 2002). In dairy farming, it is a common knowledge that the contribution in milk production due to genetic factors of the animal is between 25-33 % (Soomekh, Hatami & Bahman, 2014).

A greater sustainability of production is due to proper and adequate feeding. Pasture can be a major source of feed for dairy cows but there are some limitations to its use.

Energy and protein supplies are the most essential components in animal nutrition but in many tropical countries, these components are often the critical limiting factors to animal production (Aminah & Chen, 1991). Obviously, there are deficiencies in both quantity and quality of feeds, especially during the dry season. These deficiencies are in terms of energy, crude protein and phosphorus. The shortage of good quality feeds, especially during the long dry season in tropical and subtropical areas has increased the need to provide supplementary feed to maintain livestock production. However, there has been dramatic increase in the cost of feed in recent years owing to the economic hardship faced by most African countries. Few communal farmers as well as commercial farmers can afford to buy supplementary feed for livestock, and some have resorted to collecting tree pods and feeding them to livestock as protein supplements, especially during the dry season (Tshabalala, Sikosana & Chivandi, 2013). In Namibia, this is a common practice in both commercial and communal farmers. According to Rao and Williams (2000), a basic goal of any grazing programs is to provide high quality forage year-round to reduce the cost of using stored or purchased feed.

In order to be sustainable, future forage and livestock production systems must involve the use of all possible forage sources including legumes to fill the forage deficit period. During the forage deficit time, the digestibility of the scarcely available feed is

very low. As digestibility of the feed declines, its palatability becomes less and the intake of the fodder also declines (MAWF, 1997).

Protein content varies with stage of maturity and parts of the plant and species. Most of the tropical pastures have crude protein contents ranging from 7 to 12% for grasses and more for legumes like *Leucaena leucocephalla* which has 25% protein content. However, protein content of tropical pastures decreases rapidly as growth progresses. The critical level of crude protein required in the pasture before intake is reduced by a protein deficiency has been estimated at between 6.0 and 8.5% (Aminah & Chen, 1991). This problem of crude protein deficiency in pasture can be remedied by the use of tropical legumes or nitrogen fertilizer on pure grass pasture. But it is recommended (Aminah & Chen, 1991) that to maintain high productivity and forage quality for dairy cows, it may be better to include leguminous species in the pasture production system rather than relying on nitrogen fertilizer for the following reasons. Firstly, improvements of soil conditions due to nitrogen build up in the soil from accumulation of organic matter; secondly, the fixation of nitrogen by the legume through rhizobium-legumes symbiosis relationship; lastly, increased animal production due to the higher nutritive value of legumes and shorter digestive passage time in the gut that enhance voluntary intake(Dewhurst, 2013).

The level of protein in the diet affects voluntary intake of food (Devendra, 1991) and low protein diets are not readily eaten by ruminants. In sheep, a 7% crude protein begins to limit intake (Milford & Minson, 1968). In one trial, goats in Tanzania feeding on *Chloris gayana* hay were supplemented with 200 to 300 g of dried Leucaena leaves

which significantly increased organic matter intake, crude protein intake and daily growth rate compared to the un-supplemented control group (Devendra, 1991). In the digestibility study, *Leucaena leucocephalla* supplementation increased total dry matter intake from 42.3 g/kgW$^{0.75}$ in the control group, to 77.9 g/kgW$^{0.75}$in the group with Leucaena fed *ad libitum*. Devendra (1991) highlighted that the minimum required crude protein of a poor quality diet with a digestibility of organic matter of 50% would be between 6.1to 7.4%. Degraded pastures cannot provide sufficient nutrients to meet an animal's maintenance requirements; pristine grass pasture can provide adequate nutrition for animal production at medium to high level (Skarpe, 1991).

Mullen (1999) pointed out that cowpeas, Lablab and soybeans provide high quality forage suitable for growing and fattening stock, as well as feeding lactating cows. These legumes generally produce forage very high in crude protein, low in fiber, high in digestibility and high in metabolizable energy.

An average weight gain of 197 g/head/day over a sixty (60) day period on lambs grazing on cowpeas at Dubbo, Australia was recorded, while commercial steers on Lablab in the Merriwa/Quirindi district had weight gains ranging from 0.5 to 1.2 kg/head/day, depending on age and condition of stock (Mullen, 1999).In another experiment on Lablab, Clem (2004) reported growth rates from 0.60 to 0.86 kg/head/day. In Brazil, Zebu cattle grazing maize stalks, dry grasses and green Lablab gained 350 g/head/day over a 3-month period, while cattle without Lablab lost weight (Murphy & Colucci, 1999). In sub-tropical Australia, cattle gains have ranged from 0.09-1.04 kg/head/day depending on the feeding conditions. Trials in Zimbabwe have

demonstrated that the use of a Lablab hay supplement resulted in milk yield increases slightly less than those obtained through the use of velvet bean (*Mucuna pruriens*). Milk quality was also slightly less than that achieved with velvet bean but still very acceptable. Supplementing the diet of goats with Lablab in Zimbabwe has been shown to yield better condition for does, higher kid birth weights and growth rates, and higher milk yields (Ayisi et al., 2004).

2.10 Chemical analysis and nutritive value of fodder crops

Dry matter is the percentage of the forage that is not water. Dry matter content is important because all animal requirements are estimated on a dry matter basis (Schroeder, 2004). It would be impossible to compare different forages without using the percent dry matter as a base line. Dry matter is also very important as the moisture content will give clues as to how given forage will preserve when stored by baling or ensiling.

Undoubtedly, protein is an important nutrient supplied by forages. In legumes, protein is the primary nutrient supplied and is likely the principle reason particular forage is being fed. It is important to understand what protein analysis tells about the quantity and quality of the protein present in the forage (Schroeder, 2004).Nutritional analysis of the feed is done by using proximate analysis to determine the following: dry matter content (100 percent minus moisture content), crude protein (total nitrogen is measured), ether extract (lipids and fats), ash (mineral content) and crude fiber (cellulose and some lignin).Again, many forage analyses will include a value called digestible dry matter (DDM).Feeding studies have shown that as the percent of Neutral

detergent fiber (NDF) increases in forages, animals consume less. Therefore, percent NDF can be used to estimate dry matter intake (Schroeder, 2004). Carbohydrate digestion is more closely related to feed concentration of acid detergent fiber (ADF) than NDF (Owens et al. 2010); notwithstanding, ADF was displaced by NDF digestibility when equations for relative forage quality were developed (Undersander, 2002).

Many different chemical analysis methods may be used to determine the content of specific nutrients, such as one of the vitamins or a given mineral element or for a group of nutrients. In evaluation of feed staffs, the proximate analysis or some modification of it is normally used. While this method has received much criticism from nutritionists, it is still utilized widely although often supplemented with additional analysis (Church, 1991).

The nutritional value of grass is variable, depending on species in sward, location, weather, time of the year, age and fertilizer application rates or timings. The crude protein can range from 4% to 15% in heavily fertilized pastures, with crude fiber content ranging from 20% to 45% in very mature samples. Later in the season, grazing may provide insufficient energy for high performing animals particularly dairy cows and careful supplementation is required (Ewing, 1997). In plants such as Alfalfa, rapid change takes place as the plant matures and blooms. Crude protein values given by NRC publications indicate the following concentrations (% on dry matter basis) for second cuttings: immature, 21.5; pre-bloom, 19.4; early bloom, 18.4; mid bloom, 17.1; full bloom, 15.9; and mature, 13.6. Corresponding change in Organic matter

Digestibility (OMD) ranges from 63% to 55% as the plant matures. Interestingly, Mullen (1999) reported the crude protein % (CP) of Lablab, cowpeas, soybean and Lucerne to be 18%, 18%, 15% and 18% respectively at maturity. Dry matter digestibility was recorded to range from 59% to 65% also at maturity.

The crude protein (CP) content of *Vigna unguiculata* ranged from 89 to 110 g/kg DM for stems and for the whole sample ranged was from 136 to 168 g/kg DM (Baloyi, Ngongoni, & Hamudikuwanda, 2008).

2.11 Characteristics of selected forage legumes as potential fodder crops

2.11.1 *Lablab purpureus*

Lablab purpureus belongs to the family of Fabaceae. It is mainly grown in east, central and west Africa as fodder crop. Lablab is a vigorous trailing, twining herbaceous plant. Stems are robust, upright trailing to 3-6 m in length. Leaves are trifoliate with broad ovate-rhomboid leaflets which are 7.5-15 cm long. Flowers are white in cv. Rongai or blue to purple in cv. Highworth on short pedicels. Pods are 4-5 cm long, broadly scimitar shaped, smooth and beaked by the persistent style; containing two to four seeds. Seeds in cv. Rongai are buff or pale brown colored, ovoid, laterally compressed, with a linear white conspicuous hilum. Seeds of Highworth are black with a linear white hilum. It is a dual-purpose legume, being traditionally grown as pulse crop for human consumption in south and Southeast Asia and Eastern Africa. Flowers and immature pods are used as vegetables. It is also used as fodder legume sown for grazing and conservation in broad-acre agricultural systems in tropical environments with a summer rainfall (Ewansila, Chiezey, Tarawali & Iwuuafor, 2007). It can also be

intercropped with cereals to provide better legume/stover feed quality. Leaves have crude protein (CP) content of 21-38%, much lower for stem (7-20%) and seeds contain 20-28% CP. Digestibility ranges from 55-75% (Murungweni et al.,2004). Crude protein reported by Karachi (1997) was 25% for leaves and 11.88% for stem. Evans (2002) reported a range between 12.7-14.1% for the whole plant. Aganga and Autlwetse (2000) reported a CP content of 16.4% for the whole plant. Dry matter yields of 2 tons/ha leaf or 4 tons/ha stem and leaf are common in sub-humid sub-tropics. Lablab matures from 60 to 150 days after planting (Ayisi, Bopane & Pengelly, 2004). Days to physiological maturity ranged from 90 to 197 after planting. Although some trials on Lablab use as a green manure have been done, there is paucity of information on this fodder crop in Namibia. The versatility of Lablab to different environments combined with its high nutritional value, makes it appealing to investigate its potential for fodder production in Namibia's livestock production systems, hence its inclusion in the trials in this study.

2.11.2 *Canavalia ensiformis*

Canavalia ensiformis (Jack bean) belongs to the family of Fabaceae. It is a twig, erect plant up to 1 meter in height. It has deep roots, which makes it drought resistant. Flowers are pink to purple in color. The pods are up to 36 cm long with large white seeds. The whole plant is used for fodder, although it cannot be used in fodder mixtures containing urea, since it contains large quantities of enzyme urease which liberates harmful ammonia from urea. The large white seeds or beans are popular as a coffee substitute in the northern parts of South Africa (van Wyk & Gericke, 2000). In

Namibia, this fodder has not been studied as fodder crop, but was rather studied as soil fertility improvement crop, hence its inclusion in this study.

2.11.3 *Cullen tomentosum*

Cullen tomentosum (Rooi dagga, wilde dagga, stink klawer – Afrikaans; Mojakubu – Tswana; stink clover, wild Lucerne – English; !honab – Nama) belongs to the family of Fabaceae. This is a perennial herb with silvery toothed leaves and small purple flowers. It is a psychotropic plant (plants with effects on mind). The leaves and stems are smoked in parts of the Kalahari as a tobacco and dagga substitute and have a sedative action. A tea is drunk for the relief of abdominal pain (van Wyk & Gericke, 2000). No information could be obtained on the forage production potential of this species, but it was selected for inclusion in this study based on preliminary proximate analyses and relative abundance in central Namibia.

2.11.4 *Otoptera burchellii*

Otoptera burchellii (Bees boontjie— Afrikaans) belongs to the family of Fabaceae. It is a perennial herb often trailing or climbing with hairy stems up to 2 m long. Sometimes it is a spindly small bush, up to 1 m tall. Branchlets are described as densely pubescent. Its leaves are trifoliate with leaflets lanceolate to ovate and up to 10 × 3.5 cm in size, blue-green, pointed at the apex with a long mucronate tip. Flowers are usually in 2-5 flowered axillary heads on a long deduncle, sweetly scent with variable colors; pink, mauve, blue, violet or red, usually green or yellow at the base. Pods are up to 12 × 0.8 cm in size (Mullen, 1990). No information could be obtained on the forage

production potential of this species, but it was selected for inclusion in this study based on preliminary proximate analyses and relative abundance in central Namibia.

2.11.5 *Vigna unguiculata*

Vigna unguiculata (cowpea) is of major importance to the livelihoods of millions of people in the tropics. In fresh form, the young leaves, immature pods are used as vegetables, while several snacks and main meal dishes are prepared from the grain. All the plant parts that are used for food are nutritious, providing protein, vitamins and minerals. Cowpea grain contains, on average, 23-25% protein and 50-67% starch. Baloyi et al. (2008) reported the crude protein (CP) content ranging from 89.2 to 209 g/kg DM with leaves containing almost double the amount that is in the stems. The CP content increased up to flowering and then declined with maturation. Cowpea fodder is as important as the grains particularly in dry areas where during the driest months of the year, cost of fodder per kg is as much as that of grains (Odeyanju, Ishiyaku, Echekwu & Olarewaju, 2012). This signifies the importance of cowpea as a fodder crop in drought prone areas. However, there is a need to develop a variety with both good grain and fodder productivity (Odeyanju et al., 2012).

Vigna species are important grain legumes in the tropical and subtropical regions where shortages of animal protein sources are experienced. They can be an excellent source of dietary protein in animal nutrition especially where proteins are in short supply and expensive (Gous et al., 2003). Therefore, there is a need to study this

legume to determine their potential as fodder crop in Namibia, since farmers may underestimate the nutritive feeding value of cowpea forage.

2.11.6 *Medicago sativa*

Lucerne or Alfalfa (*Medicago sativa*), often called the "Queen of Forages", is widely known and accepted as the world's most important forage crop as it is a high quality feed for all types of livestock (Thawana, 2008). Lucerne is a vigorous perennial legume with a well-developed taproot system (3 to 5 m) that enables it to obtain water and nutrients from a large volume of soil (Thawana, 2008). The plant is highly productive, yielding 8 to 10 hay cuttings per annum under optimum growing conditions. *Medicago sativa* stores carbohydrates (sugars and starches) in the crown and root. Carbohydrate reserves are used for regrowth both in the spring and also after each cutting. When Lucerne is 150-200 mm tall, it begins replacing carbohydrates in the root that have been used during the regrowth period. The cycle is repeated after each cutting. High levels of carbohydrate root reserves promote rapid regrowth and improve winter survival especially in cool areas (Theron & Snyman, 2015).Lucerne is arguably the most important legume in pasture systems in southern Africa, as it is a genetically diverse crop with higher production than many other forage crops across a range of climatic and edaphic conditions (Swanepoel, Sanderson, Bell, Thomas & Bennett, 2015).

According to Steyn (2015), the successful cultivation of Lucerne can to a large extent be ascribed to the efficient root system of the plant and its symbiosis with nitrogen-fixing rhizobium bacteria, which reduces the plant's dependency on soil

nitrogen. The strongly developed taproot makes it possible to access water reserves as deep as 6m below the surface, which makes it extremely tolerant to drought (Steyn, 2015).However, being deep rooted, it dries soil to depth, rendering soil water replenishment following a Lucerne cultivation phase slow. Lucerne is also prone to disease in both very wet and very dry conditions (Lloyd, Johnson & O'brien, 2007).

Lucerne is widely recognized as one of the first plants to have been cultivated specifically as animal feed. Its effectiveness as an animal feed depends largely on the quality of the hay. A rich source of protein and energy, Lucerne hay is particularly important for lactating dairy cows (Steyn, 2015).However, it can cause bloat in cattle and good management in its feeding is essential (Lloyd et al., 2007). Lucerne is one of the most widely used forage crops in Namibia and it is grown in many parts of the country especially in the maize triangle and near Hardap dam near Mariental. The essence of including it in the study was to use it as a yard stick for other forage legumes.

2.12 Silage as a form of animal fodder preservation

Silage is one of the most inexpensive and versatile sources of roughage fed to animals. It supplies more nutrients and yields higher animal production per hectare than other methods of forage storage, and can be fed to various types of livestock for the maintenance of weight or for sustainable production (Lauer& Sterry, 2013).

Forage which has been grown while still green and nutritious can be conserved through a natural 'pickling' process (FAO, 2011). Lactic acid is produced when the sugars in the

forage plants are fermented by bacteria in a sealed container (‘silo’) with no air (Moran 2005). Forage conserved this way is known as ‘ensiled forage’ or ‘silage’ and will keep for up to three years without deteriorating (FAO, 2011). Silage is very palatable to livestock and can be fed at any time.

In Sub-Saharan Africa the greatest constraint to ruminant performance is the low nutritive value of most animal feeds during the dry season (Gachuiri et al., 2004). To address this problem, fodder available during the wet season can be preserved by turning it into silage. However, a proper ensiling mechanism that includes controlled fermentation, which converts perishable wet forage plants to a stable, stored feed energy source, should be followed. Good ensiling management is required for high silage quality and dry matter (DM) recovery. To guide silage management practices, it is important to understand the biological and chemical processes that occur during ensiling, their effects on silage quality, and how these processes can be controlled (Muck & Pitt, 1993). In essence, the two essential requirements for making good silage are to rapidly reduce the pH and to exclude any oxygen. For the best preservation level, silage must have a pH of 3.5 to 4.0 (Lauer& Sterry, 2013). Silage should have a light, pleasant smell with slight undertones of acid and a light-brown to dark-green color. If it is dark-brown or has definite fruity, yeast or burned smell, the heat was too much and excessive fermentation has taken place. This affects the quality of the silage (Lauer& Sterry, 2013). When producing silage, bacteria convert sugars in the forage to lactic acid which in turn reduces the pH in the silage. The more acidic conditions prevent the spoilage organisms from growing and preserve the feed (Bax, 2015).

The greatest threat to silage after the pit has been opened, is coming into contact with air. According to Lauer and Sterry (2013), it is important to ensure that the pit is sealed correctly so that the minimum amount of air comes into contact with the silage after opening. Once air has penetrated the silage, chances are that fungi and yeast will grow in the silage.

While grasses are normally ensiled relatively well or satisfactorily, ensiling of legumes is more risky (Kaldmae, Vad, Kirsel & Olt, 2003). This is due to their low sugar content, high buffering ability and high humidity content (Pahlow, Rammer, Slottner & Tuori, 2002). This is in agreement with Bax (2015) who highlighted that leguminous crops such as alfalfa, clovers and soya have a high buffering capacity, meaning the pH will drop more slowly. This is largely a consequence of the higher protein content.

Freshly cut Lucerne will normally have a dry matter content of 15-20%. It is essential to wilt plants before harvesting so that run-off is reduced and desirable fermentation can be achieved. For precision cut Lucerne silage harvest dry matter content should be 32-35%. For baled silage the dry matter content can be slightly higher (35-50%). The wilt time will depend on the wind, humidity, heat and sun but is normally between 12 and 24 hours (Pioneer, 2010).

By contrast, maize, which has a lower buffering capacity, ferments very readily and has a rapid pH drop. However, the nutritive value and digestibility of legume silages depends on the species, variety and stage of development of plants. According to Bax (2015), the management of the growing crop will also affect the

outcome. The crop has to be cut during the optimum growth stage to achieve a high feeding value. For example, cutting small grain cereals or maize too early, the crop will not only have lower starch content, but will also have lower dry matter and poorer rumen fermentation characteristics. The best digestibility of 71% at the stage of bud formation, and 64% at the stage of early flowering was observed in silage, prepared from the early-maturing red clover (*Trifolium pratence* L. subvar. *praecox* Witte) variety 'Jogeva 433' (Kaldmae et al., 2003). In dry years silage production can pose additional challenges. If plant matter is drier than usual (above 38% DM), compaction often becomes a problem. There is no other alternative but to compact it for a longer period (Venter, 2015). Wetting the silage during compaction can also aid in the process. According to Venter (2015), silage is the ideal storage crop and can be kept without significant losses for years.

Across silage types, animals consume lower quantities of grass silages. Legume silages generally lead to higher intakes than grass silages of comparable digestibility. A study by Huhtanen, Rinne and Nousainen (2007) showed curvilinear effects with increasing intake as legume silages replaced grass silage up to 80 %inclusion. Curvilinear effects were also observed in a comparison of grass silages with mixtures of legumes and cereal silages; with higher intakes in legume and cereal silages despite the lower digestibility (Cheng, Kim, Merry, and Dewhurst, 2011).

2.13 Pasture improvement through over-sowing of natural pastures with legumes

The main reason for planting legumes in the pasture is because of their ability to convert atmospheric nitrogen (N) for own use, as well as for adjacent plants, all in symbiosis with rhizobium. The amount of nitrogen formed, and the rate of nodulation, can vary greatly among different legumes. According to Agricol (2015), legume pastures can be a major asset. Many legumes, especially those adapted to dry areas have very good root systems, to access not only nutrients, but also to water (Sprent, Odee & Dakora, 2009). Successful incorporation of grass–legume pastures will further enhance soil quality as the diverse rooting systems will contribute to soil microbial diversity (Swanepoel, Botha, Truter& Surridge-Talbot, 2011).

