THE INFLUENCE OF *ACACIA MELLIFERA* ON SOIL FERTILITY, HERBAGE QUALITY AND COMPOSITION ON SANDY SOILS IN CAMEL-THORN SAVANNAS OF NAMIBIA

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Abstract

Acacia mellifera is viewed negatively due to its invasive nature to the extent that farmers tend to remove it from their farms without really considering that it may have beneficial effects. Thus the study looked at the role it plays on soil fertility, herbage quality, and botanical composition with reference to N-fixation. Soil and grass samples were collected at Corsica Resettlement farm at 6 distances within three sub-habitats from bases of five *A. mellifera* trees outwards. The nutrient concentrations of soil (Total N, % of Organic, Ca, K, Cu) and that of herbaceous plants (N, Ca, P, K, Cu) were found to be significantly higher ($p<0.01$) under tree crown zone than other sub-habitats and decreased along a distance gradient from *A. mellifera* tree outwards. This is attributed to biological N fixation, shading, litter, 'nutrient pump' and decomposition of roots and nodules. Soil Mg and P and plant Mg, Mn and Zn concentration did not significantly differ among sub-habitats. Amounts of plant N, Ca, K increased with amounts of soil N, Ca, K. Herbaceous species composition varied significantly among sub-habitats, with at most 85% similarity between areas under trees and those outside the tree crowns. Perennial grasses (*Stipagrostis uniplumis* and *Stipagrostis ciliata*) were commonly found in all clusters, while forbs only occurred under the tree crown zone, leading to the observed differences. The study confirms that *A. mellifera* enriches the soil fertility and improves herbage quality through N-fixation, but this process is also interactively linked to the dynamics of other nutrients.

Keywords: Sub-habitats; Herbaceous composition; Soil enrichment; herbaceous quality improvement; N-fixation

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List of Abbreviations

MET	Ministry of Environment and Tourism
N	Nitrogen
P	Phosphorus
Ca	Calcium
K	Potassium
Mg	Magnesium
Mn	Manganese
Cu	Copper
Zn	Zinc
Fe	Iron
OM	Organic Matter
ANOVA	Analysis of Variance
GDP	Gross Domestic Product

Dedication

I dedicate this work to my lovely wife, Mrs. Nzehengwa Esther M and our children Janevin, Janelee, Alice and Sam for being great pillars of support.

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Declaration

I, Milinga James Nzehengwa, 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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Milinga James Nzehengwa

CHAPTER 1

INTRODUCTION

1.1 General background

Namibia is one of the driest countries in sub-Saharan Africa largely formed by arid and semi-arid Kalahari savanna rangelands. The Kalahari is ‘the extensive elevated, flat, sand-covered plain that occupies a substantial part of the Southern Africa interior (Thomas, 2002). In Namibia, the Kalahari covers eastern and northern regions of the country (Mendelson *et al*, 2009). The Camel-thorn Kalahari Sand soils typically consist of over 95% fine sand-sized, aeolian-deposited sediments (Thomas & Shaw, 1991) and are predominantly deep, structure-less and limited in N, P and organic matter (Skarpe & Bergström, 1986; Dougill *et al.*, 1998). The natural rangelands in Kalahari together with other savanna types in Namibia are the major livestock production areas in Namibia. Natural rangelands are what we in southern Africa call “veld”; the richly diverse natural vegetation on which we farm (Rothauge, 2008).

In Namibia, livestock production is highly dependent on these natural rangelands. The importance of this enterprise cannot be over emphasized as it is the main support for livelihoods of the majority of Namibians. Economically, extensive livestock ranching contributes about 90% of the agricultural GDP (MET, 2011). According Rothauge (2008) the rangelands are the foundation of our eco-tourism industry, making the landscape attractive to visitors and offering a habitat to innumerable wild plant and animal species.

In Camel-thorn Kalahari of Namibia *Acacia mellifera* is suspected of fixing nitrogen. *Acacia mellifera* (Black thorn) is the major species responsible for bush thickening in Namibia. It covers the Highland Shrubland, Thorn-bush Shrubland and Southern Kalahari savannas of Namibia (de Klerk, 2004). It also occurs in South Africa, Angola and Botswana, extending northwards to Tanzania (Smit *et al.*, 1999). Other encroaching bush species in Namibia includes *Acacia fleckii* (Blade thorn), *Acacia erubescens* (Blue thorn), *Acacia reficiens* (False umbrella thorn), *Colophospermum mopane* (Mopane), *Dichrostachys cinerea* (Sickle bush), *Rhigozum trichotomum* (Three thorn), *Terminalia sericea* (Silver terminalia), and *Terminalia prunioides* (Purple-pod terminalia).

Acacia *mellifera* as described by Roodt (1998) is a small-sized tree, with more or less rounded-shaped canopy, pairs of strongly re-curved thorns, creamy-white flowers, and papery pods that make it easy to recognize in the field. *Acacia mellifera* can grow 3-4 m high. Many of the roots extend 8-15 m from the stem, parallel to the surface and at a depth of 25 cm (Adams, 1967). *Acacia mellifera* is a family member of Fabaceae subfamily Mimosoideae (legume trees) capable of fixing nitrogen. It is believed that soil fertility and ultimately herbage quality under canopy and beyond (within root areas) is improved by this N-fixing ability. Soil and herbage quality improvement in Southern

Kalahari Savannas is suspected to occur and such enrichment will be of substantial significance in view of the inherent poor nutrient status of the sandy soils that are commonly found in this ecosystem (Hagos & Smit, 2004).

The effective management of N in natural rangelands is one of the driving forces behind agricultural sustainability (Graham & Vance, 2000). Thus, the conservation of *Acacia* trees is important particularly in arid and semi-arid areas for regulating microclimate, improving conditions for survival of associated plant and animal species (Attum & Mahmoud, 2012).

1.2 Statement of the Problem

Hagos & Smit (2004) stated that the common practice by most farmers that resorts to clearing of all *A. mellifera* due to their invasive nature is a result of lack of understanding of their beneficial effects in savanna ecosystems. Soils supporting *Acacia* shrub-lands generally contain low level of nitrogen and phosphorus (Burrows *et al.*, 1986, Dougill *et al.,* 1998). Due to the N-limitation in sandy soils, the total clearing of *A. mellifera* may thus result in the loss of soil nutrients from an already nutrient poor ecosystem (Hagos & Smit, 2004). According to Treydtea *et al*. (2007), large savanna trees are known to modify soil nutrient condition, but whether that has an impact on the quality of herbaceous vegetation is unclear. The mechanisms of nutrient enrichment under *Acacia mellifera* are largely unknown (Hagos & Smit, 2004).

Acacia mellifera as a bush thickening species in Namibia and yet a leguminous tree capable of N-fixing, this aspect may be important and warrants further investigation. Thus this study investigated the influence of *Acacia mellifera* on herbaceous composition, herbage and soil quality in order to improve on the understanding on the role played by *Acacia mellifera* in these ecosystems.

1.3 Objective of the study

The main objective of this study was to determine the role played by *A. mellifera* on soil fertility, herbage quality, and botanical composition with reference to N-fixation.

1.4 Specific Objectives:

i. To determine the amount of plant and soil Nitrogen along a distance gradient radiating from the bases of *Acacia mellifera* trees outwards.

ii. To determine if there is a relationship between amounts of soil Nitrogen (N), P, K, Ca, and amounts of N, P, K, Ca found in herbaceous plants at those sites.

iii. To determine the amounts of nutrients in grasses and soils in the three sub-habitats radiating from the bases of *A. mellifera* trees.

iv. To determine the composition of herbaceous vegetation among subhabitats from the bases of *Acacia mellifera* trees outwards.

1.5 Hypotheses

(a) Grasses and soils closer to *Acacia mellifera* trees will have higher levels of Nitrogen than those further away due to N-addition through fixation by *Acacia mellifera* trees.

(b) Amounts of plant N, P, K & Ca, will increase with increases in amounts of soil N, P, K, Ca due to their availability for uptake from soil by plants.