Legumes can produce up to 350 kg nitrogen per hectare, provided that all contributing factors are optimal. Legumes can easily be established together with other forage crops. The correct choice of legume is important when considering this option. The choice of legume is also influenced by the growth rate of other crops, which will ensure that the total mixture is ready for grazing at the same stage (Swanepoel et al., 2.11).

Natural pastures can be improved through employing a combination of approaches involving over-sowing of natural pastures with improved species, particularly legumes (Swanepoel, Botha, du Preez, Snyman & Labuschagne, 2015). It is a more realistic approach in that over-sowing techniques improve the natural pastures development. Therefore, reseeding rangelands with indigenous legumes is expected to

improve nutrition of ruminants because of their ability to fix atmospheric nitrogen into soils, hence increasing herbage yield, crude protein and digestibility (Richardson and Smith, 2006).

According to Bayer and Waters-Bayer (1998), forage legumes can also improve the quality of standing hay during the dry season, provided they are able to survive in the standing hay at that time needed. Indeed Akundabweni (1981) in studying the restoration of deteriorated rangelands west of the Mississippi river in South Dakota with sod-seeded or inter-seeded alfalfa, encountered dramatic stand failures of the legume at mid phase growth stage. Limited experience in Swaziland has shown that desired species could be successfully introduced into the natural pastures with minimum operations such as hard grazing, burning, use of herbicides and minimum cultivation (Ogwang, 1985).

Richardson and Smith (2006) maintain that grass-legume pastures may double or triple the live weight gain of steers per hectare; but this can only be sustained through maintenance of the composition through application of phosphate fertilizers at the beginning of the rain season and ensuring appropriate stocking rates. Legume dominant stands show better response to phosphorus application because they obtain their nitrogen requirements via symbiotic pathways (Miller and Reetz, 1995). An increase in hay production from 2.95 tons per hectare to 5.5 tons per hectare and an increase in legume ratio in botanical composition from 49.8% to 80.3% were recorded in legume dominant pasture following 100kg P_2O_5 per hectare application (Miller and Reetz, 1995). The quantity of such P is in agreement with Akundabweni (1984) in the

Ethiopian highlands on the African clover species. On the contrary, Boitumelo and Mahabile (1991) observed that application of superphosphate fertilizer did not show any significant effect (P > 0.05) on Lablab dry matter yield.

2.14 Response of forage legumes to phosphorus application

Phosphorus (P) is one of the most important elements that significantly affect plant growth and metabolism (Abed, Ticconi & Delatorre, 2002). Specifically on forage legumes, Haque, Nnadi and Mohames-Salee (1997) and Akundabweni (1984) pointed out that phosphorus was the most important nutrient in the successful establishment of forage legumes particularly on African clovers on vertisol soils in the Ethiopian highlands. The effect of soil type and phosphorus (P) supply on dry matter production of three African clovers grown on P-deficient vertisol soil in the Ethiopian highlands was studied by Haque, Nnadi andMohamed-Saleem (1986) where the results showed that applying 15 kg P/ha as EPR increased dry matter yield more than six-fold compared with the unfertilized control. In the same study, the clover grew very poorly when no P was applied and reacted similarly to both triple superphosphate (TPS) and EPR at 15, 30, and 45 kg P/ha.

In addition to its effects on dry matter yields of legumes, phosphorus (P) often increases nodulation and hence increases N or crude protein content, P concentration or uptake by the plant (Haque et al., 1986). Phosphorus application may also increase the digestibility of dry matter. Acute deficiency of Phosphorus (P) can prevent nodulation by legumes (Zamah-Allah, Sifi, Taref, El Aouni & Drevon, 2006).Again, phosphorus deficiency appears to be the most limiting nutrient to legume biomass productivity and

N2-fixation leading to low yield of subsequent cereal crops (Giller, 2001). Therefore, phosphate fertilizer application is necessary to support the luxurious growth of green manures. For example, application of 8 kg P/ha + 4kg S/ha was shown to improve the biomass of *Mucuna pruriens*, *Cajanus cajan* and *Tephrosia vogelii* in Malawi (Malwanda et al., 2002). In the indigenous legume fallow system, it was suggested that even low P levels application might be adequate to support indigenous legume species establishment and growth (Tauro, 2009).

Phosphorus movement in soil is very limited, hence it is recommended to apply and incorporate fertilizer prior to pasture establishment. When a phosphate fertilizer is applied to a soil, the phosphorus is quickly immobilized in the soil profile. It typically moves only about an inch (Whiting, Wilson & Reeder, 2013). Therefore, it needs to be tilled into the rooting zone to be more effective. In contrast, surface broadcast applications are also effective and should be made in the fall or early spring (Koenig, Beaver, Barnhill& Miner, 2002). According to Giller (2003) an initial application of 20-30 kg P/ha is critical in biomass productivity in most soils. Application of plant residues or manure will provide some P but mineral P fertilizers are the most effective. However, legumes differ in their ability to utilize available forms of P in the soil and large differences exist between plant species and cultivars within species (Tauro, 2009).

2.15 SPAD – 502 as a measure of chlorophyll content

SPAD (Soil Plant Analysis Development) meter is designed to help users in improving crop quality and increase crop yield by providing an indication of the amount of chlorophyll present in plant leaves (Scharf, Brouder & Hoeft, 2006). The chlorophyll content of the plant leaves is related to the condition of the plant, and thus can be used to determine when additional fertilizer is necessary. By optimizing nutrient conditions, healthier plants can be grown, resulting in a larger crop yield of higher quality.

The SPAD – 502 determines the relative amount of chlorophyll present by measuring the absorbance of the leaf in two wavelength regions. The chlorophyll present in the plant leaves is closely related to the nutritional condition of the plant (Loh, Grabosky & Bassuk, 2002). The chlorophyll content will increase in proportion to the amount of nitrogen present in the leaf. For a particular plant species, a higher SPAD value indicates a healthier plant. Nitrogen (N) management is very important issue for plant growers and for environment. For growers, knowing the N requirement of plant enables the proper amount of N fertilizer supply to be managed. Some experiments show that the SPAD series contributed to reductions in the use of N fertilizer with no loss in yield. By optimizing the N fertilizer efficiency in the field, proper N fertilizer management reduces the possibility of excessive supply of fertilizer which can cause diseases in plants and environmental contaminations.

Loh et al. (2002) reported a linear correlation of leaf N concentrations with their corresponding SPAD-502 meter readings. A curvilinear relationship between total

chlorophyll content and SPAD units was reported by Coste, Daraloto, Leroy, Marcon, Renaud, Richardson, …Herault (2010). While linear and exponential relationships between SPAD values and chlorophyll concentrations have previously been proposed, a much stronger fit using second-order polynomial functions for linear and exponential relationships were recently observed (Coste et al., 2010; Uddling, Gelang-Alfredsson, Piikki & Pleijel, 2007; Ling, Huang and Jarvis, 2011). Percival, Keary & Noviss, (2008) indicated a SPAD value less than 22 as a level when N fertilization should start in three tree species (*Acer pseudoplatanus*, *Quercus robur* and *Fagus sylvatica*) to prevent N-related deficiency problems. In the case of rice crops, a SPAD threshold value of 35 is generally recognized as a critical value (Peng, Garcia, Laza, Sanico, Visperas & Cassman, 1996). Whenever SPAD readings fall below the critical value of 35, the rice crop suffers from N deficiency, and yields will decline if N fertilizer is not applied (Peng et al., 1996). Studies have shown that the higher the SPAD units, the higher the chlorophyll content. Markwell, Osterman and Mitchell (1995) concluded that the SPAD-502 meter is able to provide a rapid and reasonably accurate estimate of leaf chlorophyll and they further suggested that the meter is also a valuable nondestructive tool with which to facilitate studies on photosynthesis and crop physiology.

2.16 Forage legume studies done in other countries

Most research has concentrated on legumes as soil improving crop rather than animal feed. For example, *Canavalia ensiformis*, *Crotalaria grahamiana*, L*ablab purpureus*, *Mucuna pruriens*, *Tephrosia vogellii* and *Tithonia diversifolia* were cultivated as potential species for soil fertility replenishment in on-farm adaptive trials

in Uganda (Nyende & Delve, 2004).Studies have shown that range reinforcement with improved fodder species is a common way to increase carrying capacity of the natural pasture. In Botswana, the major constraints to exploiting potential legume species include inadequate water, soil degradation, low soil nutrients concentrations and high soil temperatures (Pule-Meuelenberg & Dakora, 2007). Research work in Costa Rica indicated that the perennial legume *Arachis pinto* improved soil conservation and animal production as well as profitability (Argel, 1994). This was due to characteristics such as: incorporation of nitrogen as well as organic matter into the soil; growth habits that resulted in dense stolon layers; deposition of seeds in the soil and intense seedling recruitment from those seed banks; high quality animal feed; a degree of drought tolerance due to deep-reaching roots; and flood tolerance. *Arachis pintoi*can be mixed with grasses or used in legume-only pasture (protein banks). When *Arachis pintoi* was mixed, it supported grass growth by providing nitrogen (Wunscher, Schultze-Kraft, Peters & Rivas, 2004).

Muir et al. (2014) highlighted that successful adoption of tropical and subtropical forage legumes by farmers has occurred in some specific regions of the world. For example, *Stylosanthes* species are now the most widely known tropical and subtropical herbaceous legume throughout the world. Focused supplementation of confined cattle for milk or finishing using annual legumes has occurred (Chigariro, 2004). Using Lablab and Mucuna, farmers have reduced their dependence on commercial feeds for pen-fattening by about 25% (Chigariro, 2004).

In South Africa, *Trifolium vesiculosum* (Arrow leaf clover) has been studied and used as green spring grazing at Umpukane for the past 22 years (Gwatyu & Jooste, 2011). It is an annual forage legume that sprouts on its own and seeds easily. Large and small stock do equally well on the crop, since the protein content compares well to that of Lucerne (18% CP). In the test conducted at Umpukane, a biomass yield of 50 tons/ha per year was recorded (Van Rooyen, 2011). In its green form, arrow leaf clover can be grazed, cut and fed in mangers or mixed with dry material in feed mixers (Gwatyu & Jooste, 2011).

2.17 Biomass yield of forage legumes

Species growth habits can influence the biomass contribution in a system despite the soil being fertile. Ayisi et al. (2004) in Limpopo Province, South Africa recorded biomass yields between 1000 kg/ha to7000 kg/ha of Diverse Lablab (*Lablab purpureus*) germplasm while Clem and Cook (2004) recorded dry matter yield of over 4000 kg/ha for *Lablab purpureus* cv. Rongai. In Zimbabwe, Dry-matter yields greater than 1500 kg/ha was recorded for *Vigna unguiculata* CPI 121688(Nyoka, Chikumba, Chakoma, Mazaiwana, Mukombe, & Magwenz, 2004).Moreover, Anikwe and Atuma (2003) indicated that *Lablab purpureus* and *Mucuna pruriens* produced the highest ($P < 0.05$) above ground biomass compared to *Pueraria phaseoloides*, *Cajanus cajan* and *Vigna subterranea*. For *Vigna unguiculata*, fodder yields of 0.5 t/ha (air dry haulms) are commonly obtained in northern Nigeria. Yields as high as 2-4 t/ha can also be obtained (Singh et al., 1997).For *Medicago sativa*, a standard yield of 9 tons dry matter in year 1 and 15 tons dry matter in year 2 is obtainable (Pioneer, 2010).In New South Wales state

in Australia (Mullen, 1999) under dry land conditions, yields of cowpeas have ranged from 500 kg dry matter (DM)/ha to over 4000 kg dry matter (DM)/ha under favorable conditions. Yields of up to 8000 kg DM/ha have been recorded in irrigated areas. *Lablab* has also produced from around 500 kg DM/ha to over 5000 kg DM/ha, with irrigated areas recording yields of up to14 000 kg DM/ha. Soybeans have yielded up to 10 000 kg DM/ha in irrigated areas.

In Botswana, Boitumelo and Mahabile (1992) recorded the average dry matter (DM) yield (t/ha) of *Lablab* by farmers and on the research plots in 1985/86 and 1986/87to be 1.38 and 1.54 respectively. It is further stated that fertilizer application had no effect ($P > 0.05$) on average dry matter yields on farmers' plots or on research plots, and there were no significant differences ($P > 0.05$) in dry matter yield between farmers' fields and the research plots. Apparently, low dry matter yields and lack of fertilizer response could be due to lower than average rainfall that was received in both seasons (Boitumelo & Mahabile, 1992).

2.18 Constraints associated with the establishment of forage legumes

A limitation to commercializing forage legumes is the seed availability. Much time and efforts have been invested in domesticating new species that are productive and nutritious but whose seed yields or harvestability make them difficult to commercialize (Muir et al., 2014). Based on Diggs, Lipscomb & O'Kennon (1991), seed production may be indeterminate that could be a common survival and dissemination strategy for specific species or mature pods shutter so quickly and violently that harvestable yields at any given time are uneconomical. Notwithstanding,

many forage legumes have been established in one or more countries of sub-Saharan Africa but relatively few have been widely adopted or have made sustained impact on animal productivity. The reasons for this lack of success are difficult to discern but appear to be related to climatic limitations, an indifferent acceptability by the animal and the problem of introducing a new crop to small farmers without the assurance of its success within a minimum alteration to their farming system (Anikwe& Atuma, 2003).

Again, Phosphorus (P) deficiency is often a major factor limiting biomass production and N2-fixation of legumes in both cropping and natural systems (Giller & Mapfumo, 2002). A successful establishment of legumes is determined by adaptation, biomass productivity, amount of N-fixed, weed suppression and persistence in a given environment (Kamanga and Shamudzarira, 2001). The understanding of the emergence and growth habits of indigenous legumes would improve the knowledge base, for easy management and adoption in the resource-constrained farming system (Tauro, Nezomba, Mtambanengwe& Mapfumo, 2007).

In Namibia, the principal constraints to successful pasture and fodder production, and to attempts at research are as follows: Low rainfall and poor soils throughout most of the country are the main constraints to the productivity of natural pastures and to the establishment of exotic pasture species (Sweet &Burke, 2000). The availability and price of seeds for pasture/fodder improvement are major constraints to communal area farmers. The open access to rangeland grazing, at least within communities, in the communal areas necessitates broad collective agreement and cooperation in any pasture improvement venture (FAO, 2005). Conventionally,

communal area farmers do not retain exclusive use of their unfenced croplands after harvest for their own livestock, so limiting the opportunities and incentives for under sowing or alley cropping (Sweet &Burke, 2000).

2.19 Propagation of forage legumes

Propagation by seed is the main method by which plants reproduce in nature. It is also very efficient and widely used in tree or shrub propagation (Venter & Venter, 1996). Problems are often encountered with hard seeds that do not imbibe water readily and thus germinate irregularly (Franklin, 1993).

Not much work has been done on cuttings as a means of propagation of indigenous forage legumes or trees. This is unfortunate as this method enables one to commence with a plant of reasonable size and it is much quicker than with seed (Venter & Venter, 1996). Many indigenous species can be propagated by means of cutting but the method has not yet been properly tested. An advantage of rooted cuttings is that it they produce fairly uniform plants. Cuttings taken from spring to early summer usually produce the best results. The site at which the cutting is taken will determine the growth habit of the cutting. For example, *Podocarpus falcatus* cuttings taken from lateral branches and shoots produce plants with a lateral growth habit rather than an upright one (Venter & Venter, 1996). The best time of day to take cuttings is in the early morning when transpiration is at its lowest and the cuttings have the least chance of dying out.

2.20 Scarification of legume seeds

Scarification has long been used in the horticulture industry to increase the germination rate of seeds by physically or chemically altering the seed coat (Pandrangi, Elwell, Anantheswaran & Laborde, 2003). The effect is attributed to increased diffusion of water and gases into the seed. Seed dormancy is the most limiting factor for plant propagation. Thus, the blocking of water access into the seed is the most common cause of delay in seed germination. Some seeds suffer from dormancy owing to the presence of water impermeable thick seed coat that prevents water and oxygen from reaching and activating the embryo, or because of the presence of germination-inhibitor chemical compounds that require specific treatments for breaking dormancy (Soliman & Abbas, 2013).

External dormancy is determined by the outer layer of the seed (endocarp); it restricts the uptake of water and oxygen and mechanically prevents the embryo from swelling (Ramamoorthy, Rajendran & Sivasubramarian, 2005). In nature, seed dormancy ensures that the seed germinates only under favorable environmental conditions. This ensures the survival of the seedling and the continuous existence of the given plant species. This dormancy is broken if the seed coat is removed or scarified, while internal dormancy is regulated by biochemical or biophysical processes that occur during and after-ripening at0–5◦C(Taylor, 2005). Mechanical scarification is accomplished by physically nicking, filing, grinding away the seed coat or cracking the outer case physically and removes the vulnerable, soft seed. Chemical scarification commonly involves exposing seeds to a concentrated sulfuric acid solution until a

sufficient amount of seed coat material is removed (Hartman & Kester, 1997).Care must be taken to determine optimal acid concentration and treatment times necessary to increase seed permeability while avoiding damage to underlying tissue. Following chemical scarification, seeds are rinsed thoroughly with water to remove residual acid. The hard, impermeable seed coat of certain tree and shrub species can be broken down by immersing the seed in boiling water and allowing it to soak overnight.

CHAPTER 3

METHODOLOGY

3.1 Research design

The study employed two types of experimental designs: In experiment A1, a split-plot design was used with the main factor A being fertilizer level (which could be conveniently applied to the whole plots by broadcasting) and factor B legume species (which was randomized to the subplots) to study the growth characteristics and biomass yield of forage legumes. The plots where the experiment was done were homogeneous.

In experiment A2, a Completely Randomized Design (CRD) with two (2) replications was used to determine the proximate parameters of forage legumes harvested at two growth stages (early vegetative and post-bloom).

In experiment A3, a Completely Randomized Design (CRD) with three (3) replications was used to study the ensiling characteristics of forage legumes.

3.2 Study site

The study was conducted at Neudamm Campus (30 km east of Windhoek) in the Highland savanna of Namibia (Figure 3.2). Neudamm Campus lies between 22° and 23.30^{o}S and 15.30^{o} and 18.30^{o}E. The vegetation type in this area is classified as highland savanna (semi-arid savanna) (Figure 3.2). The long term average annual rainfall around Neudamm or in Highland savanna of Khomas Hochland ranges from 350-400 mm, with much of the rain experienced during summer season (January-April) (Mendelsohn et al, 2002). The vegetation is dominated by homogenous Lithic Leptosols

and Eutric Regosols soil types. The amount of rainfall received was only 229.50 mm in 2014/15 rainy season compared to 544.00 mm recorded in 2013/14 rainy season (Figure3.1).

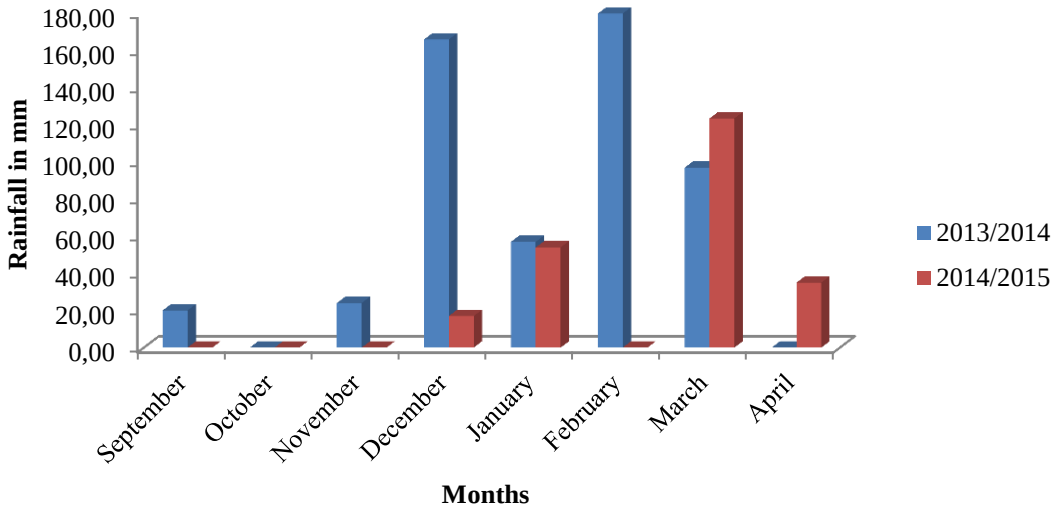


Figure 3.1: Neudamm Campus rainfall figures for 2013/2014 and 2014/2015 rainy season

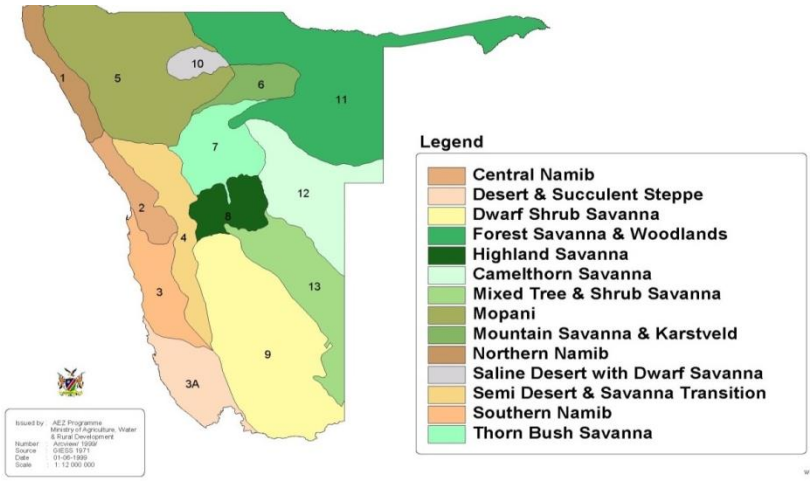


Figure 3.2: Vegetation types of Namibia depicting the Highland Savanna (8) (MAWF, 2003)

3.3 Population

The population of this study encompassed all indigenous forage legume species and improved legumes in the central, north-western and eastern parts of the Republic of Namibia.