(c) Essential nutrients will be higher under-canopy than in other sub-habitats away from the bases of trees.

(d) Herbaceous composition will differ among sub-habitats from the base of the *Acacia mellifera* trees outwards due to the influence of the trees (Nutrient availability, N-fixation) on the herbaceous layer.

1.6 Significance of the study

Livestock production in Namibia is heavily dependent on natural rangelands. The quantity and quality of herbaceous layer influenced by the available soil nutrients and moisture determines the performance of livestock on the range. The Semi-arid and arid Savanna biomes, like the Camel-thorn Kalahari savanna with deep sands, are generally poor in Nitrogen (N) and Phosphorus (P). Much is known regarding the disadvantages of *Acacia mellifera*, ranging from bush encroachment, to high water use due to high transpiration rates (Colin Christian & Associates CC, 2010, de Klerk, 2004). Many researchers have reported some soil and herbaceous improvement under tree crown zones but the mechanisms that bring about these improvements are still largely unclear (Hagos & Smit, 2004, Ludwig, 2004, Scholes & Archer, 1997). Hagos & Smit (2004) studied *Acacia mellifera* in a similar eco-zone in neighbouring South Africa, but only focused on the influence of *Acacia mellifera* on soil fertility without examining the effect of plant nutrients.

This study has attempted to address these gaps by quantifying the role played by *A. mellifera* trees on these rangelands, alluding to N fixation and other factors. *Acacia mellifera* as the major bush encroaching species in Namibia (de Klerk, 2004), the scientific research findings in this study will help the decision makers and farmers in better managing rangelands dominated by *Acacia mellifera* considering this species contribution to the functioning of these biomes. The study has also drawn some recommendations regarding management of *Acacia mellifera* and suggested further related research gaps.

1.7 Limitation of the study

The researcher planned to have more trees (replicates) to investigate, but to get isolated trees was a limiting factor because of the non-open nature of these rangelands. However through a purposive sampling method, the researcher was able to identify only five isolated trees to investigate.

CHAPTER 2

Literature review

2.1 N-fixation capabilities of *Acacia* trees

Nitrogen is required by plants in the largest quantity and is most frequently the limiting factor in crop productivity and rangeland plant productivity. Kalahari sands lack Nitrogen (Dougill *et al.*, 1998), while N is abundant in natural rangelands in organic form (N_2) which is not available for plants. All organisms use the ammonia (NH_3) form of nitrogen to manufacture amino acids, proteins, nucleic acids, and other nitrogen-containing components necessary for life. Biological nitrogen fixation is the process that changes inert N_2 to biologically useful NH_3 (Brady, 1974). This process is mediated in nature only by bacteria. In some legumes and a few other plants, the bacteria live in small growths on the roots called nodules. Within these nodules, nitrogen fixation is done by the bacteria, and the NH_3 is made available to the host plant, and some of the nitrogen can be passed into the surrounding soil by excretion or by the sloughing off of the roots with nodules (Brady, 1974).

Acacia mellifera is a family member of Fabaceae subfamily Mimosoideae capable of fixing nitrogen. N-fixation capabilities of *Acacia mellifera* in Namibia was reported by Schulze *et al*., (1991) in the study of estimating nitrogen fixation by trees on an aridity gradient in Namibia. This study calculated the contribution of N_2 fixation to leaf nitrogen (N) concentration of the four trees *Faidherbia albida, Acacia hereroensis,* *Dichrostachys cinerea,* and *Acacia mellifera*. The study concluded that N-fixation in *Faidherbia albida* was only 2%, 49% in *Acacia hereroensis* and *Dichrostachys cinerea*, respectively and reached 71 % in *Acacia mellifera*.

2.2 Nodulation by *Acacia* trees

Nodulation is the process of forming nodules, especially root nodules containing symbiotic bacteria. Nodulation in legumes provides a major conduit of available nitrogen into the biosphere. The development of nitrogen-fixing nodules results from a symbiotic interaction between soil bacteria, commonly called rhizobia, and legume (host) plants (Kinkema, *et al.*, 2006, Sprent, 2001).