3.4 Sample

Initially fifteen (15) indigenous forage legumes (*Otoptera burchellii*, *Ptycholobium biflorum*, *Crotalaria argyraea*, *Crotalaria heidmannii*, *Crotalaria dinteri*, *Crotalaria podocarpa*, *Indigofera alternans*, *Meulobium candicans*, *Leobordea platycarpa*, *Rhynchosia totta*, *Rhynchosia holoserica***,** *Medicago laciniata*, *Lablab purpureus* (wild type), *Cullen tomentosum*, and *Vigna lobatifolia*) were screened from a companion study based on information such as indigenous knowledge, physical characteristics (waxiness, degree of leafiness, hairiness, potential biomass production, palatability and presence of thorns) and laboratory analyses for crude protein and other nutrients. Seed availability together with the above attributes led to a reduction in the number of indigenous legumes studied further to four (*Cullen tomentosum*, *Otoptera burchellii*, *Crotalaria argyraea* and *Vigna lobatifolia*) (Appendix 2).The improved legumes (*Lablab purpureus*, V*igna unguiculata*, *Medicago sativa* and *Canavalia ensiformis*) (Appendix 2),were selected based on current usage and availability of seed.

3.5 Research instruments

This study used a number of instruments to collect data. These included informal interviews, scouting and collection of indigenous forage legumes and improved legumes planting materials such as seeds, cuttings and seedlings in the wild. Structured field experiments and laboratory analyzes were also carried out in the study.

3.6 Research procedures

3.6.1 Farmer mobilization and participation

Farmers were interviewed to gain indigenous knowledge on indigenous forage legumes' palatability to livestock (Figure 3.3). They were also involved in obtaining samples of seeds, inflorescence, leaves and complete plants which were taken to the National Botanical Research Institute (NBRI) for identification and accessions determination. It was also envisaged that they would play an important role in the promotion of promising forage legumes at the end of the study.

Figure 3.3: Farmers' meeting at Neudamm Campus

3.6.2 Legume collection and identification

Forage legumes were obtained from the semi-arid (central and north-central) agro-ecological zones of Namibia. Seeds and other planting materials (cuttings, plantlets, stolons) of indigenous forage legumes (*Otoptera burchellii*, *Crotalaria argyraea*, *Cullen tomentosum*, and *Vigna lobatifolia*) were collected from the wild with the assistance of farmers and University of Namibia undergraduate students during the 2013/2014 rain season. They were grown in the nursery for further establishment. When they were vigorous enough, they were transplanted into trial plots. Improved legumes (*Lablab purpureus*, V*igna unguiculata*, and *Canavalia ensiformis*) were planted by seed, which were obtained from Mannheim Research Station of the Ministry of Agriculture, Water and Forestry (MAWF) in Tsumeb district. *Medicago sativa* seeds were procured in Windhoek from commercial suppliers. Improved legumes were included in the trials to compare their performance in terms of growth and biomass yield with indigenous forage legumes.

3.6.3 Experiment A1: Agronomic trials to study the growth, phosphorus requirements and biomass yield of forage legumes [Objectives (i)-(iii)]

The growth rate and biomass yield of four (4) indigenous legumes (*Otoptera burchellii*, *Vigna lobatifolia*, *Crotalaria argyraea* and *Cullen tomentosum*) *and* four (4) improved legumes (*Lablab purpureus*, *Medicago sativa*, *Canavalia ensiformis* and *Vigna unguiculata*) were investigated. A split-plot design was used with fertilizer level as the main factor and forage legume species as the secondary factor. Single super phosphate (SSP – 83 g/kg) was applied at four (4) levels (0, 60, 80 and 100 kg P/ha) to

each of eight (8) legumes, each with three (3) replications, giving a total of 96 plots. All factors were randomized to the main plots and subplots. Based on the type of fertilizer that was used (P %), the following formula was used to calculate the fertilizer application rate (Equation 1).

$$Fertilizer\ application\ rate(kg/ha) = (Nutrient\ application\ rate\ (kg/ha)/ (\%\ of\ nutrient\ in\ the\ fertilizer) \times 100 \qquad \text{(Eq. 1)}$$

Where:

$Fertilizer\ application\ rate(kg/ha =$ Amount of fertilizer to be applied per ha

Nutrient application rate (kg/ha) = Amount of nutrient, e.g. P required per ha

% of nutrient in the fertilizer = % of nutrient in the bag (usually depicted on the bag or packet) in this case 8.3 % P.

Therefore, the amount of fertilizer applied was as follows: 0 kg P/ha = 0 kg SSP; 60 kg P/ha =723 kg SSP/ha (i.e. at a nutrient application rate of 60 kg P/ha using SSP containing 83 g P/kg [8.3% P], the fertilizer application rate equals 723 kg SSP/ha); 80 kg P/ha =963 kg SSP/ha; and 100 kg P/ha = 1205 kg SSP/ha.

Single superphosphate (SSP – 83g P/kg) was applied by broadcasting and a portion (20 g) was applied to the planting station a day prior to either planting (using seed) or transplanting (using cuttings). The subplot size was 12 m^2 (4 m × 3 m = 12 m^2), with 1m between subplot rows and0.5m between subplot columns. Spacing between plants was 1m, with 1m from the border. Within subplots, the spacing was 1m inter-rows and 1m in rows, giving six (6) plants per subplot for all forage legumes, except *Medicago sativa* that was planted thinly in rows.

Plantlets and cuttings of *Otoptera burchellii*, *Cullen tomentosum* and plantlets of *Vigna lobatifolia* were collected from the wild in the Neudamm farm and other surrounding farms during the 2013/2014 rain season (February – March) and transplanted into planting pots in the nursery until they commenced active growth. They were kept in the nursery for a period ranging from three (3) to four (4) weeks. These seedlings were then transplanted in the trial plots on the 7th March 2014, with the filling up of plots completed in three (3) weeks' time. Forage legumes such as *Vigna unguiculata*, *Lablab purpureus*, *Canavalia ensiformis*, *Rhynchosia holoserica* and *Crotalaria argyraea* were propagated by seed on the 7th March 2014. Kraal manure was applied in each planting/transplanting station at the rate of 100g per station. This was done to give plants a boost, since the soil was almost sandy and lacked organic matter. Table 3.1 shows the days taken to seedling emergence for five of the legumes. Indigenous forage legumes such as *Vigna lobatifolia*, *Cullen tomentosum* and *Otoptera burchellii* do not appear in the table because they were propagated through cuttings and or plantlets.

Table 3.1: Emergence dates and number of days to 50 % emergence of forage legumes propagated by seed

Forage species	**Emergence date (50%)**	**Days to 50% emergence**
Medicago sativa	12/03/2014	5
Vigna unguiculata	15/03/2014	8
Lablab purpureus	16/03/2014	9
Canavalia ensiformis	16/03/2014	9
Crotalaria argyraea	29/03/2014	22

The trial was rain fed but supplementary irrigation was given to facilitate successful establishment and when severe moisture stress was experienced. Weeding was done by hand with hand hoe when weeds were noticeable. Four (4) weeding were carried out during the entire growing season. Minimum mulch was placed around plants to conserve moisture and also to act as weed control measure. The emergence and seedling establishment percentages as well as plant heights or lengths were recorded for a period of two (2) months (April – May 2014).

The growth rate (cm/day) of the legumes was monitored early in the growing season with height or length (cm) being recorded, depending on the growth characteristic of the legume. Vegetative materials (leaves, twigs and stems) were collected at monthly intervals during the growing season and were air-dried in a laboratory to 92 – 94 % dry matter for two weeks at room temperature before the dry weight was measured to determine the biomass yield (tons/ha).

Forage legumes were damaged by frost on the 21st and 22nd May 2014. With the exception of *Medicago sativa* and *Cullen tomentosum*, all other forage legumes were damaged (Figure 3.4).

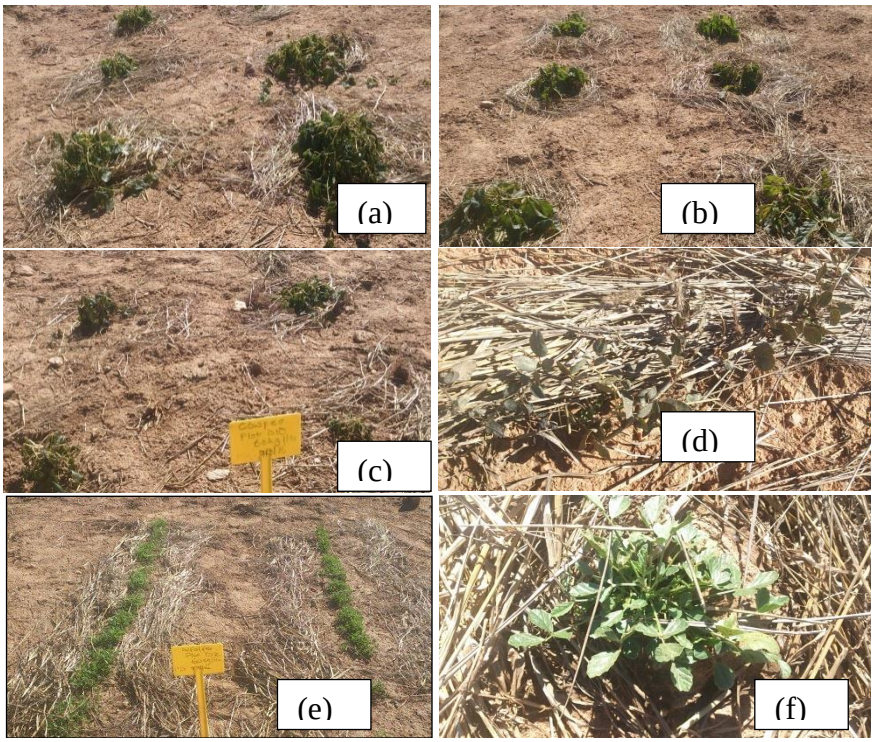


Figure 3.4: Forage legumes damaged by frost - (a) *Lablab purpureus*, (b) *Canavalia ensiformis*, (c) *Vigna unguiculata*, (d) *Otoptera burchellii*, (e) *Medicago sativa* and (f) *Cullen tomentosum*

As a result of this frost damage, the experiment was repeated during the 2014/2015 rain season. *Vigna unguiculata*, *Canavalia ensiformis*, *Medicago sativa*, *Lablab purpureus*, *Crotalaria argyraea* and *Rhynchosia holoserica* were planted by seed on the 7th – 10th October 2014 while *Otoptera burchellii*, *Cullen tomentosum* and *Vigna lobatifolia* sprouted from previous plants that were transplanted in March 2014.

3.6.3.1 Measurements of forage legume characteristics (growth rate, biomass yield and seed weight) for trial A1

Growth characteristics of forage legume species were monitored and recorded from planting (7th -10th October 2014 for legumes propagated by seed or from re-sprouts for *O. burchellii*, *C. tomentosum* and *V. lobatifolia*) until May 2015 just before they were affected by frost. Data collected were days to seedling emergence, sprouting date, plant heights for erect species or length for prostrate species, days to 50% flowering (counted from planting until the plot/species attained 50% flowering), 100 seed weight, biomass yield and proximate parameters.

Biomass yield was determined by cutting one randomly selected plant with a pruning shear from each plot at 30 cm height, where its canopy or the area it covered was measured. The fresh weights were recorded and then air-dried at room temperature in a laboratory for two (2) weeks until completely dry (92-94 % DM) and the biomass yield (tons dry weight per hectare) was determined for each plot. For *Medicago sativa*, the entire line in the plot was cut at the height of 15 cm above the ground to avoid crown damage and to allow rapid re-growth from the stem shoots. Three cuttings (Feb, April and May) timed through inspection of plots to gauge when there was sufficient growth (re-growth) were made in 2015 for all legumes.

Plant heights or length depending on the growth characteristic of a given forage legume species were recorded three (3) times in the growing season, i.e., from December 2014 to January 2015, where all plants in a plot were measured. For forage species that grow erect, the highest point was recorded while for prostrate forage

species the longest runner was measured (Figure 3.5). Because of the different growth characteristics of studied forage legumes, the growth rate might not be a suitable variable to compare these forage legumes.

Figure 3.5: Recording height and length of forage legumes A and B

SPAD values of leaves of the forage legumes were taken using the Minolta SPAD -502 meter. Three plants were randomly sampled and measured per plot, with three readings taken from each plant and the average reading recorded. Readings were taken three times during the entire growing season. It is well documented that there is a relationship between SPAD meter values and the chlorophyll content of the plant. Therefore, SPAD values were taken to determine whether there is a relationship between them and the growth rate and also the biomass yield of forage legumes.

To determine seed weight, pods were threshed by hand and 100 seeds per forage legume species in each fertilizer level (0, 60, 80, 100 kg P/ha) were weighed; two (2) separate replications of seed weights were obtained.

3.6.4 Experiment A2: Determination of the nutritional values of forage legumes [Objective (iv)]

Forage legume samples were obtained in February, April and May 2015 (roughly corresponding to early vegetative, flowering and pod maturation stages) from randomly selected plots in experiment A1 to determine proximate parameters. The forage samples were air-dried in the laboratory for about two (2) weeks.

Forage legume samples were ground in a hammer mill to 1 mm particle sizes and sent to the Ministry of Agriculture, Water and Forestry (MAWF) laboratory for proximate analysis as per guidelines in Association of Official Analytical Chemists (AOAC, 1995). Samples were analyzed for moisture, crude protein (CP), crude fiber (CF), phosphorus (P), calcium (Ca), acid detergent fiber (ADF), neutral detergent fiber (NDF), fat and ash in duplicates.

3.6.4.1 Moisture determination

Moisture content was determined by the standard method where samples were dried at 105ºC for five hours. The difference between the initial weight of the sample and that of the final weight of the sample constituted the moisture content while the final weight was the dry matter (Equation 2).

$$MC(\%) = \frac{[(W_1 - W_0) - (W_2 - W_0)]}{(W_1 - W_0)} * 100 \qquad \text{(Eq. 2)}$$

Where:

MC (%) = Moisture content of sample (MC %)

W_0 = Weight of the dish

W_1 = Weight of the dish + wet sample

W_2 = Weight of the dish + dry sample

DM (%) = 100 – MC (%)

3.6.4.2 Nitrogen and calculation of crude protein

Nitrogen was determined by total combustion of the sample at 950 ºC as per Dumas principle. Ethylenediaminetetraacetic acid, $C_{10}H_{16}N_2O_8$ powder was used as reagent. It was used as the calibration standard for this analysis. Crude protein percentage was calculated using equation 3.

$$\% CP = \% N \times F \qquad \text{(Eq. 3)}$$

Where:

% CP = Crude protein %

% N = Percent Nitrogen automatically calculated by the equipment

F = 6.25 (conversion factor for all forages, feeds and mixed feeds)

3.6.4.3 Crude fiber determination

Crude fiber was determined by acid-base digestion using 1.25% H_2S0_4 (w/v) and 1.25% Sodium hydroxide (NaOH) (w/v) solution. A 1g samples were boiled in weak acid of 0.128 M HCl and afterwards placed in weak base, 0.313 M Sodium hydroxide. Samples were further subjected to heating at 550ºC temperature for 5 hours using a muffle furnace and then cooled. Crude fiber was then quantified by expressing the loss in weight after ashing as a percentage of the original weight of the sample (Equation 4).

$$Cf(\%) = \frac{W_2 - W_3}{W_1} * 100 \qquad \text{(Eq. 4)}$$

Where:

Cf (%) = Crude fiber in (%)

W_1=Sample weight

W_2= Weight of the crucible + Dry residue

W_3 = Weight of the crucible + Ash

3.6.4.4 ADF determination

Acid detergent fiber (ADF) was determined as per Van Soest procedure using Acid Detergent Solution (ADS) [Cetyl trimethyl ammonium bromide in 5dm3 of 0.5 M sulphuric acid] and Pepsin-acid solution (4 g of pepsin (activity 1:10000) in 0.075 M hydrochloric acid. One (1) gram samples were boiled in this solution in a fiber extracting machine for 30 minutes. The ADF solutions were filtered out by suction and washed with warm water. They were then rinsed with acetone and dried for 5 hours at 105ºC, cooled in a desiccator for 30 min and weighed (W_2). Samples were ashed at 550ºC for5 hours in the furnace. They were allowed cool to below 250ºC before the crucibles were removed and placed in a desiccator for 30 minutes and weighed (W_3). ADF was then quantified by expressing the loss in weight after ashing as a percentage of the original weight of the sample (Equation 5).

$$ADF(\%) = \frac{W_2 - W_3}{W_1} * 100 \qquad \text{(Eq. 5)}$$

Where:

W_1 = Mass of original sample, in g

W_2 = Mass of residue in crucible after drying, in g

W_3 = Mass of residue in crucible after ashing, in g

3.6.4.5 NDF determination

Neutral detergent fiber (NDF) was determined as per Van Soest (1981) using neutral detergent solution (NDS) [2-ethoxyethanol Di-sodium-EDTA, Sodium borate decahydrate, Di-sodium hydrogen phosphate and Alpha-amylase, type X1-A]. Sample preparation is similar to what is described in ADF determination. NDF was then quantified by expressing the loss in weight after ashing as a percentage of the original weight of the sample (Equation 6).

$$ADF(\%) = \frac{W_2 - W_3}{W_1} * 100 \qquad \text{(Eq. 6)}$$

Where:

W_1 = Mass of original sample, in g

W_2 = Mass of residue in crucible after drying, in g

W_3 = Mass of residue in crucible after ashing, in g

3.6.4.6 Ash determination

The ash was determined by heating the sample in the furnace at 550ºC for 5 hours. Ash (%) was calculated using Equation 7.

$$Ash(\%) = \frac{W_2 - W_0}{W_1 - W_0} * 100 \qquad \text{(Eq. 7)}$$

Where

Ash (%) =Ash Content of the Sample (%)

W_0 =Weight of clean, dry crucible

W_1 = Weight of clean, dry crucible + dry sample

W_2 =Weight of clean, dry crucible + ash

3.6.4.7 Mineral determination (phosphorus and calcium)

Dry ashing was used for sample preparation in the determination of phosphorus and calcium in the samples. Hydrochloric acid (HCl), 6 M and nitric acid (HNO_3), 6 M reagents were used to digest samples.2 g of dried samples were weighed and placed in porcelain crucibles and ashed for 5 hours at 550ºC muffle furnace. After cooling, samples were heated in 5 cm^3 of 6 M hydrochloric acid (HCI) for 2-3 hours to dissolve the samples. They were again cooled and 5 cm^3nitric acid (HNO_3) was added. Crucibles were heated and then removed as soon as solutions had started to boil. The solutions were filtered through filter papers into 100 ml volumetric flasks. The solution was diluted to volume with de-ionized and mixed well. Elements were analyzed using ICP Spectrometer (icap 6000 series).

3.6.5 Experiment A3: Ensiling characteristics of the forage legumes [Objective (v)]

Samples of forage legumes were collected from trial fields (experiment A1) on Neudamm Campus farm of the University of Namibia in May 2015 when almost all forage legumes had reached maturity. The effect of ensiling on the silage characteristics looked at physical appearance (texture, color, aroma, and consistence), pH and nutritional value. Forage legumes ensiled were *Medicago sativa*, *Lablab purpureus*, *Canavalia ensiformis*, *Cullen tomentosum* and *Otoptera burchellii*. These were the only forage legumes that had ensilable materials at the time of ensiling. They were cut with a pruning shear and wilted for twenty two (22) to twenty four (24) hours in the field. Thereafter, they were chopped into 2 – 3cm pieces with a knife and vacuum packed in 1 kg plastic bags using a Vama VacBox line vacuum pack machine and with three (3) replicates of each legume arranged in a Completely Randomized Design (CRD) in the open shelf in laboratory. After sixty days (60) of incubation, the plastic bags were opened to determine the silage characteristics (texture, color, smell and consistence) through a subjective sensory evaluation method as per BAPH (1996) and Jiaxin & Jun (2002). The pH was determined using pH tester and Macherey-nagel pH test papers concurrently. The subjective sensory evaluation (smell, color and texture) was carried out by undergraduate students using an evaluation form (appendix 1).After the subjective evaluation, silage samples were oven-dried at 60ºCfor 2 hours, removed and then allowed to dry completely at room temperature. They were ground in a hammer mill to a particles size of 1 mm and sent to the Ministry of Agriculture, Water and

Forestry feed analyses laboratory for proximate analysis as per guidelines in Association of Official Analytical Chemists (AOAC, 1995).

3.7 Data analysis

The square root transformation was used to obtain normally distributed data for both growth rate and biomass yield measurements before analysis. The same transformation helped in variance stabilization. After transformation and analysis, the resulting least square means were back-transformed and an error term for the original units was estimated using the untransformed data. The GLM procedure (SAS, 2003) was used to analyze the data from all the growth trial and silage experiments. Means were separated by a PDIFF statement. Effects were considered significant at $P < 0.05$; trends were accepted if $.05 < P < .10$.

Growth rate, biomass yield and days to 50% flowering from the split-plot design were analyzed according to the model in equation (8).

$$Y_{ijk} = \mu + \alpha_i + \sigma_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \qquad \text{(Eq. 8)}$$

Where:

μ = Overall mean

α_j = effects of the i-th (i = 1, 2, 3, 4) level of phosphorus

σ_{ik} = whole plot error component

β_j = effect of the k-th (j = 1, 2, …, 8) legume treatment

$(\alpha\beta)_{ij}$ = interaction effect of the phosphorus level and legume species

ε_{ijk}= sub plot error component

Based on the expected mean squares, the fertilizer x legume interaction term was used as the error term to test significant effects in the model.

Data on 100 seed weight were separately analyzed for each legume by GLM (SAS, 2003) with fertilizer level as the predictor variable. Data on forage legume proximate parameters (moisture, CP, P, Ca, CF, ADF, NDF, fat [ether extract] and ash) during the growing season could only be obtained for the February and May harvest and was analyzed by GLM (SAS, 2003). Where there was no significant difference between the February and May harvest, the data was pooled to obtain better precision of the least square means. The log transformation was used to normalize and stabilize variance for Phosphorous data; for Calcium a square root transformation was used; for fat and ash content a reciprocal transformation was used.

Data on forage legumes silage proximate analyses (moisture, CP, P, Ca, CF, ADF, NDF, fat [ether extract]and ash were analyzed separately by GLM (SAS, 2003).Residual analysis of moisture and CP on silage showed moderate departure from the assumption of constant variance, but no suitable transformation was found. Hence the Kruskal-Wallis non-parametric test was used and implemented using Proc NPAR1WAY (SAS, 2003). Comparisons of individual location (medians) differences were also done using the same procedure.

CHAPTER 4

RESULTS

Table 4.1shows the univariate statistics for growth rate, biomass yield, SPAD, seed yield and days to 50 % flowering. Table 4.2 shows the univariate statistics for the legume silage proximate parameters and sensory evaluation. Table 4.3 shows the univariate statistics for the forage legume hay proximate parameters.

Table 4.1: Univariate statistics (growth rate, biomass yield, SPAD, seed weight and days to 50 % flowering)*

		Mean	N	CV (%)	SEM
Growth rate (cm/day)		0.82	98	73.96	0.06
Biomass yield (tons/ha)		4.42	105	57.54	0.25
100 seeds weight (g)					
	C. argyraea	2.21	7	8.45	0.07
	C. ensiformis	125.41	15	7.20	2.33
	C. tomentosum	1.37	9	2.89	0.01
	L. purpureus	23.09	12	10.64	0.71
	O. burchellii	8.59	24	13.10	0.23
	R. holoserica	0.78	3	0.20	0.00
	V. lobatifolia	3.12	17	9.20	0.07

SPAD Reading 1	54.22	110	23.21	1.20
SPAD Reading 2	55.48	109	22.32	1.19
Days to 50 % flowering	97.27	93	39.00	3.93

*N = sample size; CV = Coefficient of Variation; SEM = Standard Error of Mean

Table 4.2: Univariate statistics for the legume silage proximate parameters and sensory evaluation*

	Mean	**N**	**CV (%)**	**SEM**
Moisture	6.34	18	11.69	0.17
Crude protein	19.08	18	11.04	0.50
Phosphorus	0.22	18	29.34	0.02
Calcium	1.68	18	34.53	0.14
Crude fiber	22.58	18	16.72	0.89
ADF	28.39	18	16.07	1.08
NDF	45.51	18	12.95	1.39
Ash	12.03	18	21.58	0.61
Overall score	27.94	53	37.33	1.43
pH	6.06	53	10.86	0.09
Moisture	43.17	53	20.17	1.20

*N = sample size; CV = Coefficient of Variation; SEM = Standard Error of Mean

Table 4.3: Univariate statistics for the forage legume hay proximate parameters*

	Mean	N	CV (%)	SEM
Moisture	6.39	138	19.45	0.12
Crude protein	21.69	138	15.78	0.29
Phosphorus	0.36	136	146.65	0.04
Calcium	1.72	136	75.72	0.11
Crude fiber	21.61	68	28.14	0.74
ADF	26.49	102	24.06	0.63
NDF	37.79	103	22.27	0.83
Ash	14.05	68	35.06	0.60
Fat	3.14	99	40.13	0.13

*N = sample size; CV = Coefficient of Variation; SEM = Standard Error of Mean

4.1 Biomass yield [Objectives (ii) and (iii)]

The biomass yield was affected ($P < 0.05$) by forage legume species (Table 4.4) and phosphorus (P) fertilizer level (Table 4.5). The least square means (tons/ha) at 0, 60, 80 and 100 kg P/ha fertilizer application rates were: 3.8 ± .2, 3.5 ± .2, 4.2 ± .3, 2.9 ± .3, respectively (Table 4.5). *Lablab purpureus* with a biomass yield of 8.9 ± 3 tons/ha outperformed all forage legume species ($P < 0.05$). There was no significant difference ($P > 0.05$) between *C. ensiformis*, *M. sativa* and *V. unguiculata*. *O. burchellii* performed fairly well, yielding 2.5 ± 0.3 tons per hectare (Table 4.4). The least yielding forage

legumes were *V. lobatifolia* and *C. argyraea*, with 1.5 ± 0.4 and 0.9± 0.5 tons per hectare, respectively.

Table 4.4: Least square means (**± SEM)** of biomass yields (tons/ha) of the forage legumes

Forage Legume species	**Biomass yield (tons/ha)**
Crotalaria argyraea	0.9 ± 0.5^{e}
Canavalia ensiformis	4.0 ± 0.3^{b}
Cullen tomentosum	5.1 ± 0.4^{b}
Lablab purpureus	8.9 ± 0.3^{a}
Medicago sativa	4.7 ± 0.3^{b}
Otoptera burchellii	2.5 ± 0.3^{c}
Vigna lobatifolia	1.5 ± 0.4^{d}
Vigna unguiculata	4.4 ± 0.3^{b}
P-value	< .0001
R^2	0.85

Means with different superscripts within the column differ significantly ($P < 0.05$)

Table 4.5: Least square means (**± SEM)** of biomass yields (tons/ha) at different levels of phosphorus (P) fertilizer application

Phosphorus (P) fertilizer levels (kg P/ha)	**Biomass yield (tons/ha)**
0	3.8^{ab}
60	3.5^{ac}
80	4.2^{a}
100	2.9^{bc}

Means with different superscripts within a column differ ($P < 0.05$)

4.2 Growth characteristics of forage legumes [Objective (i) and (ii)]

4.2.1 Germination and establishment of forage legumes during 2013/2014 rainy season

The germination percentages and seedling establishment rates (%) were: *Canavalia ensiformis* (87.4 ± 7.5), *Crotalaria argyraea* (54.6 ± 10.6), *Cullen tomentosum* (83.3 ± 8.7), *Lablab purpureus* (80.5 ± 6.7), *Otoptera burchellii* (90.0± 7.5), *Vigna unguiculata* (72.1 ± 9.7) and *Medicago sativa* (91.7 ± 5.3).

4.2.2 Growth rate of forage legumes during 2014/2015 rainy season

Although growth rate was not an objective measurement to compare the growth characteristics of the studied forage legumes because of their different growth habits, it was evident that forage legumes had different growth rates($P < 0.05$) as shown in Table 4.6.The level of P fertilizer did not influence growth rates of forage legumes ($P > 0.05$).

Legume x fertilizer interaction tended toward significance (P = 0.0706).Forage legumes growth rate least square means (cm/day) are depicted in Table 4.6.

Table 4.6: Least square means (± SEM) of growth rates of forage legumes

FORAGE LEGUME	Growth rate (cm/day)
*Crotalaria argyraea**	.
Canavalia ensiformis	0.43 ± 0.1^{d}
Cullen tomentosum	0.70 ± 0.1^{c}
Lablab purpureus	1.72 ± 0.1^{a}
Medicago sativa	0.51 ± 0.1^{d}
Otoptera burchellii	1.09 ± 0.1^{b}
Vigna lobatifolia	0.80 ± 0.2^{bc}
Vigna unguiculata	0.47 ± 0.1^{d}
P-value	< .0001
R^2	0.76

Means within a column with different superscripts are different (P < 0.05)

* Insufficient data available on *Crotalaria argyraea* for analysis.

Growth rate of *Cullen tomentosum* tended to decrease with increased level of phosphorus (P) application. Least square means for growth rate were: 1.01 ± 0.10 at 0 kg P/ha, 0.75 ± 0.10 at 60 kg P/ha, 0.94 ± 0.10 at 80 kg P/ha and 0.64 ± 0.10at 100 kg P/ha for *Cullen tomentosum*; a similar trend was observed with *L. purpureus* (Table4.7).

There was a tendency for growth rate to increase with increasing P application in *C. argyraea, C. ensiformis, O. burchelllii* and *V. lobatifolia*. For example the least square means for *O. burchellii* were: 0.88 ± .10 at 0 kg P/ha, 1.04 ± .10 at 60 kg P/ha, 1.21 ± .10 at 80 kg P/ha and 1.05 ± .10at 100 kg P/ha. No clear trend regarding growth response to P application could be discerned for *M. sativa* and *V. unguiculata* (Table 4.7)

Table4.7: Least square means (± SEM) of legume growth rates (cm/day) at different P fertilizer levels

Legume	**0**	**60**	**80**	**100**
*Crotalaria argyraea**	0.82 ± .12^{a}	.	0.73 ± .17^{a}	0.96 ± .17^{a}
Canavalia ensiformis	0.54 ± .07^{a}	0.62 ± .07^{ab}	0.65 ± .10^{ab}	0.8 ± .10^{b}
Cullen tomentosum	1.01 ± .10^{c}	0.75 ± .10^{ac}	0.94 ± .10^{c}	0.64 ± .10^{a}
Lablab purpureus	1.54 ± .09^{a}	1.28 ± .08^{bc}	1.03 ± .10^{b}	1.40 ± .10^{ac}
Medicago sativa	0.76 ± .08^{a}	0.67 ± .08^{a}	0.77 ± .10^{a}	0.66 ± .10^{a}
Otoptera burchellii	0.88 ± .10^{b}	1.04 ± .10^{ab}	1.21 ± .10^{a}	1.05 ± .10^{ab}
Vigna lobatifolia	0.85 ± .12^{a}	0.83 ± .17^{a}	0,93 ± .10^{a}	0,98 ± .12^{a}
Vigna unguiculata	0.72 ± .07^{b}	0.65 ± .07^{b}	0,80 ± .10^{b}	0,59 ± .17^{b}
P–Value				< 0.0001
R2				0.76

Means with different superscripts within a row differ (P < 0.05)

It has been observed that forage legumes growth habits differ from one season to another especially those grown from seedling or cuttings. This scenario is depicted in Figure 4.1. Forage legumes that where propagated by seed in this study (*Vigna unguiculata*, *Medicago sativa*, *Lablab purpureus* and *Canavalia ensiformis*) grew faster ($P < 0.05$) in the first season compared to those propagated through cuttings or seedlings (*Otoptera burchellii*, *Cullen tomentosum* and *Vigna lobatifolia).*

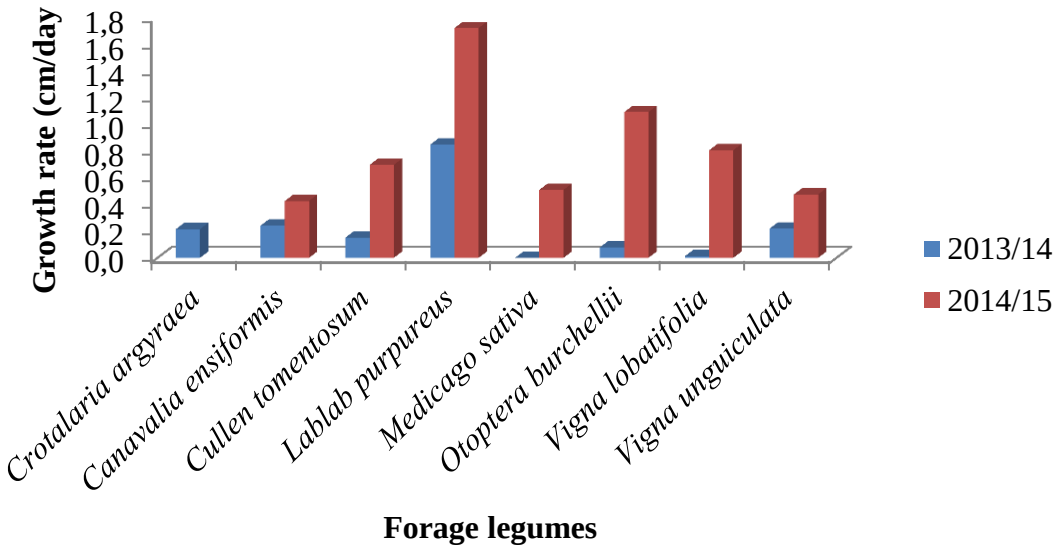


Figure 4.1: Forage legumes 2013/14 and 2014/15 seasons' growth rates

The growth rate of *Otoptera burchellii*, *Cullen tomentosum* and *Vigna lobatifolia* picked up in the second growing season (2014/15) in comparison to the 2013/14 growing season.

4.2.3 Days to 50% flowering of forage legumes

There was a significant difference (P < 0.05) among forage legumes studied for days to 50% flowering (D50FLOWER). The least square means for D50FLOWERwere: *Canavalia ensiformis* (84.0 ± 0.8), *Cullen tomentosum* (57.0 ± 1.0), *Lablab purpureus* (177.0 ± 1.0), *Medicago sativa* (106.0 ± 0.9), *Otoptera burchellii* (89.0 ± 1.1) and *Vigna unguiculata* (67.0 ± 1.1) (Figure4.2). Phosphorus (P) fertilizer level did not affect (P > 0.05) D50FLOWER.

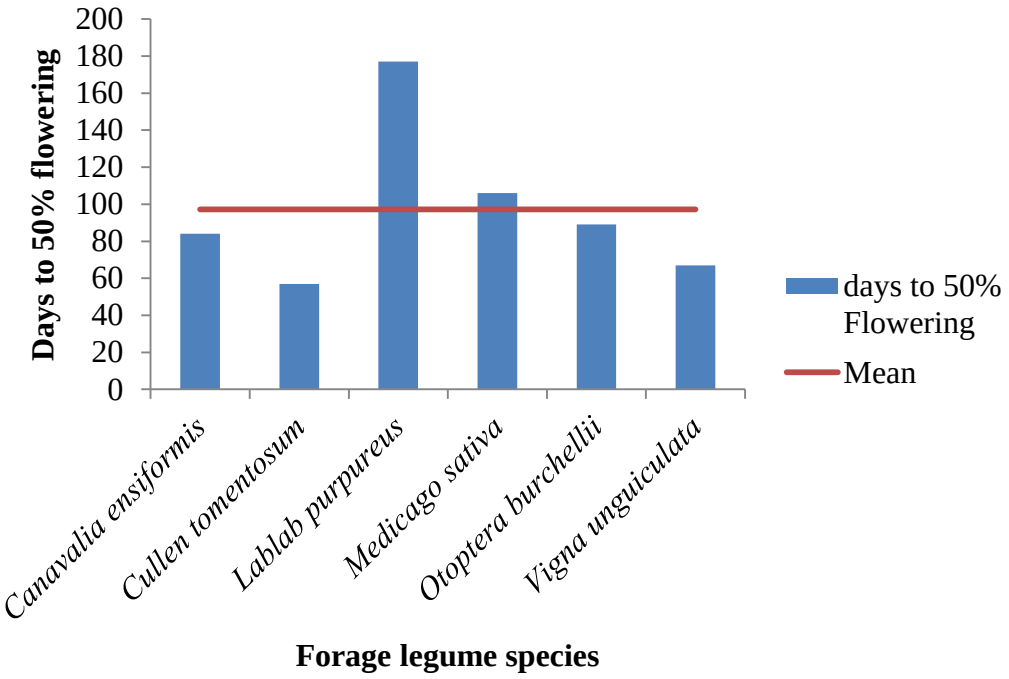


Figure 4.2: Days to 50 % flowering (D50FLOWER) of forage legumes

4.2.4 SPAD meter values

SPAD meter values were influenced (P < 0.05) by forage legume species. Table 4.8 depicts SPAD meter values of different forage legumes during the early vegetative

stage, taken one month apart. *Vigna unguiculata* SPAD values were much higher ($P < 0.0001$) than those for other forage legumes, with least square mean value of 71.4 ± 1.5 and 72.1 ± 1.3 for SPAD 1 and SPAD 2, respectively. The least values recorded were for *Lablab purpureus* (42.4 ± 1.8 and 40.4 ± 1.6) and *Otoptera burchellii* (40.9 ± 1.9 and 43.4 ± 1.6) for SPAD 1 and SPAD 2, respectively (Table 4.8).

Table 4.8: SPAD values least square means (± SEM) of forage legumes

Legume species	**SPAD 1**	**SPAD 2**
Crotalaria argyraea	64.0 ± 2.1^{a}	66.8 ± 2.1^{a}
Canavalia ensiformis	56.7 ± 1.6^{b}	53.3 ± 1.4^{b}
Cullen tomentosum	40.5 ± 1.9^{c}	48.7 ± 1.6^{c}
Lablab purpureus	42.4 ± 1.8^{d}	40.4 ± 1.6^{d}
Medicago sativa	55.4 ± 1.7^{b}	54.5 ± 1.5^{b}
Otoptera burchellii	40.9 ± 1.9^{d}	43.4 ± 1.6^{e}
Vigna lobatifolia	56.3 ± 2.3^{b}	56.8 ± 2.0^{b}
Vigna unguiculata	71.4 ± 1.5^{e}	72.1 ± 1.3^{a}
P-value	< .0001	< .0001
R^2	0.82	0.86

Least squares means with different superscripts within a column differ significantly ($P < 0.05$)

4.3 Influence of phosphorus (P) fertilizer on 100-seed weights (SDWT100) of forage legumes [Objective (ii)]

The level of phosphorus (P) fertilizer affected ($P < 0.05$) 100-seed weight (SDWT100) of forage legumes. The SDWT100 least square means of forage legumes are presented in Table 4.9.

Table 4.9: Least square means (± SEM) of 100-seed weight (SDWT100) (g) of forage legumes at different P fertilizer levels

Legume	**0**	**60**	**80**	**100**	R^2
C. argyraea	2.42 ± 1.04^{a}	.	2.00 ± 1.05^{a}	2.30 ± 1.05^{a}	0.6
C. ensiformis	117.82 ± 1.03^{b}	123.94 ± 1.02^{b}	139.55 ± 1.03^{a}	121.37 ± 1.03^{b}	0.7
L. purpureus	20.35 ± 1.03^{c}	22.85 ± 1.02^{b}	.	26.19 ± 1.03^{a}	0.8
O. burchellii	9.54 ± 1.03^{a}	9.48 ± 1.03^{a}	7.38 ± 1.03^{b}	7.88 ± 1.03^{b}	0.8
V. lobatifolia	2.76 ± 1.01^{b}	.	3.33 ± 1.01^{a}	3.29 ± 1.01^{a}	0.9
C. tomentosum	1.35 ± 1.01^{b}	1.34 ± 1.01^{b}	.	1.41 ± 1.01^{a}	0.6
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	

LS means with different superscripts within each row differ significantly ($P < 0.05$).

Canavalia ensiformis increased its SDWT100 up to 80 kg P/ha and started to decline at 100 kg P/ha. The same trend was observed with *Vigna lobatifolia*. *Lablab purpureus* increased linearly its SDWT100 from 0 up to 100 kg P/ha; the same trend applied to *Cullen tomentosum* (Table 4.9). These results in general tend to mirror those

obtained for biomass yield. *Otoptera burchellii* behaved differently from the rest of forage legumes, with highestSDWT100 recorded at 0 kg P/ha and then declining.

4.4 Chemical composition of forage legumes [objective (iv)]

There were significant differences ($P < 0.05$) among forage legumes in moisture, crude protein (CP), calcium (Ca), crude fiber (CF), acid detergent fiber (ADF), Neutral detergent Fiber (NDF), fat and ash contents (Table 4.10 and Table 4.11). Crude protein percentage of forage legumes were high and ranged from 16.7 ± 0.8 to 25.2 ± 0.7 % in harvest 1 and 18.9 ± 0.3 to 26.9 ± 0.3 in harvest 3 (Table 4.10).

Table 4.10: Least square means (± SEM) for moisture, CP and fat (% DM)*

	Moisture (%)		**CP (%) DM**		**Fat (%) DM**
Legume	**Harvest 1**	**Harvest 3**	**Harvest 1**	**Harvest 3**	
C. ensiformis	7.8 ± 0.3^{a}	7.5 ± 0.3^{a}	22.1 ± 0.7^{b}	20.4 ± 0.3^{c}	2.9 ± 0.2^{b}
C. tomentosum	5.2 ± 0.4^{c}	5.9 ± 0.4^{b}	16.7 ± 0.8^{c}	20.9 ± 0.3^{c}	4.2 ± 0.2^{a}
L. purpureus	5.4 ± 0.3^{c}	6.4 ± 0.3^{b}	23.4 ± 0.7^{a}	21.9 ± 0.3^{b}	2.2 ± 0.2^{c}
M. sativa	5.4 ± 0.3^{c}	7.0 ± 0.4^{a}	25.2 ± 0.7^{a}	26.9 ± 0.3^{a}	2.0 ± 0.2^{c}
O. burchellii	N/E	6.4 ± 0.4^{a}	N/E	21.3 ± 0.3^{b}	3.3 ± 0.3^{ab}
V. lobatifolia	5.7 ± 0.4^{c}	6.5 ± 0.4^{a}	23.8 ± 0.8^{ab}	18.9 ± 0.4^{d}	2.6 ± 0.3^{b}
V. unguiculata	6.5 ± 0.3^{b}	6.9 ± 0.3^{a}	17.7 ± 0.7^{c}	18.9 ± 0.3^{d}	4.1 ± 0.2^{a}
P-value	< 0.0001	0.0027	< 0.0001	< 0.0001	< 0.0001
R^2	0.65	0.37	0.77	0.94	0.70

Least Square Means with different superscripts within a column differ ($P < 0.05$)

* N/E = Not estimable

Phosphorus (P) % did not differ (P > 0.05) across forage legumes. Level of Phosphorus fertilizer effected (P < 0.05) phosphorus and NDF content (Table 4.12). Fat content was also affected by the level of phosphorus fertilizer (Table 4.12).

Table 4.11: Chemical composition of forage legumes (% DM)*

Legume	**CF**	**ADF**	**NDF**	**Ash**	**Ca**	**P**
C. ensiformis	13.9 ± .4^{e}	19.4 ± .9^{c}	30.5 ± 1.6^{c}	17.7 ± .6^{a}	3.0 ± .2^{a}	0.1 ± .1^{a}
C. tomentosum	30.2 ±0.5^{a}	33.0 ± 1.1^{a}	42.4 ± 1.8^{a}	8.8 ± .7^{e}	0.9 ± .3^{b}	0.2 ± .1^{a}
L. purpureus	24.9 ± .4^{b}	29.1± .9^{a}	39.9 ± 1.6^{a}	13.1 ± .6^{c}	1.3 ± .2^{b}	0.2 ± .1^{a}
M. sativa	21.8 ± .4^{c}	26.0 ± .9^{b}	36.2 ± 1.6^{b}	11.0 ± .6^{d}	1.2 ± .2^{b}	0.2 ± .1^{a}
O. burchellii	N/E	30.1 ± 1.4^{a}	41.9 ± 2.2^{a}	10.4 ± .7^{d}	1.0 ± .3^{b}	0.2 ± .2^{a}
V. lobatifolia	N/E	29.6 ± 1.4^{a}	40.3 ± 2.3^{a}	13.8 ± .8^{bc}	1.1 ± .2^{b}	0.2 ± .2^{a}
V. unguiculata	15.8 ± .4^{d}	23.8 ± .9^{b}	37.8 ± 1.6^{b}	14.6 ± .6^{b}	1.8 ± .2^{b}	0.2 ± .1^{a}
P-value	< .0001	0.0004	0.0009	< .0001	< .0001	0.2345
R^2	0.97	0.74	0.59	0.75	0.34	0.068

Least Square Means with different superscripts within a column differ (P < 0.05)

** N/E = Not estimable

Calcium ranged from 1.0 ± .3 to 3.0 ± .2 %DM. *Canavalia ensiformis* had significantly (P <0.05) higher Calcium than other forage legumes. ADF ranged from 19.4 ± .9 to 33.0 ± 1.1 %; NDF ranged from 30.5 ± 1.6 to42.4 ± 1.8%.NDF (%) increased with P fertilizer application up to 80 kg P/ha and then declined(Table 4.12).

Table 4.12: Least Square Means (± SEM) of phosphorous, NDF and fat (% DM) at different levels of phosphorus (P) fertilizer application

P Level (kg P/ha)	**P**	**NDF**	**Fat**
0	0.13 ± 0.09^{b}	38.0 ± 1.2^{b}	2.8 ± 0.2^{ab}
60	0.20 ± 0.09^{ab}	37.7 ± 1.2^{b}	2.5 ± 0.2^{b}
80	0.23 ± 0.11^{ab}	45.0 ± 1.4^{a}	3.2 ± 0.2^{a}
100	0.17 ± 0.12^{b}	32.8 ± 1.7^{c}	2.9 ± 0.2^{ab}
P-value	< 0.0001	0.0001	0.0157
R^2	0.068	0.59	0.70

LS means with different superscripts within a column differ ($P < 0.05$)

Fat (%) was affected ($P < 0.05$) by forage legume and fertilizer level. Highest fat percentages were in *C. tomentosum* and *V. unguiculata* (Table 4.10). Just like for NDF, fat content tended to increase with increasing P fertilizer application and was highest at 80 kg P/ha application level (Table 4.12). Ash content differed ($P <0.05$) among legumes. *C. ensiformis* had highest ash content among the forage legumes studied.

There were no major changes in crude protein concentration at different harvests (harvest 1 and 3). CP content for *Canavalia ensiformis*, *Lablab purpureus* and *Vigna lobatifolia* declined slightly while *Cullen tomentosum*, *Medicago sativa* and *Vigna unguiculata* increased slightly at harvest 3 (Figure 4.3).

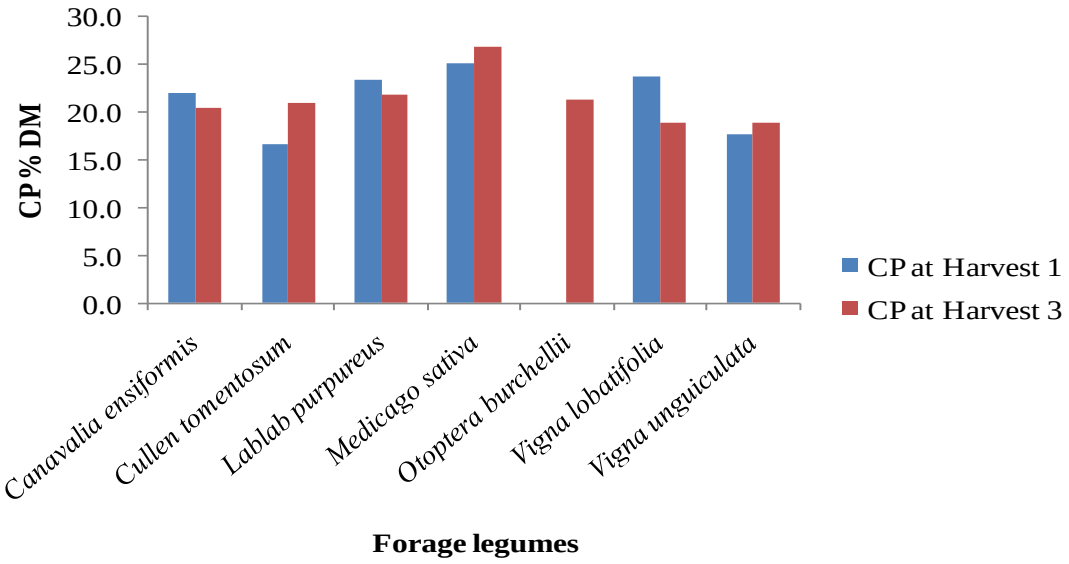


Figure 4.3: CP concentration at harvest 1 and harvest 3.

4.5 Ensiling characteristics of forage legumes [Objective (v)]

4.5.1 Sensory evaluation and pH of silages harvested at maturity

The pH, moisture content and overall score differed ($P < 0.05$) among forage legumes. The pH ranged from 5.4 ± 0.1 to 6.7 ± 0.1 (Table 4.13) which was above the ideal pH values of good quality silage. The overall score of silages varied from 15.4 ± 2.7 to 36.0 ± 1.9 (Table 4.13). *Lablab purpureus* produced satisfactory silage compared to the rest of forage legumes.

Table 4.13: Least square means (± SEM) of pH and sensory evaluation of forage legume silages harvested at maturity

Forage legume	pH	Moisture	Overall Score	Silage quality
Canavalia ensiformis	5.8 ± 0.1^{a}	43.3 ± 1.5^{d}	26.7 ± 2.7^{b}	Average
Cullen tomentosum	6.4 ± 0.1^{b}	40.1 ± 1.5^{d}	26.4 ± 2.8^{b}	Average
Lablab purpureus	5.4 ± 0.1^{c}	47.4 ± 1.0^{c}	36.0 ± 1.9^{a}	Average
Medicago sativa	6.8 ± 0.1^{d}	51.8 ± 1.5^{b}	27.0 ± 2.7^{b}	Average
Otoptera burchellii	6.5 ± 0.1^{bd}	28.5 ± 1.5^{a}	15.4 ± 2.7^{c}	Bad
P-value	< 0.0001	< 0.0001	< 0.0001	
R^2	0.65	0.77	0.46	

LS means with different superscripts within a column differ ($P < 0.05$)

4.5.2 Chemical composition of silages

The proximate parameters (moisture, CP, CF, ADF, NDF, ash, Ca and P) differed ($P < 0.05$) among forage legumes (Tables 4.14). Median CP (%) values differed among the legumes. *Lablab purpureus* had higher CP than *C. tomentosum*. A trend ($P = 0.10$) was observed in median CP values for the pairs: *C. ensiformis* and *C. tomentsum*; *C. ensiformis* and *O. burchellii*; *C. tomentosum* and *M. sativa*; and *C. tomentosum* and *O. burchellii*. The values obtained for the other proximate parameters were similar to those observed for the un-ensiled samples. However, ash values (%) for *C. ensiformis* (13.7 ± 1.5) were much lower than those obtained for the un-ensiled material (22.1 ± 0.7).

Table 4.14: Least square means of Chemical composition of forage legumes silages (% DM)*

Species	Moisture	CP	CF	ADF	NDF
Canavalia ensiformis	16.00	13.33	17.1 ± 1.3^{ac}	21.8 ± 1.4^{a}	41.3 ± 2.4^{a}
Cullen tomentosum	11.67	2.33	23.2 ± 1.3^{bc}	30.2 ± 1.4^{b}	42.3 ± 2.4^{a}
Lablab purpureus	7.83	12.67	24.6 ± 0.9^{b}	32.1 ± 1.0^{b}	49.7± 1.7^{b}
Medicago sativa	11.67	9.33	26.1 ± 1.3^{b}	29.8 ± 1.4^{b}	50.3 ± 2.4^{b}
Otoptera burchellii	2.00	6.67	20.0 ± 1.3^{ac}	24.4 ± 1.4^{a}	39.8 ± 2.4^{a}
P-value	0.0177	0.0419	< 0.0001	< 0.0001	< 0.0001
R^2	-	-	0.71	0.78	0.66

* Wilcoxon scores (means scores) computed in Proc NPAR1WAY (SAS, 2003) are indicated for the parameters moisture and CP. The p-value is given by the Kruskal-Wallis test, with four degrees of freedom.

LS means with different superscripts within a column differ (P < 0.05)

Table 4.14 cont.: Least Square means (± SEM) of Chemical composition of forage legume silages (% DM)

Forage legume species	Ash	Ca	P
Canavalia ensiformis	13.7 ± 1.5^{a}	2.54 ± 0.22^{a}	0.17 ± 0.03^{a}
Cullen tomentosum	9.4 ± 1.5^{a}	0.98 ± 0.22^{c}	0.21 ± 0.03^{a}
Lablab purpureus	12.1 ± 1.0^{a}	1.59 ± 0.16^{b}	0.28 ± 0.02^{b}
Medicago sativa	12.4 ± 1.5^{a}	1.64 ± 0.22^{b}	0.15 ± 0.03^{a}
Otoptera burchellii	12.6 ± 1.5^{a}	1.72 ± 0.22^{b}	0.24 ± 0.03^{ab}
P-value	< 0.0001	< 0.0001	< 0.0001
R^2	0.27	0.65	0.62

LS means with different superscripts within a column differ (P < 0.05)

CHAPTER 5

DISCUSSION

5.1 Biomass yield and the effects of fertilizer on the biomass yield of forage legumes: Objectives (ii) and (iii)

5.1.1 Biomass yield

The level of animal production achieved in any environment is related to quality, quantity and continuity of supply of feed throughout the year (Ayisi et al, 2002). Biomass yield is an important determinant of range productivity; hence it is a crucial parameter in assessment of forage species. Many crops, especially legumes do not grow well in low P-status soils (Bationo, Fairhurst, Giller, Kelly, Lunduka, Mando,…Zingore, (2012), as is found in most of southern Africa. Despite a poor rain season, *Lablab purpureus* produced a high biomass of 8.9 ± 0.3 tons/ha comparable to other studies. Ayisi et al. (2004) reported the yield of *Lablab purpureus* ranging from 1-7 tons per hectare; Clem and Cook (2004) reported 4.0 tons/ha. In contrast, Mullen (1999) obtained a biomass yield of *Lablab purpureus* of 14 tons/ha in irrigated fields; a lower yield of 1.5 tons/ha was reported by Boitumelo and Mahabile (1992). In contrast, to the lower yields reported by Boitumelo and Mahabile (1992), the results here were encouraging showing that even in areas with poor rainfall, substantially high yields can be obtained as long as there is good initial legume establishment.

Lablab purpureus provides good soil cover and once established, is quite drought tolerant (Adebisi and Bosch, 2004) and this explains its high yields. The results

have shown the potential of *Lablab purpureus* as an alternative forage crop to *Medicago sativa*. *Lablab purpureus* has been selected for improved biomass yield and this gives it an advantage over the other indigenous forage legumes in this study. High DM yield of *Lablab purpureus* is due to its aggressive and vigorous growth habit (Nworgu & Ajayi, 2005). Other attributes, however, need to be assessed for instance persistence, resistance to pests and diseases, before firm recommendations can be made.

The yield of *V. unguiculata* was comparable to the 2-4 tons/ha reported (Singh et al., 1997). Similarly, Madamba et al. (2006) reported that under sole-cropping with good management *V. unguiculata* can yield 4 tons/ha of hay. Mullen (1999) reported 2-3 tons DM/ha production per season for *V. unguiculata*; a much lower yield of 1.5 tons/ha was reported by Nyoka et al (2004). Interestingly, a very high average yield of 5.98 tons/ha was reported in Turkey (Ayan, Mut, Basaran, Acar & Asci, 2012).

Also the yield of 4.7 ± 0.3 tons/ha for *M. sativa* compares well with what has been reported elsewhere. For example the 4.6 tons/ha reported by Geleti, Hailemariam, Mengistu and Tolera (2013). Pioneer (2010) reported 9 tons/ha in year 1 as a standard biomass yield for *Medicago sativa*. Under dryland production yield range is 5-15 tons/ha (Smith, 2006).

Cullen tomentosum gave a biomass yield (5.1 ± 0.4 tons/ha), that is well in the range for *M. sativa. C. tomentosum* is frost tolerant and survives mild winters and hence once conditions are favorable; it has rapid growth contributing to its high biomass yield. *C. tomentosum* also produces volatile compounds that may act as a deterrent to feeding by insects and to grazing animals. Indeed in a companion study, Boer goats under

confinement disliked feeding on *C. tomentosum* (Thamina, 2015). There may, however, be other potential uses for *C. tomentosum* for example as a cover crop, in integrated pest control or for extraction of volatile oils.

Canavalia ensiformis yield (4.0 ± 0.3 tons/ha) was lower than 8-10 tons/ha reported by Sheahan (2012). We could not find any reports in the literature on the yield for *Otoptera burchellii*, but the yield obtained (2.5 ± 0.3 tons/ha) was reasonable, given that it was still in its establishment stage, having been transplanted nine months earlier. Given its prostrate growth habit, with many stolons produced, higher yields might be possible if *O. burchellii* is harvested two or more years after establishment. The biomass yield (1.5 ± .4) of *V. lobatifolia* was low and we could not find estimates reported in the literature. *V. lobatifolia* is a perennial and stores its food reserves in a tuber from which its regenerates after the adverse winter conditions. It is possible that the biomass yield was underestimated for *V. lobatifolia* because it was still in its establishment phase and had not yet accumulated sufficient storage reserves for fast regrowth after the winter.

Crotalaria argyraea produced the lowest biomass yield (0.9 ± 0.5 tons/ha). Different species of *Crotalaria* studied in Zimbabwe such as *C. ochroleuca*, *C. grahamiana*, and *C. incana* produced a biomass yield of 9 tons/ha (Ojiem, Ransom, Odongo & Okwuossa, 1998). This biomass yield is much higher than what was recorded in this study for *Crotalaria argyraea*. The possible explanation of this disparity is that *Crotalaria argyraea* is a woody shrub that can grow up to 1.5 meters high. It was harvested during the first season of its growth and on average it only

reached a height of 54 cm. If it was harvested in its second or third season of growth, the biomass yield might possibly have been higher.

The indigenous forage legumes (*O. burchellii* and *V. lobatifolia*) have potential as fodder crops due to their notable biomass yield, hardiness, well developed root systems, frost tolerance and drought tolerance which makes them adaptable to environmental conditions of Namibia rangelands. They could contribute substantially to improving nutrition of ruminants if well managed in rangelands. Biomass production of *Lablab purpureus* and *Cullen tomentosum* roughly corresponded to the growth rates; no similar correspondence was observed for *Otoptera burchellii*, *V. lobatifolia* and *Medicago sativa*. It may be that *V. lobatifolia* and *O. burchellii* which are perennial and have different growth habits, preferably channel their food reserves to tubers or root systems (which was not assessed in this study) as part of their survival strategy, hence adaptability to the semi-arid environment.

Species growth habits can influence the biomass contribution in a system despite the soil being fertile (Ojiem et al., 1998). Species such *as O. burchellii*, *V. lobatifolia* and *C. argyraea* had relatively low yields. This is likely to change in subsequent seasons or years as they accumulate root reserves and grow bigger as seasons progress. Despite their low biomass yield, their drought tolerance, early spouting and persistence could be key factors in forage legumes establishment either as pure stands or in rangeland re-sowing to improve animal performance.

All improved forage legumes (*L. purpureus*, *M. sativa*, *C. ensiformis* and *V. unguiculata*) performed well (> 4 tons/ha), which should not be surprising given that

they have undergone genetic selection for increased biomass yield. *C. tomentosum* also gave a comparable yield (5.1 ± 0.4 tons/ha) showing its adaptability to the semi-arid environment. Although the yields for the rest of the indigenous legumes were lower, there is potential for genetic improvement given the likely existence of many accessions from the wilderness. The study established that indeed there are significant differences in biomass yields of the different legumes, but use of a combination of legumes in pastures enhances resilience of the rangelands and may be important for sustainability.

5.2 Growth characteristics of forage legumes: Objectives (i) and (ii)

5.2.1 Growth rate and the effect of phosphorus (P) fertilizer on growth of forage legumes

Nutrients are required for cultivated forages so that they can attain higher yields or better forage quality than existing natural range. Applying phosphorous can increase the legume content in the diet of grazing animals. Phosphorous is usually applied as superphosphate (10% P or 20%P_2O_5) with recommended rates varying from 50 to 200 kg/ha and year (Bayer and Waters-Bayer, 1998). Fertilizer x legume interactions for growth rate tended towards significance (P = 0.07), which is not surprising given the differences in nutrient requirements and growth habits of different plants. Anikwe and Atuma (2003) observed the same trend that *Lablab purpureus* grew faster compared to other forage legumes. Once established two to three months after sowing, *Lablab purpureus* is quite drought tolerant (Adebisi and Bosch, 2004). It also forms a dense soil cover which helps in moisture preservation, so that faced with poor rainfall and its late

arrival during the growing season as happened during the trial, *Lablab purpureus* had an edge in growth rate over other legumes. The results also showed a linear increase in growth of *Canavalia ensiformis*, *Vigna lobatifolia*, and *Crotalaria argyraea* with increased phosphorus (P) fertilizer level. Phosphorous encourages root development and is needed in other physiological processes in the plant. Some legumes (*Medicago sativa, Vigna unguiculata*) did not respond (or even had reduced growth [*Lablab purpureus, Cullen tomentosum*]) to increasing P fertilizer level which may indicate lower P requirements for them. Response to fertilizer application, however, also depends on soil moisture levels and given the poor and late rainfall received in the 2014/15 rain season, may explain the lack of response. Although the legume by fertilizer interaction tended towards significance, which indicates differential responses of legumes to phosphorus fertilizer application, analysis of biomass yields is indicative in general of a positive response to increasing fertilizer application up to about 80 kg P/ha. Growth rate was in fact only monitored during the early vegetative stage and its accurate assessment may be tenuous given the different growth habits (trailing, prostrate, upright or a combination thereof) of the legumes.

Crotalaria argyraea had poor germination and this could be attributed to seed dormancy. Slower growth rates were observed for *Otoptera burchellii*, *Vigna lobatifolia* and *Cullen tomentosum*. These three forage species were established from plantlets. They establish their root systems first, prior to vegetative growth as their survival mechanism. Thomas (2003) has noted that there is a conflict between a plant's ability to maximize both leaf development and root development. Strong development of deeply

penetrating roots must be at the expense of shoot production and vice versa. Thus, the growth form of every species is a compromise that can be envisaged as perhaps the best solution for the environment in which it evolved. It was evident from the experiment that *Otoptera burchellii*, *Cullen tomentosum*, could be established from cuttings, plantlets or seeds while *Vigna lobatifolia* could only be established from plantlets and seeds.

In the 2013/2014 growing season, indigenous forage legumes that were established using cuttings or seedlings had poorer growth compared to those established directly from seed. This could be because in their initial growth, all energy reserves were dedicated to the development and growth of their root systems at the expense of vegetative growth. Once their root systems are well developed, energy is channeled to vegetative growth (Thomas, 2003). Indigenous forage legumes such as *Otoptera burchellii*, *Cullen tomentosum* and *Vigna lobatifolia* outgrew improved forage legumes like *Medicago sativa* and *Vigna unguiculata* in the following (2014/2015) growing season, because they were able to mobilize their storage reserves for fast regrowth after the dormant winter season. The growth habits coupled with the perennial nature of the indigenous forage legumes (*O. burchellii*, *V. lobatifolia*) and the frost tolerance of *C. tomentosum*, make them attractive in the face of climate change and its associated negative impacts on production systems. These legumes contribute to diversity and increase resilience of rangelands in recovering from a drought and hence may play an important role in sustainability of rangelands, if well managed.

5.2.2 Days to 50% flowering of forage legumes

Maintenance of soil seed banks is crucial to persistence of legumes in rangelands; thus timing of flowering may be important in the survival of species, particularly in areas with a short growing season. As would be expected, there was a wide range in the days to 50% flowering (D50FLOWER), with *C. tomentosum*, *C. ensiformis* and *O. burchellii* having the shortest number of days. *Cullen tomentosum* is frost resistant and begins sprouting right after the dormant winter period. Similarly *O. burchellii* mobilizes its reserves for rapid vegetative growth as soon as winter is over and flowers sooner to ensure production of seed. Days to 50% flowering for *Canavalia ensiformis* was similar to the 86 days reported (Shiningayamwe, 2012); similarly for *Vigna unguiculata*, D50FLOWER was in the range reported (Shiningayamwe, 2012). In Ethiopia, Gebreyowhans and Gebremeskel (2014) reported a mean of 48 days to 50% flowering for *Vigna unguiculata*. In this study, D50FLOWER for *Lablab purpureus* was much higher (177.0 ± 1.0) than the 109 days reported (Shiningayamwe, 2012). Ogedegbe, Ogunlela, Odion and Olufajo (2011) reported 93 days to 50% flowering for *Lablab purpureus*. Ayisi et al. (2003) recorded the range of 51-150 days in South Africa while the range of 56-224 days (Pengelly & Maas, 2001) in Australia was in line with the 177.0 ± 1.0 days reported in this study. The range of 90-100 days has also been reported in Botswana (Aganga & Tshwenyane, 2003).Onset of flowering is triggered by environmental cues like temperature and light signals (Halliday, Salter, Thingnaes and Whitelam, 2003), hence the variation in the range of values reported for the same species.

5.2.3 Influence of phosphorus fertilizer application on biomass yield

As expected, the biomass yield positively responded to increasing levels of P fertilizer application up to an optimum. In this study, biomass yield increased up to 80 kg P/ha and then declined A similar trend was also observed for 100-seed weight, which increased up to 80 kg P/ha application rate and plateaued. *O. burchellii* was the exception, with decreasing 100-seed weight as P application rate increased. Inconsistent response to P fertilizer level application has two possible bases. First, forage legumes differ in their ability to utilize available forms of P in the soil and large differences exist between plant species and cultivars within species (Tauro 2009). Second,there was poor rainfall (250 mm) received during the 2014/2015 growing season when the trials were carried out, hence the potential benefits of phosphorus (P) application could not be realized.

Phosphorous is a macronutrient required for crop production (Bationo et al., 2012). It plays a role in almost all biochemical pathways as a component of the energy carrier compounds ADP and ATP (Khalil and Jan, 2003). Hence fertilizer application makes this nutrient available to forage legumes resulting in improved growth and development. Response to phophorous fertilizer application is greater where the environmental conditions are more favourable to plant growth (Singh and Saxena, 1999); hence inadequate soil moisture in the soil which curtailed plant growth may be responsible for the weak response. Most studies have indeed shown the significance of phosphorus (P) fertilizer for forage legume growth and development. For example,

acute deficiency of Phosphorus (P) can prevent nodulation by legumes (Zamah-Allah et al., 2006). Phosphorus (P) is one of the most important elements that significantly affect plant growth and metabolism (Abed et al., 2002). Phosphorous fertilizer influences growth rates, biomass yield and 100-seed weight and this study has shown differential responses among legumes; further studies are needed to determine optimum levels which may also depend on the soil types, moisture and nutrient levels.

5.2.4 SPAD values and their relationship with biomass yield

Vigna unguiculata had the highest SPAD values among the forage legumes in this study; *L. purpureus* and *O. burchellii* had the lowest. *Vigna* species fix more nitrogen in the soil compared to other forage legumes. Rusinamhodzi, Murwira & Nyamangara (2006) reported nitrogen fixation by *Vigna unguiculata* of 68-138 kg N/ha in Zimbabwe. Therefore it could be this nitrogen (N) that contributed to their high SPAD values since it is linked to chlorophyll content of the plant (Loh et al., 2002; Coste et al., 2010 and Percival, 2008). Chlorophyll content will increase in proportion to the amount of nitrogen present in the leaf (Loh et al., 2002). For a particular plant species, a higher SPAD value indicates a healthier plant. The results in this study for SPAD values were in sharp contrast to the plant vigour and growth as judged by growth rate and biomass yield. For example *Lablab purpureus* and and *Cullen tomentosum* which had the lowest SPAD values, produced the highest biomass, indicating an inverse relationship. There may be other associations between SPAD values and other forage attributes not investigated in this study.

5.3 Influence of phosphorus (P) fertilizer levels on the 100- seed weight of forage legumes: Objective (ii)

Average 100-seed weight for *Canavalia ensiformis was* 125.7 g. This was lower than the 178 g reported by Akpapunam and Sefa-Dedeh (1997). *Lablab purpureus*100-seed weight (23.13g) was within the range (22.2-45.50 g) reported by Chattopadhyay and Dutta (2010); Murphy and Colucci, (1999) reported 25.32 g/100 seeds. Aganga and Tshwenyane (2003) reported 25.30 g. Lower weight reported in this study could be attributed to poor rainfall recorded in 2014/2015 rainy season.

With the exception of *O. burchellii*, the100-seed weight generally increased as P fertilizer application increased. Successful seed germination depends partly on stored food reserves in the endosperm, hence for purposes of commercial seed multiplication, it may be beneficial to apply optimal fertilizer rates which encourages growth and high seed weight.

5.4 Chemical composition and nutritional value of forage legumes: Objective (iv)

The nutritional value of grass is variable, depending on species in sward, location, weather, time of the year, age and fertilizer application rates or timings (Barnhart, Mallarino&Sawyer, 2013). Similar factors may influence the nutritional value of forage legumes. Protein is a key nutrient that must be considered both in amount and type for various animal diets (Ball, Collins, Lacefield, Martin, Mertens, Olson, . …Undersander, 2001). The crude protein can range from 4% to 30% in heavily fertilized pastures, with crude fiber content ranging from 20% to 45% in very mature samples (Ewing, 1997). In this study, crude protein of forage legumes ranged from 16

to 26 % DM (Table 4.10) and it was not affected by the level of phosphorus fertilization. This is quite adequate to meet requirements for animals in all categories.

The minimum crude protein (CP) content in ruminant diets should be around 6.0 - 8.0% of dry matter for adequate activity of rumen microorganism (Gebreyowhans & Gebremeskel, 2014; Van Soest, 1994), suggesting that crude protein (CP) content in investigated forage legumes are more than twice the requirement. Ayisi et al. (2002) reported that crude protein of 10% on a dry matter basis is adequate for fattening cattle, but above 15% crude protein or more is required for high producing milking cows. In this study, the CP content of all forage legumes was in excess of the recommended minimum requirements for lactation (120 g/kg DM) and growth (113 g/kg DM) in ruminants (NRC, 2001).

The CP content of *Vigna unguiculata* reported in this research is in line with the range of 17.7 to 18.6 % reported (Gebreyowhans & Gebremeskel, 2014) and 17.0 -18.5 % (Ayan et al., 2012). Mullen (1999) also reported the CP % in the range of 14-24 % DM.

The crude protein for *Lablab purpureus* was 23.4 ± .7 % DM in this study, much higher than the 12.7-14.1 % reported by Evans (2002) and 16.4 % reported by Aganga and Autlwetse (2000). Similarly, the CP % in this was again higher than 13.6-22 % reported by Murphy & Colucci (1999).The CP for *Medicago sativa* in this research was higher than the range of 18.2-18.9 (Geleti et al., 2013). The CP for *Canavalia ensiformis* was higher than the 15 % DM reported by Bressani, Brenes, García and Elías (1987).

Forage protein serves as a source of absorbed protein to the ruminant by providing both rumen degradable protein (RDP) and rumen undegradable protein (RUDP) (Broderick, 1995). Rapid and extensive ruminal degradation of proteins in legume and grass forages generally leads to decreased protein efficiency. The properties of a protein determine the proportion of CP that is RDP and RUP in any forage (Broderick, 1995). Very rapid protein degradation, implies that ruminal microbes cannot utilize all of the amino acids and ammonia released and more protein will be degraded than is synthesized (Broderick, 1995).

In a study with several legumes, reduced degradation and increased rumen escape were proportional to tannin concentration (Broderick and Albrechit, 1994). In that study, however, several of the forages not containing condensed tannins, particularly red clover and kura clover had protein degradabilities comparable to those of forages with low levels of tannin suggesting that differences in rumen protein degradation among forage legumes is only partly explained by tannin concentration (Broderick and Albrechit, 1994).Although the CP content was high in the indigenous forage legumes, their utility for improving productivity will depend on among other factors the degradability in the rumen. In this research condensed tannins and other antinutrients were not be assayed for to determine potential protein degradability of the forage legumes and is an open area for future investigation.

The essentiality of P for animals is beyond question and this element may be limiting animal performance in some areas of the world. Namibia is no exception since most of the soils are inherently poor in phosphorus. It plays an essential role in

metabolism of plants, animals and micro-organisms(Pfeffer, Beede & Valk, 2005). During dry veld conditions, nitrogen is the first weak link in the cattle food chain, whereas during the growing season, the weak link is phosphate (Feed master, 2013). Research has repeatedly proven that phosphate supplements increase calving percentages, milk production and therefore pre-weaning growth.

The availability of individual minerals in the diet often varies with age of animal, level of intake and interactions with other elements or compounds (Holmes, Brooks, Garrick, Mackenzie, Parkinson &Wilson, 2002).The P % DM in this study ranged from 0.1 ± 0.1 to 0.2 ± 0.2 and for assumed availability of 50%, these levels of phosphorus (P) may not be able to meet the P daily requirements for both beef cattle and sheep, to optimize growth during the plant growing season. Therefore P supplementation has to be carried out. For example, a beef cow with live weight of 400 kg with average daily gain of 1 kg/day would require 30 g P/day (ARC, 1980). Therefore, P fertilization was not able to raise the phosphorus content in forage legumes to the amount of P required by animals daily.

Legumes differed ($P < 0.05$) in their calcium content. The highest calcium % DM (3.0 ± .2) was recorded for *Canavalia ensiformis* while the lowest was 0.9 ± .3 for *Cullen tomentosum*. Higher calcium (Ca)content in legumes increases demand for P supplementation (Minson, 1990),otherwise voluntary feed intake will be suppressed. For *Canavalia ensiformis* to be efficiently utilized, P supplementation has to be carried out because of its high calcium content.

Phospholipids are essential compounds of cellular membranes and give strength to structural components of plants (Pfeffer et al., 2005). It is against this background that phosphorus (P) fertilization affected ($P < 0.05$) NDF content of forage legumes (Table 4.12).Inline with the roles of P as structural components of plants, increasing levels of P fertilizer application simultaneously increased NDF and fat content. The NDF ranged from 30.5 ± 1.6 to 42.4 ± 1.8 % DM across forage legumes investigated. This was in line with the minimum requirement of 35 % DM for a good quality pasture diets (Kolver, 2003).

In general, forages that contain less than 70 % NDF and more than 8% crude protein will contain enough digestible protein and energy, vitamins and minerals to maintain older animals. The NDF range (30.5 ± 1.6 to 42.4 ± 1.8 % DM) reported in this study is ideal for a number of animal production classes such as nursing cows (< 55 %), lactating dairy cows, ewes and goats (25-30 %) and fattening (< 25 %). For young, growing animals nutrient and energy density of the diet should be highest shortly after birth (16 to 18 % crude protein and 30 to 40 % NDF), and gradually decrease to 12 % crude protein and 55 % NDF by the time they reach 50 % of mature weight (Ball et al., 2001).NDF of all forage legumes investigated were within the allowable range,therefore they will not have a negative bearing on the productivity of ruminant animals,hencethey could serve as supplementary forages.

Acid detergent fiber (ADF) and neutral detergent fiber (NDF) are frequently used as standard forage testing techniques for fiber analysis. NDF approximates the total cell wall constituents including hemicellulose, whereas ADF primarily represents

cellulose and lignin. ADF is often used to calculate digestibility, and NDF is used to predict intake potential (Ball et al., 2001). As fiber increases, forage quality declines. Voluntary intake, a prime consideration in feeding, is often estimated based on neutral detergent fiber (NDF) content. NDF consists of the slowly digested and non-digestible fibrous portion of the plant which is most of the cell wall material. Forages high in NDF tend to have lower intake and those with high ADF tend to have low digestibility (Solaiman, 2007). However, if NDF of the ration is too low, health problems such as acidosis, displaced abomasum, and foundering may occur (Ball et al., 2001). Therefore, NDF plays an important role in stimulating rumination, saliva production and hence buffering of rumen to prevent a fall in rumen pH and the development of acidosis (Kaiser, Moran & Piltz, 2003).

ADF is of particular interest as it is a good predictor of *invivo* digestibility in a range of tropical legumes (Aganga & Tshwenyane, 2003). As ADF % increases, the digestibility of forage declines. With the exception of *Cullen tomentosum*, the ADF content of all forage legumes investigated was below the 31 % DM upper threshold level that good quality forage was reported to contain (Geleti et al., 2013).*Cullen tomentosum* was observed to have a low leaf to stem ratio, which may explain its higher ADF content. The NDF values of forage legumes in this study fell below the reported higher levels of 55.2 % (Laura, Ioan, Andre, Roxana,Vasile& Anamaria, 2012) or 46.9% (Yu, Christensen, Mckinnon & Markert, 2003) that are regarded as having negative bearing on the productivity of foraging animals. This study has shown that chemical composition varied among investigated forage legumes and

this information, together with analysis for antinutrients which was not part of this study, could be utilised in formulating diets for supplementary feeding of ruminants; alternatively, under pasture grazing combinations of legumes could be sown to improve range productivity.

5.5 Ensiling characteristics of Forage legumes: Objective (v)

5.5.1 Sensory characteristics and pH of silages

While grasses are normally ensiled relatively well or satisfactorily, ensiling of legumes is more risky (Kaldmae et al., 2003). This is due to their low sugar content, high buffering ability and high moisture content (Pahlow et al., 2002). In this study, only *Lablab purpureus* produced satisfactory silage. The high moisture content of the forage legumes, high buffering ability and low sugar content may have inhibited proper and speedy fermentation. Fermentation quality can easily be improved by using additives (Kaldmae et al., 2003; Lattemae, 2000). The high dry mater content of samples at the time of ensiling, may have contributed to the poor ensiling. The dry matter percentages at ensiling were: *Otoptera burchellii* (71.7), *Canavalia ensiformis* (55.1), *Lablab purpureus* (43.9), *Cullen tomentosum* (57.9) and *Medicago sativa* (50.7). Ideally, forage should be ensiled at 30-37 % dry matter (Moran, 2005). *Lablab purpureus* was ensiled at 43.9 % DM; hence it produced satisfactory results in contrast to the rest of forage legumes.

In general, the range of pH values for silage should be 3.5 to 4.3 (Jianxin & Jun, 2002). In this study, the pH values ranged from 5.4 ± 0.1 to 6.8 ± 0.1, which was an indication that proper fermentation did not take place. *Otoptera burchellii* scored lowest

on overall score and was rated bad because of high dry matter percentage (71.7) at ensiling, which made the elimination of oxygen difficult during compaction, leading to aerobic spoilage of silage.

5.5.2 Chemical composition of silages

Crude protein (CP) of *Canavalia ensiformis* was high compared to the results obtained from un-ensiled samples. The rest of the forage samples had decreased CP content even though it was within the allowable content. Dewhurst (2013) reported 18.7 % crude protein DM for *Medicago sativa* which was similar to what is recorded in this study. However, this was lower than the range of 20-24 % DM reported by Pioneer (2010). The low crude protein percentage for some legumes (*L. purpureus* and *M. sativa*) reported in this study could be attributed to the physiological maturity of forage legumes at the time ensiling was carried out. All forage legumes were at post-bloom stage with some already having ripe seeds. The other contributing factor could be frost that affected forage legumes prior to ensiling. The substantial loss of crude protein during the ensiling process could also be linked to protein degradation, which has been documented during fermentation of many legumes (Albrecht & Muck, 1991). The crude protein (CP) in silage has been reported to be lower than in fresh fodder (Amoudu, Adamu, Adeyinka, Alawa& Jegede, 2005). Notwithstanding the losses during the ensiling process, crude protein content was still higher that the critical allowable content of 12 % DM.

The NDF for *L. purpureus* and *M. sativa* silages were in the range of 45-55% DM, indicating increased concentration of fiber which is associated with lower

digestibility (Holmes et al., 2002); the rest of the legumes were in the more acceptable ranges. For a good quality pasture diet, NDF percentage should range between 35 and less than 70 % DM (Kolver, 2003), while ADF should be below 31 % DM (Geleti et al., 2013). The ADF for both *L. purpureus* and *M. sativa* silages were within acceptable ranges for increasing productivity of ruminants.

Mineral concentrations in the silages were variable among the forages, with *Canavalia ensiformis* having the highest calcium concentration. The critical level of Ca in the diet has been set at 0.30% DM Ca (NRC, 1984; Holmes et al., 2002), and Ca concentrations in this study were above this threshold (Table 4.14). The critical value for Phosphorus in herbage is 0.18% DM (NRC, 1984; Holmes et al., 2002) and the values for silages in this study, more or less meet this requirement (Table 4.14). However, fast-growing young stock and lactating cows have the highest mineral requirements and hence are most likely to be deficient when grazing pasture and warrant supplementation to avoid disorders (Holmes et al., 2002).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Biomass yields of forage legumes in this study were different thus rejecting the second null hypothesis. The study indicated that *L. purpureus* had the highest biomass yield (8.9 ± .3 tons/ha), far exceeding *Medicago sativa* (4.7 ± 0.3tons/ha), the most common cultivated forage legume in Namibia.
- The indigenous legumes *Otoptera burchellii* and *Vigna lobatifolia* had substantial biomass yields (2.5 ± 0.3 vs. 1.5 ± 0.4 tons/ha) and their yields may have been underestimated because they are perennial and were still in early establishment phases. The regeneration capacity of *O. burchellii* and *V. lobatifolia* is an important adaptive characteristic that hinges on having deep root systems and storage tubers, which are important for persistence and adaptability to semiarid environments. Therefore, they showed potential as forage crops and could contribute substantially to improving nutrition of ruminants if well managed in rangelands.
- Although germination and establishment were not uniform across all the legumes investigated, it is apparent that the P fertilization was beneficial in improving biomass yield of most legumes. The optimal P fertilization application rate was not clearly depicted in this study because of the low moisture content in soils, hence a need for additional research to determine optimal levels. Special attention should be

paid to *O. burchellii*, which gave inconsistent results for growth rates, biomass yield and 100-seed weight as the P fertilizer application was increased.

- Phosphorous fertilizer application also increased NDF, P and fat (% DM) in forage legumes. With the exception of *O. burchellii*, phosphorous application up to 80 kg P/ha tended to increase 100-seed weight of forage legumes and hence may be beneficial to commercial seed producers.
- The legumes should be grown in the wet season, harvested and conserved to be fed as supplements in the dry season. It is during the dry season that natural pasture is inadequate and of poor quality and the legumes would offer a relatively cheap source of supplementary feeding. Alternatively, legumes could be grown in protein banks and the animals allowed access to them under restricted grazing (Piaggio, Marichal *& Pastorin, 2*015). The legumes could also be over-sown in natural pastures.
- *Cullen tomentosum* produced a substantial biomass yield (5.1 ± 0.4 tons/ha) comparable to that of Lucerne, but based on the palatability trial (Thamina, 2015), it was not readily eaten by livestock, but could be useful as a cover crop.
- The study has demonstrated that indigenous forage legumes can be successfully domesticated. Various planting materials (seed, plantlets or cuttings) may be required for fast establishment and appropriate agronomic practices (e.g. sowing, weeding, staking and fertilization) have to be tailored to the different legumes depending on whether the interest is on seed multiplication or biomass production.

- All forage legumes contain adequate crude protein (> 12% CP on DM basis) that can meet the requirements for animals in all categories. However, adequacy of a specific legume for ruminant nutrition is dependent on the degradability of the CP in the rumen. Also anti-nutrients may differ among legumes and this aspect needs investigation. Phosphorous (P) fertilization was not able to raise the phosphorus content in forage legumes to the amount of P required by animals daily. Feeding a variety of legumes may be better able to meet the nutritional needs of animals, especially the young and those in lactation with high requirements for maximum performance.
- More work is needed on optimizing seed germination and fertilizer application; also persistence of different legumes in rangelands needs to be investigated.
- While grasses are normally ensiled relatively well, ensiling of legumes is more cumbersome. With the exception of *Lablab purpureus*, ensiling did not yield satisfactory results as shown by the higher pH values and low overall scores obtained. This may be due to the low sugar content and high buffering ability of legumes. Also forage legumes were ensiled at high dry matter content (43 – 70%) which led to microbial spoilage of silages. It was also evident that different forage legume species had varied ensiling characteristics and hence the null hypothesis is rejected.
- To improve the ensiling of legumes, it is advisable to use chemical conservants or additives that inhibit aerobic spoilage such as propionic and acetic acid (Jianxin & Jun (2002). Addition of such additives inhibits growth of aerobic spoilage

organisms particularly the ones causing the onset of deterioration. Since legumes are low in water soluble carbohydrates, addition of sugar is required for them to produce good quality silage. This is achieved either by adding sugars directly such as molasses or by adding enzymes that release extra sugars from forage crops. Caution should also be exercised to ensure the legumes are wilted to acceptable DM (30-37%) to ensure proper fermentation (Moran, 2005).

- All silages from all ensiled forage legumes contained sufficient percentage of protein that could meet the requirements of all categories of ruminant animals. Since crude protein in silages was lower than the concentration in hay, it was an indication that protein degradation occurred during the ensiling process. ADF and NDF levels in the legume hays were generally in the acceptable ranges for improved animal performance. Conservation of legumes as hays may be less cumbersome because of the fast wilting time under the conditions in central Namibia.

6.2 Recommendations

- It is recommended that *Lablab purpureus* be incorporated into forage production in Namibia because of its high biomass yield potential, high protein content and drought tolerance. *Otoptera burchellii* and *Vigna lobatifolia*had good growth rates and biomass yield. They are perennial, highly nutritious and could contribute substantially to improving nutrition of ruminants if well managed in rangelands. Companion work (Thamina, 2015) looks in the aspects of nutritive value for goats and will provide guidance on future research work to be done on these species.

- It was oberved that indigenous forage legumes such as *Otoptera burchellii*, *Vigna lobatifolia* and *Crotalaria argyraea* did not produce vigorous growth in the first season. However, the growth was substantial in the second growing season. Therefore it is recommended that they should only be harvested or grazed the second season after propagation for them to persist and produce adequate amounts of forage.
- Phoshorous fertilizer application up to about 80 kg P/ha may improve biomass yield and facilitate forage legume establishment. Application of P fertilizer is also recommended to boost forage legume seed yield especially under commercial seed production.Further research under controlled moisture regimes is, however, needed to optimize P fertilizer application rates for the different legumes, specifically for *O. burchellii* which showed inconsistent trends for the different characteristics studied (growth rate, biomass yield and 100-seed weight). Soil analysis is also needed before determining appropriate fertilizer choice and amount.
- Even though *Cullen tomentosum* was not palatable and not prefered by animals in the companion study (Thamina, 2015), alternative usage needs to be explored for example in the fields of cosmetics and pharmaceutics. It is a psychotropic plant, (van Wyk & Gericke, 2000); hence this distinct characteristic could be explored in pharmaceutical industry. Therefore, it is recommended that further research be done on the plant to reap the benefits of its sedative nature. Its healing power also needs further research. This study has demonstrated that it can easily be domesticated to boost biomass yield and may be a useful cover crop.

- It is recommended that whenever SPAD values of forage legumes are taken, chlorophyll content of the leaves should also be determined to draw useful inferences.
- The study indicated that indigenous forage legumes were resilient to cutting and may in fact produce higher biomass yields. Therefore future studies should be aimed at determining optimal cutting intervals for indigenous legumes grown for cut-and-carry systems.
- Forage legumes produced hay of exceptional quality compared to silage. Since legumes are normally difficult to ensile, it is recommended that efforts should be geared towards producing hay of good quality either cut or standing. In cases where silage has to be produced, additives should be used to enhance proper fermentation.
- This study has demonstrated that indigenous forage legumes can be successfully domesticated. Additional work should be done to assay for anti-nutrients (e.g. tannins, saponins) that affect utilization by ruminants. Other aspects that warrant research are: persistence; compatible legumes and grasses for over-sowing; micro-nutrient supply to optimize growth; nitrogen fixation potential. Furthermore, other indigenous legumes not investigated should be studied to exploit the wide diversity in forage legumes that exists.

REFERENCES

Abed, S., Ticconi, C. A., & Delatorre, C. A. (2002). Phosphorus sensing in high plants. *Physiologia Plantarum*, *115*, 1-8.

Adebisi, A. A., & Bosch, C. H. (2004). *Lablab purpureus* (L.) sweet. In G. J. H. Grubben, & O. A. Denton (Editors). *Plant resources of tropical Africa 2: Vegetables* (pp 343-348). Leiden, Netherlands: Backhuys Publishers.

Adeyanju, A. O., Ishiyaku, M. F., Echekwu, C. A., & Olarewaju, J. D. (2012). Generation mean analysis of dual purpose traits in cowpea (*Vigna unguiculata* [L.] walp). *African Journal of Biotechnology*, *11*(46), 10473-10483.

Aganga, A. A., &Autlwetse, M. N. (2000). Utilization of sorghum forage, millet forage, veldt grass and buffer grass by Tswana sheep and goats when fed *Lablab purpureus L*. as protein supplement. *Asian-Australian Journal of Animal Science*, *13*: 1035-1188.

Aganga, A. A., & Tshwenyane, S. O. (2003). Lucerne, lablab and *Leucaena leucocephalla* forages: Production and utilization for livestock production. *Pakistan Journal of Nutrition*, *2*(2), 46-53.

Agricol. (2015, June). Feed facts: The advantage of legumes in pastures. *Stock Farm*, *5*(6), 26.

Agricol. (2015, August). Feed facts: Successful mixtures for summer pastures. *Stock Farm*, *5*(8), 37.

Agricultural Research Council (ARC). (1980). *The nutrient requirements of ruminant livestock*. Slough, England: Commonwealth Agricultural Bureaux.

Akpapunam, M. A., & Sefa-Delah, S. (1997). Jack bean (Canavalia ensiformis): Nutrition related aspects and needed nutrition research. *Plant Foods Human Nutrition Journal, 50*(2), 93-99.

Akundabweni, L. M. S. (1984). Native clovers of the Ethiopian Highlands: The blackwood champion. *ILCA Newsletter, 3*, 5-6.

Albrecht, K. A., & Muck, R. E. (1991). Proteolysis in ensiled forage legumes that vary in tannin concentration. *Crop Science, 31*, 464–469.

Aminah, A., & Chen, C. P. (1991). *Future prospects for fodder and pasture production*. FAO Animal Production and Health Paper, Thailand.

Amira, S., Soliman, A. S., & Abbas, M. S. (2013). Effects of Sulfuric Acid and Hot Water Pre-Treatments on Seed Germination and Seedlings Growth of *Cassia fistula* L. American-Eurasian. *Journal of Agriculture & Environmental Science, 13*(1),7-15.

Amoudu, J. T., Adamu, A. M., Adeyinka, I. A., Alawa, J. P., & Jegede, J. O. (2005). The nutritive value of laboratory ensiled lablab (*Lablab purpureus*) and pearl millet (*Pennisetum americanum*). *Tropical Grasslands, 39*, 117-123.

Anikwe, M. A. M., & Atuma, J. (2003). *Characterizing the suitability of selected indigenous soil improving legumes in a humid tropical environment using shoot and root attributes*. Enugu, Nigeria: University of Science and Technology.

Argel, P. J. (1994). Regional experience with forage *Arachis* in Central America and Mexico. In P. C. Kerridge &B. Harding (Eds), *Biology and Anatomy of Forage Arachis* (pp. 257-268). Cali, Colombia: CIAT

Association of Official Analytical Chemists International (AOAC).(1995). *Official methods of analysis of AOAC International* (16th ed.). Maryland, USA: AOAC International.

ARC. (1984). *Feed requirement*s. Pretoria, South Africa: Agricultural Research Council.

Ayan, I., Mut, H., Basaran, U., Acar, Z., & Asci, O. O. (2012). Forage potential of cowpea (*Vigna unguiculata* L. Walp). *Turkish Journal of Field Crops, 17*(2), 135-138

Ayisi, K. k., Bopane, M. P., & Pengelly, B. C. (2004). Assessment of the Variation in Growth and Yield of Diverse Lablab (*Lablab purpureus*) Germplasm in Limpopo Province, South Africa. In A. M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 44-50). Canberra, Australia: Australian Centre for International Agricultural Research.

Ayisi, K. K., Mokoboki, H. K., & Ndlovu, L. R. (2002). Chemical and physical parameters of forage legume species introduced in the Capricorn region of Limpopo Province: *South African Journal of Animal Science, 32*(4).

Ball, D. M., Collins, M. M., Lacefield, G. D., Martin, N. P., Mertens, D. A., Olson, K. E. …Undersander, D. J. (2001). *Understanding forage quality*. Park Ridge, IL: American Farm Bureau Federation Publication.

Baloyi, J. J., Ngongoni, N. T., &Hamudikuwanda, H. (2008). Chemical composition and ruminal degradability of cowpea and silver leaf desmodium forage legumes harvested at different stages of maturity. *Tropical and Subtropical Agro ecosystems, 8*(1), 3-13.

Baph (Bureau of Animal Production and Health). (1996). Criteria for evaluation of silage quality. In Ministry of Agriculture (Ed.), *Trial execution Baph* (pp. 1-9). Beijing, China: Baph.

Bationo, A., Fairhurst, T., Giller, K., Kelly, V., Lunduka, R., Mando, A.,…Zingore, S. (2012). A*frica soil health consortium: Handbook for integrated soil fertility management* (T. Fairhurst, Ed.). Pondicherry, India: CAB International.

Bax, J. (2015, May). Quality is king when making silage. *Stock Farm, 5*(5), 27-29.

Bayer, W., &Waters–Bayer, A. (1998). Forage Husbandry: The Tropical Agriculturalist. (R. Coste, Ed.), London: Macmillan.

Berrie, A. M. M. (1985). *Germination and Dormancy. In: M.B. Wilkins (Ed.),* Advanced Plant Physiology, Melbourne, Australia: Pitman Ltd. pp. 440-468.

Boitumelo, W.S., & Mahabile, W. (1992*).* Improving milk production in small-scale dairy farms in Botswana: Incorporating legume fodder in the farming system: In (J.E.S. Staves, A.N. Said, & J.A. Kategelie (Eds.), *Proceedings of the Joint Feed*

Resources Networks Workshop held in Gaborone, Botswana 4 - 8 March 1991 (1991) (pp353-362). Addis Ababa, Ethiopia.

Bressani, R., Brenes, R. G., García, A. & Elías, L. G. (1987). Chemical composition, amino acid content and protein quality of *Canavalia* spp. seeds. *Journal of the Science of Food and Agriculture, 40*(1), 17–23.

Cheng, L., Kim, E. J., Merry, R. J., & Dewhurst, R. J. (2011). Nitrogen partitioning and isotopic fractionation in dairy cows consuming diets based on a range of contrasting forages. *Journal of Dairy Science, 94*, 2031-2041.

Chigariro, B. (2004). The farming systems of the Zimbabwean district of Wedza and the role and adoption of forage legumes in small-scale crop-livestock enterprises. In A. M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 12-16). Canberra, Australia: Australian Centre for International Agricultural Research.

Church, D. D. (1991). *Livestock feeds and feeding*. New Jersey: Prentice-Hall Inc.

Clem, R. L. (2004). Animal production from legume based ley pastures in south-eastern Queensland. In A. M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 135-144). Canberra, Australia: Australian Centre for International Agricultural Research.

Clem, R. L., & Cook, B. G. (2004). Identification and development of forage species for long-term pasture leys for the southern spear grass region of Queensland. In A.

M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115*. *Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 64-79). Canberra, Australia: Australian Centre for International Agricultural Research.

Coste, S., Baraloto, C., Leroy, C., Marcon, E., Renaud, A., Richardson, A.,…Herault, B. (2010). Assessing foliar chlorophyll contents with the SPAD 502 chlorophyll meter: Calibration test with thirteen tree species of tropical rain forest in French Guiana. *Annals of Forest Science, 67*(6), 607-609.

Dakora, F. D. (2003). Defining new roles for plant and rhizobial molecules in sole and mixed plant cultures involving symbiotic legumes. *New Phytologist, 158*, 39-49.

Devendra, C. (1991). Nutritional potential of fodder trees and shrubs as protein sources in ruminant nutrition: Legume trees and other fodder trees as protein sources for livestock. In A. Speedy, & P. Pugliese (Eds.),*Proceedings of the FAO Expert Consultation Held at the Malaysian Agricultural Research and Development Institute (14-18 October 1991)* (pp. 95-116). Rome: FAO

Dewhurst, R. J., Delaby, L., Moloney, A., Boland, T., & Lewis, E. (2009). Nutritive value of forage legumes used for grazing and silage. *Irish Journal of Agricultural and Food Research, 48*, 167-187.

Diggs, G. M. Jr., Lipscomb, B. L., & O'Kennon, R. J. (1991). *Shinners and Mahler's illustrated flora of north central Texas*. Fort Worth: Botanical Research Institute of Texas.

Drought: Ministry urges farmers. (2015, May 06). Drought: Ministry urges farmers to sell livestock. *The Namibian Sun*, p. 1.

Evans, D. O. (2002). *Sustainable agriculture in Hawaii: Green manures: Legumes-lablab*. Retrieved from Hawaii sustainable agriculture website: http://www.2.ctahr.Hawaii.edu/sustainag/SustainableAg/GreenManures/lablab.asp

Ewansila, S. U., Chiezey, U. F., Tarawali, S. A., & Iwuafor, N. O. (2007). Potential of *Lablab purpureus* accessions for crop-livestock production in the West African savanna. *The Journal of Agricultural Science, 145*(3), 229-23.

Ewing, W. W. (1997). The feeds directory. Leicestershire, England: Context Publications.

Farley, R. A., & Fitter, A. H. (1999). The responses of seven co-occurring woodland herbaceous perennials to localized nutrient-rich patches. *Journal of Ecology 87*, 849-859.

Feed Master. (2013). *Product guide* (Product information booklet). Windhoek: Feed Master.

Food and Agricultural Organization (FAO). (2005). *On-line statistical database*. Retrieved from FAO website: http://www.fao.org/ag/AGPC/doc/couprof/

Food and Agricultural Organization (FAO). (2011). *Silage making for small scale farmers*. USA: Food and Agricultural Organization.

Franklin, W.M. (1993). *Forages: Echo technical notes*. Myers FL, USA: Echo.

Fraser, M.D., Speijers, M. H. M., Theobald, V.J., Fychan, R., &Jones, R. (2004). Production performance and meat quality of grazing lambs finished on red clover, Lucerne or perennial ryegrass swards. *Grass Forage Science Journal, 59*, 345-356.

Fraser, M. D., Haresign, W., & Speijers, M. H. (2004). The effect of ensiled forage legumes on performance of store finishing lambs. Retrieved from http://www.aginternetwork.net/

Gathumbi, S. M., Cadisch, G., & Giller, K. E. (2004). Improved fallows: effects of species interaction on growth and productivity in monoculture and mixed stands. *Forestry Ecology and management, 187*, 267-280.

Gebreyowhans, S., & Gebremeskel, K. (2014). Forage production potential and nutritive value of cowpea (*Vigna unguiculata*) genotypes in the northern lowlands of Ethiopia. *E3 Journal of Agricultural Research and Development, 5*(4), 066-071.

Geleti, D., Hailemariam, M., Mengistu, A., & Tolera, A. (2013). Biomass yield potential and nutritive value of selected alfalfa (Medicago *sativa L*.) cultivars grown under tepid to cool sub-moist agro-ecology of Ethiopia. *E3 Journal of Agricultural Research and Development, 4*(1), 007-014.

Giller, K. E. (2001). *Nitrogen fixation in tropical cropping system* (2nd ed.). Wallingford: CAD International.

Giller, K. E., & Mapfumo, P. (2002). Biological nitrogen fixation, forms and regulation factors (R. Lal, Ed.) *Encyclopedia of Soil Science*, NY: Marcel Dekker.

Gous, R. M., Nesamvuri, A. E., Raphulu, T., & Tshovhote, N. J. (2003). The chemical composition, energy and amino acid digestibility of cowpeas used in poultry nutrition. *South African Journal of Animal Science*, *34*(2), 116-117.

Grubben, G. J. H., & Denton, O. A. (2004). Plant resources of tropical Africa 2: Vegetables. Wageningen, Netherlands: Backhuys Publishers.

Gwatyu, M., & Jooste, C. (2011, July). Arrow leaf: This hardy legume can reduce farming costs when feed sells at a premium. *Farming South Africa, 047*, 12-13.

Halliday, K. J., Salter, M. G., Thingnaes, E., & Whitelam, G. C. (2003). Phytochrome control of flowering is temperature sensitive and correlates with expression of the floral integrator FT. *The Plant Journal, 33*, 875–885.

Haque, I., & Jutzi, S. (1984). Nitrogen fixation by forage legumes in Sub-Saharan Africa: Potential and Limitations. *ILCA Bulletin 20*, 2-13.

Haque, I., Nnadi, L. N., & Mohamed-Saleem, M. A. (1985). Phosphorus management with specific reference to forage legumes in sub-Sahara Africa: Potentials of forage legumes in farming systems of sub-Sahara Africa, *Proceedings of a Workshop Held at ILCA (16-19 September 1985)* (pp. 100-119) Addis Ababa: International Livestock Centre for Africa.

Hartman, H. T. & Kester, D. E. (1997). *Plant Propagation Principles and Practices* (4th ed.). New Jersey: Prentice Hall, Inc.

Helmstetter, D., & McKee, J. (1995). *The fodder situation in an overgrazed area: the case of Onamutanda (Ohangwena Region)*. Ongwediva, Namibia: Ministry of Agriculture, water and Rural Development.

Holmes, C. W., Brooks, I. M., Garrick, D. J., MacKenzie, D. D. S., Parkinson, T. J., & Wilson, G. F. (2002). Milk production from pasture. Palmerston North, N.Z.: Massey University.

Huhtanen, P., Rinne, M., & Nousainen, J. (2007). Evaluation of the factors affecting silage intake of dairy cows: A revision of the relative silage dry matter intake index. *Aminal 1*, 758-770.

Humphreys, L. R. (1994). *Tropical forages: their role in sustainable agriculture*. Harlow: Longman Scientific and Technical.

ILDT. (2006). Information about the family leguminosae. Retrieved from ILDIS website: http://www.ildis.org/legumeminosae

Jianxin, L., & Jun, G. (2002). Ensiling crop residues. In G. Tingshuang, M. D. Sánchez, & G. P. Yu (Eds.), Animal production based on crop residues - Chinese experiences. *FAO Animal Production and Health Paper, 149*, 79-96.

Joint Presidency Committee (JPC). (2008). *Large stock management: Training manual*. Windhoek, Namibia: Namibia National Farmers Union.

Kaiser, A. G., Moran, J. B., & Piltz, J. W. (2003). *Feeding silage to dairy cows*. New South Wales, Australia: Department of Primary Industries.

Kaldmae, H., & Vadi, M. (2000). *The nutritive value of the graminaceus and tetraploid clover at different growth stages for ensiling: Proceedings of the Inter. Conference "Animal Nutrition"*. Tartu, Estonia: Institute of Animal Science of Estonian Agricultural University.

Kaldmae, H., Vadi, M., Kirsel, R., & Olt, A. (2003*). Effect of growth stage of legumes*

on silage digestibility. Tartu, Estonia: Institute of Animal Science of Estonian Agricultural University.

Kamanga, B.C.G. & Shamudzarira, Z. (2001).*7th Eastern and Southern Africa Maize Conference: On-farm legume experimentation to improve soil fertility in Zimuto Communal Area*. Nairobi, Kenya: Syngenta Foundation for Agricultural Development.

Karachi, M. (1997). Growth and nutritive value of *Lablab purpureus* accessions in semi-arid Kenya. *Tropical Grasslands, 31*, 214-218.

Khalil, H., Osuji, P. O., Umunna, N.N., & Crosses, S. (1994): The effects of forage type (maize- lablab or oats- vetch) and level of supplementation (wheat millings) on food intake, diets apparent digestibility purine excretion and milk production of cross bred (Bos taurus and indicus) cows. *Animal production 58*, 321-328.

Khalil, I. A., &Jan, A. (2003). *Cropping technology*. Islamabad, Pakistan: National Book Foundation.

Koenig, R., Beaver, M. N., Barnhill, J. & Miner, D. (2002). *Fertilizer management for grass and grass-legume mixtures*. Utah, USA: Utah State University.

Kolver, E. S. (2003). Nutritional limitations to increased production on pasture-based systems. *Proceedings of the Nutrition Society, 62*, 291–300.

Kruger, B., & Lammerts-Imbuwa, L. (2008). *Training manual: Livestock marketing in Namibia*. Windhoek, Namibia: Namibia National Farmers Union.

Kuvare, U., Maharero, T., & Kamupingene, G. (2008). *Research on farming systems change to enable adaptation to climate change*. Windhoek, Namibia: University of Namibia.

Kyffhauser Flora. (2014). *Otoptera burchellii*. Retrieved from http://www.kyffhauser.co.za/plants/otopteraburchellii/index.htm

Lattemae, P. (2000). *Influence of additives and duration of herbage wilting on quality of round bale silage*. Proceedings of the Animal Nutrition Conference May 25-26. Tartu, Estonia: Institute of Animal Science of Estonian Agricultural University.

Lauer, J., & Sterry, R. (2013). Pricing corn silage. *Field Crops, 28*, 104.

Laura, M. D., Ioan, R., Andre, T., Roxana, V., Vasile, F., & Anamaria, C. (2012). Determination of alfalfa crude fiber, NDF, ADF and Lignin content by NIR Spectrometry. *Lucrari Ştiin ţifice-seria Agronomie, 55*, 245-249.

Leep, R., Dietz, T., & Min, D. (2002). Perennial legume and grass forage variety selection for Michigan. *Extension Bulletin E-2787*. Michigan: Michigan State University.

Ling, Q., Huang, W., & Jarvis, P. (2011). Erratum to: Use of a SPAD-502 meter to measure leaf chlorophyll concentration in Arabidopsis thaliana. *Photosynthesis Research, 107*, 209-214.

Lloyd, D., Johnson, B., & O'brien, S. (2007). Sown pasture grasses and legumes for marginal cropping lands in southern inland Queensland. *Tropical Grasslands, 41*, 164-173.

Loh, F. C. W., Grabosky, J. C., & Bassuk, N. L. (2002). Using the SPAD 502 meter to assess chlorophyll and nitrogen content of Benjamin fig and cottonwood leaves. *Hortechnology, 12*(4), 682-686.

Madamba, R., Grubben, G.J.H., Asante, I.K., & Akromah, R. (2006). *Vigna unguiculata* (L.) walp. In M. Brink& G. Belay (Eds.) *Plant resources of Tropical Africa: Cereals* (pp 221-229). Wageningen, Netherlands: Backhuys Publishers.

Majewski, C. (2007). *Forages: Pasture production with selected forage species*. USA: University of New Hampshire.

Mapfumo, P., Mtambanengwe, F., Giller, K.E., &Mpepereki, S. (2005). Tapping indigenous herbaceous legumes for soil fertility management by resource-poor farmer in Zimbabwe. *Agriculture Ecosystem and Environment, 109*, 221-233.

Markwell, J., Osterman, J. C., & Mitchell, J. L. (1995). Calibration of the Minolta SPAD-502 leaf chlorophyll meter. *Photosynthesis Research, 46*, 467-472.

Martin, F. W. (1993). *Forages*. Retrieved from Echo website: http://www.echonet.org/

MAWF (Ministry of Agriculture, Water and Forestry). (1997). *Livestock production and health in North Central Namibia* (Technical report 2). Ongwediva, Namibia: FSRE.

MAWF (Ministry of Agriculture, Water and Forestry). (2003). *Vegetation map of Namibia*. Windhoek: Ministry of Agriculture, Water and Forestry.

MAWF (Ministry of Agriculture, Water and Forestry). (2007). *Agricultural Statistics Bulletin*. Windhoek: Directorate of Planning

Megan, R. (2003). *Native legumes yield wide-range benefits*. Canberra: University of West Australia.

Mendelsohn, J., Jarvis, A., Roberts, C., & Robertson, T. (2002). Atlas of Namibia: A portrait of the land its people. David Philip Publisher. Cape Town. South Africa.

Mendelsohn, J., el Obeid, S., de Klerk, N., & Vigne, P. (2006). *Farming Systems in Namibia*. Windhoek, Namibia: RAISON.

Milford, R., & Minson, D. J. (1968). The digestibility and intake of six varieties of Rhodes grass (*Chloris gayana*). *Australian Journal of Experimental Agriculture and Animal Husbandry 8*, 413-418.

Miller, D.A., &Reetz, H. F. (1995). *Forage fertilization: Forages*. USA: Iowa State University Press.

Minson, D. J. (1990). *Forage in ruminant nutrition*. San Diego, New York: Academic Press, Inc.

Mokoboki, H. K., Ndlovu, L. N. & Ayisi, K. K. 2002, Chemical and physical parameters of forage legume species introduced in the Capricorn region of Limpompo Province. *South Africa, Journal of Animal Science, 32*(4).

Moran, J. (2005). *Tropical dairy farming: Feeding management for small holder dairy farmers in the humid tropics*. Retrieved from Land Links website: http://www.landlinks.com.au

Muck, R. E., & Pitt, R. E. (1993). Ensiling and its effect on crop quality. In NRAES Cooperative Extension (Ed.), *Proceedings of the National Silage Production*

Conference (Syracuse - 23-25 February 1993) (p. 57). Ithaca, NY: NRAES Cooperative Extension.

Muir, J. P., Pitman, W. D., Dubeux, J. C. Jr., & Foster, J. L. (2014). The future of warm-season, tropical and subtropical forage legumes in sustainable pastures and rangelands. *African Journal of Range & Forage Science, 31*(3), 187-198.

Mukulu, O., & Sweet, J. (1997). *On station screening of fodder species in North Central Regions* (Report). Ongwediva, Namibia: FSRE Unit.

Mullen, C. (1999). Summer legume forage crops: Cowpeas, lablab, soybeans. Retrieved from Department of Primary Industry website of New South Wales of Australia: http://www.dpi.nsw.gov.au/agriculture/broadacre/forage-fodder/crops/summer-legume-forag

Murphy, A. M., & Colucci, P. E. (1999). A tropical forage solution to poor quality ruminant diets: A review of *Lablab purpureus*. *Livestock Research for Rural Development, 11*(2). Retrieved from Livestock Research for Rural Development website: http://www.lrrd.org/

Murungweni, C., Mabuku, O., & Manyawu, G. J. (2004). Mucuna, Lablab and Paprika Calyx as Substitutes for Commercial Protein Sources used in Dairy and Pen-fattening Diets by Smallholder Farmers of Zimbabwe. In A. M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115*. *Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 126-135). Canberra, Australia: Australian Centre for International Agricultural Research.

Namibia National Farmers Union (NNFU). (2006). *Farming systems in Namibia*. Cape town, South Africa: ABC press.

National Planning Commission. (2012). *Namibia development plan 4* (Document). Windhoek, Namibia: Office of the President.

National Research Council (NRC). (1984) *Nutrient requirements of domestic animals: Nutrient requirements of beef cattle* (6th Ed.). Washington, D.C: National Academy of Sciences.

National Research Council (NRC). (2001). *Nutrient requirements of dairy cattle*. Washington, DC: National Academy Press.

Nordin, A., Hogberg, P., & Nasholim, T. (2001). Soil N form availability and plant N uptake N uptake along boreal forest productivity gradient. *Oecologia, 129*, 125-132.

Nworgu, F. C., & Ajayi, F. T. (2005). Biomass, dry matter yield, proximate and mineral composition of forage legumes grown as early dry season feeds. *Livestock Research for Rural Development, 17*(11), 234-241.

Nyende, P., & Delve, R. J. (2004). Farmer participatory evaluation of legume cover crop and biomass: Transfer technologies for soil fertility improvement using farmer criteria, preference ranking and logic regression analysis. *Experimental Agriculture*, *40*(1-4), 77-88.

Nyoka, R., Chikumba, N., Chakoma, I., Mazaiwana, P., Mukombe, N., & Magwenzi, N. (2004). Evaluation and screening of forage legumes for sustainable integration into crop–livestock farming systems of Wedza district. In A. M. Whitbread, &B.

C. Pengelly (Eds.), *ACIAR Proceedings: No. 115*. *Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 58-63).

Ogedegbe, S. A., Ogunlela, V. B., Odion, E. C., & Olufajo, O. O. (2011). Growth and growth attributes of lablab (*Lablab purpureus* L. Sweet) as influenced by phosphorus application, cutting height and age of cutting. *Research Journal of Agronomy, 5(1), 10-19*.

Ogwang, B. H. (1985). *Research on forage legumes in Swaziland*. Luyengo, Swaziland: University of Swaziland

O'Hara, G.W. (2001). Nutritional constraints on root nodule bacteria affecting symbiotic nitrogen fixation. *Australian Journal of Agricultural Experiments*, 417-433.

Ojiem, J. O., Ransom, J. K., Odongo, O. M., & Okwuossa, E. A. (1998). *Chemical characterization and agronomical evaluation of potential green manure species in 103 western Kenya*: *Proceedings of the 6th, Eastern and Southern Africa CIMMYT maize conference*. Kenya, Nairobi: CIMMYT.

Owens, F. N., Sapienza, D. A., & Hassen, A. T. (2010). Effect of nutrient composition of feeds on digestibility. *Journal of Animal Science, 88*, 151-169.

Pahlow, G., Rammer. C., Slottner, D., & Tuori, M. (2002). Ensiling of legumes (R. J. Wilkins & C. Paul, Eds.). *Legume Silages for Animal Production: LEGSIL*. Braunschweig, Germany: Landwirtschaft.

Pandey, G. S., & Volkuil, G. C. J. (2011). *Conservation of fodder as silage and hay for the dry season: Manual on improved feeding of dairy cattle by smallholder farmers*. Lusaka, Zambia: Golden Valley Agricultural Research Trust.

Pandrangi, S., Elwell, M. W., Anantheswaran, R. C., & Laborde, L. F. (2003). Efficacy of sulfuric acid scarification and disinfectant treatments in eliminating Escherichia Coli O 157: H7 from alfalfa seeds prior to sprouting. *Journal of Food Science*, *68*(1).

Peng, S., Garcia, F. C., Laza, R. C., Sanico, A. L., Visperas, R. M., & Cassman, K. G. (1996). Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. *Field Crops Research*, *47*, 243–252.

Pengelly, B. C., & Maass, B. L. (2001). Lablab purpureus – diversity, potential use and determination of a core collection of this multi-purpose tropical legume. *Genetic Research Crop Evolution*, *48*, 261-272.

Pengelly, B. C., Whitbread, A., Mazaiwana, P. R., & Mukombe, N. (2004). Tropical Forage Research for the Future: Better Use of Research Resources to Deliver Adoption and Benefits to Farmers. In A. M. Whitbread, & B. C. Pengelly (Eds.), *ACIAR Proceedings: No. 115*. *Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia* (pp. 28-37).

Percival, G. C., Keary, I. P., & Noviss, K. (2008). The potential of a chlorophyll content SPAD meter to quantify nutrient stress in foliar tissue of sycamore (*Acer pseudoplatanus*), English Oak (*Quercus robur*), and European Beech (*Fagus sylvatica*). *Arboriculture & Urban Forestry*, *34*(2), 89–100.

Pfeffer, E., Beede, D. K., & Valk, H. (2005). Phosphorus metabolism in ruminants and requirements in cattle. In E. Pfeffer and A. N. Hristov (Eds.), *Nitrogen and phosphorus nutrition of cattle*. Oxford shire, UK: CAB International.

Piaggio, M., Marichal, J., & Pastorin, A. (2014). A 'protein bank' of *Lotus uliginosus* cv. Maku as an alternative to conventional protein supplements for weaned lambs grazing on natural pastures during summer and autumn. *Animal Production Science 55*(1) 27-30.

Pioneer, Brand and Products. (2010). *Lucerne manual* (Manual). Retrieved from Pioneer website: http://www.pioneer.co.nz/

Pule-Meuelenberg, F., & Dakora, F. D. (2007). Assessing the biological potential of N2-fixing leguminosae in Botswana for increased crop yields and commercial exploitation. *African Journal of Biotechnology, 6* (4), 325-334.

Ramamoorthy, K., Rajendran, C., & Sivasubramarian, S. (2005). Seed treatment for alleviation of hard seededness in senna (*Casia angustifolia* L.). *Advances in Plant Sciences*, *18*(1), 429-430.

Rao, S. C., & Williams, R. D. (2000). Water utilization of Pigeon pea used as forage VS grains. *International Chicken pea and Pigeon pea newsletter, 7*, 75-77.

Richardson, D., & Smith, A. J. (2006). *Beef: The tropical agriculturist*. London and Basingstoke, United Kingdom: Macmillan Education Ltd.

Rothauge, A. (2001). Drought Management Strategies for Namibian Ranchers. *Agricola 12*, 99-105.

Rothauge, A. (2000). New ecological perspectives of arid rangelands. *Agricola, 11*, 49-56.

Rusinamhodzi, L., Murwira, H. K., & Nyamangara, J. (2006). Cotton–cowpea intercropping and its N2 fixation capacity improves yield of a subsequent maize crop under Zimbabwean rain-fed conditions. *Plant and Soil Journal, 287*, 327-336.

SAS Institute. (2003). *SAS/STAT1 9.1 User's Guide*. Cary, NC: SAS Institute Inc.

Scharf, P.C., S.M. Brouder, S. M., &Hoeft, R. G. (2006). *Agronomy Journal, 98*:655-665.

Schroeder, J. W. (2004). *Forage nutrition for ruminants*. Retrieved from the website of Northern Dakota State University: http://www.ag.ndsu.edu/pubs/ansci/dairy/as1250w.htm

Sheahan, C.M. (2012). *Plant guide for jack bean (Canavalia ensiformis): USDA-Natural Resources Conservation Service*. Cape May, NJ: Cape May Plant Materials Center.

Shiningayamwe, E. N. (2012). Crop rotation as a soil fertility improvement strategy using different legumes on pearl millet field. *Agricola, 2012*, 40-44.

Singh, K. B., & Saxena, M.C. (1999). *The tropical agriculturist: Chickpeas*. London, UK: MacMillan Education Ltd.

Skarpe, C. (1991).Impact of grazing in savanna ecosystems. *Ambio, 20*(8), 351-356.

Solaiman, S. G. (2007). *Feeding value of seed-harvested cowpea vines for goats: Notes on goats* (Technical Paper No. 06-11). Washington, DC: Tuskegee University.

Soomekh, L., Hatami, S. M., & Bahman, S. G. (2014). Estimation of hereditary parameter in Iranian Holstein crossbred dairy cows. *International Journal of Animal Breeding and Genetics, 1*(3), 046-047.

Sprent, J. I. (2001). Nitrogen fixation in legume and non-legume trees. *Field Crops Research, 65*, 183-196.

Sprent, J. I., Odee, D. W., & Dakora, F. D. (2009). African legumes: A vital but under-utilized resource. *Journal of Experimental Botany, 25*, 1-9.

Stehn, H. (2008). *Rangeland management manual*. Windhoek, Namibia: Joint Presidency Committee.

Steyn, D. (2015, July 24). South Africa's world-class lucerne hay grading system. *Farmer's Weekly*, 28-29.

Swanepoel, P. A., Botha, P. R., Truter, W. F., &Surridge-Talbot. A. K. (2011). The effect of soil carbon on symbiotic nitrogen fixation and symbiotic Rhizobium populations in soil with Trifolium repens as host plant.*African Journal of Range and Forage Science, 28*, 121–127.

Swanepoel, P. A., Botha, P. R., du Preez, C.C., Snyman, H. A., &Labuschagne, J. (2015). Managing cultivated pastures for improving soil quality in South Africa: Challenges and opportunities. *African Journal of Range & Forage Science, 32*(2), 91–96.

Swanepoel, P. A., Sanderson, M. A., Bell, L. W., Thomas, D. T., & Bennett, J. E. (2015). *African Journal of Range and Forage Science, 32*(2), iii–iv.

Sweet, R. J., & Burke, A. (2000). *Namibia: Country pasture/forage resources profile*. Retrieved from FAO website: http://www.fao.org/ag/AGPC/doc/couprof/

Tainton, N. (2000). *Pasture Management in South Africa*. Pietermaritzburg, South Africa: University of Natal Press.

Tauro, T. P. (2009). *Population dynamics and management response of N2-fixing indigenous legumes for soil fertility restoration in smallholder farming systems of Zimbabwe*. (Unpublished master's thesis). University of Zimbabwe, Harare.

Tauro, T. P., Nezomba, H., Mtambanengwe, F., & Mapfumo, P. (2007). Field emergence and establishment of indigenous N2-fixing legumes for soil fertility restoration. *Conference Proceedings of African Crop Science Society. 8*, 1929-1935.

Taylor, K., (2005). Biological flora of the British Isles: Rubus vestitus Weihe. *Journal of Ecology, 93*, 249‑262.

Thamina, D. N. (2015). *An evaluation of the potential of selected indigenous Namibian forage legumes for feeding goats*. (Unpublished master's thesis). University of Namibia. Windhoek.

Thawana, S. B. (2008). *Lucerne (Medicago sativa L.)* (Spotlight on Agriculture No. 104). Windhoek, Namibia: Directorate of Agricultural Research and Training.

Theron, J. F., &Snyman, H. A. (2015). Productivity evaluation of *Medicago sativa* cultivars under irrigation in a semi-arid climate. *African Journal of Range and Forage Science 32*, 161–171.

Thomas, R. G. (2003). *Comparative growth forms of dry land forage legumes*. Palmerston North, New Zealand: Elsevier

Tshabalala, T., Sikosana, J. L. N., & Chivandi, E. (2013). Nutrient intake, digestibility and nitrogen retention in indigenous goats fed on *Acacia nilotica* fruits treated for condensed tannin. *South African Journal of Animal Science, 43(*4), 457-463.

Uddling, J., Gelang-Alfredsson, J., Piikki, K., &Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis Research, 91*, 37-46.

Van Rooyen, B. (2011). *Quality seed: Expert advice*. Retrieved from Umpukane website: http://www.umpukane.co.za

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant*. London, England: Cornell University Press.

Van Wyk, B., & Bericke, N. (2000). *People's plants: A guide to useful plants of Southern Africa. Pretoria, South Africa: Briza Publications.*

Venter, F., & Venter, J. A. (1996). *Making the most of indigenous trees*. Pretoria, South Africa: Briza Publications.

Venter, R. (2015, June). Drought and roughage: What now. *Stock Farm, 5*(6), 21.

Wesuls, D., Neumann, C., & Limpricht, C. (2009). *Common Plants in the Rehoboth area: a farmer's field guide*. Hamburg, Germany: University of Hamburg.

Whiting, D., Wilson, C., & Reeder, J. (2013). CMG garden notes: Understanding fertilizers. Retrieved from http://www.ext.colostate.edu/mg/gardennotes/232.html

Woyengo, T. A., Gachuiri, C. K., Wahome, R. G., & Mbugua, P. N. (2004). Effect of protein supplementation and urea treatment on utilization of maize stover by Red Maasai sheep. *South African Journal of Animal Science, 34*(1), 23-30.

Wunscher, T., Schultze-Kraft, R., Peters, M., & Rivas, L. (2004). Early adoption of the tropical forage legume *Arachis pintoi* in Huetar Norte, Costa Rica. *Experimental Agriculture*, *40(1-4)*, 257-268.

Yu, P., Christensen, D. A., Mckinnon, J. J., & Markert, J. D. (2003). Effect of variety and maturity stage on chemical composition, carbohydrate and protein sub fractions, in vitro rumen degradability and energy values of timothy and alfalfa. *Canadian Journal of Animal Science, 83*(2), 279-290.

Zamah-Allah, M., Sifi, B., Taref, B. L., El Aouni, M. H., & Drevon, J. J. (2006). Rhizobial inoculation and P fertilization response in common bean *Phaseolus vulgaris* under glass house and field conditions. *Experimental Agriculture, 43*, 1-4.

Zemmelink, G. (2000). Cowpea and groundnut haulms as supplements to sorghum stover: Intake, digestibility and optimum feeding levels. *Animal Feed Science and Technology87*.

Zomlefer, W. B. (1994). *Guide to flowering plant families*. Chapel Hill: University of North Carolina Press.

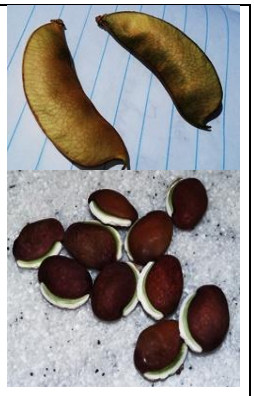
APPENDICES

Appendix 1: Silage evaluation form

Sample ID	pH		Temp.	Smell		Color		Texture		Overall Score
	Value	Score		Description	Score	Description	Score	Description	Score	

Appendix 2: Characteristics of Forage Legumes investigated in this research

Species	**Growth habits**	**Leaf characteristics**	**Flowers shape**	**Pods**
Otoptera burchellii	Prostrate with underground and above ground stolon			
Vigna lobatifolia	Prostrate			
Cullen tomentosum	Prostrate with above-ground stolon			

Lablab purpureus	Upright and prostrate			
Canavalia ensiformis	Upright			
Medicago sativa	Upright			

Vigna unguiculata	Upright and prostrate			
Crotalaria argyraea	Upright			
Rhynchosia holoserica	Prostrate			