According to the Society for General Microbiology (2002), the nodulation process is controlled by sets of genes in the bacteria. One *Rhizobium* strain can infect certain species of legumes but not others. Specificity genes determine which *Rhizobium* strain infects which legume. Even if a strain is able to infect a legume, the nodules formed may not be able to fix nitrogen. Therefore, such rhizobia are termed ineffective. Effective strains induce nitrogen-fixing nodules. Effectiveness is governed by a different set of genes in the bacteria from the specificity genes. Nod genes direct the various stages of nodulation (Society for General Microbiology, 2002). The specificity of nodulation is important; this study will not determine the nodulation capacity of *Acacia mellifera* tree in this research, therefore, warrants further study.

According to Oyun (2007) generally, greater number of nodules inhabits the upper soil layer than the deeper soil layer. *Acacia mellifera* occupies this rhizosphere given their lateral root system which can extend up to 20m and lie 25cm below ground.

Several factors affect nodulation, namely pH and temperature. Habish (1970) confirmed nodulation and nitrogen fixation by *A. mellifera* up to 35°C soil temperature. The optimum pH for nodulation was recorded at pH 6.5 – 7.0, while pH 3.8-4.2 nodulation did not take place while pH 8.5-9.0 inhibited nodulation (Habish, 1970). Further research is required to identify pH related constraints, such as effects on rhizosphere growth of the bacterium or effects on infection and nodule development.

2.3 Influence of *Acacia* trees on sandy soils

Kalahari sand soils are known to be poor in N and P. *Acacia* trees as legumes are suspected to enrich soil N with Rhizobium-legume symbioses. Many researchers have reported soil enrichment under legume trees. Hagos & Smit (2004) reported significantly higher total N, organic matter (OM), Ca, limited P under canopy of *Acacia mellifera*, and limited N in the open on deep Kalahari sand soils in South Africa. However Mg, Na, K, pH, P were not significant among sub-habitats. According to Hagos & Smit (2004) the soil enrichment under trees is due to N fixation by *Acacia mellifera* which improves the understory. Felker and Clark, (1982), also concluded that the occurrence of N fixation due to microbial activities under leguminous trees is a possible source of N enrichment. In Namibia's camel-thorn savannas, similar reports of significantly higher content of soil N, Organic matter, P, K, Mg, pH, Na were recorded by Rothauge *et al*., (2003), on *Acacia eriolaba,* in semi-arid Camel thorn savannas, alluding to soil enrichment by legume trees.

Belsky *et al.,* (1989) recorded similar trends of higher total N, K, P, Ca, and Na under tree than in the grassland zone, and lower pH under *Acacia tortilis* trees on rich volcanic soils. According to Belsky *et al*., (1989), the greater total cation exchange capacities, higher microbial biomasses, higher water-infiltration rates, lower bulk densities, greater water holding capacities than adjacent soils is responsible for these differences (Bernhard-Reversat, 1982).

Similar trends were reported by Ludwig *et al.,* (2004) on *Acacia tortilis*, and attributed to the "nutrient pump" phenomenon of Scholes & Archer (1997) that creates island of fertility patches to be responsible for the soil enrichment under trees.

Abdallah *et al.,* (2008), studied *Acacia tortilis* and confirmed higher amounts of total N, P, K, Ca, Na, Mg under trees than in the open, and attributed this to tree leaf litter, bird and large mammal droppings to be responsible for this soil enrichment. Overall the exact reasons for these variations and the mechanisms involved are largely still unclear (Abdallah *et al.,* 2008).

2.4 Influence of *Acacia* trees on herbage quality

Legume trees are believed to creating patches of fertility (islands of fertility), thereby improving the nutrient content of the herbaceous layer under these trees. Ludwig *et al.*, (2004), in a study of the influence of savanna trees on nutrient, water and light availability and the understory vegetation, *Acacia tortilis* trees did not increase grass productivity, but they did have a positive effect on the grass quality for herbivores. Grasses growing under trees were reported to have higher nutrient and protein concentrations, due to soil enrichment by *Acacia* trees (Ludwig *et al.*, 2004). Ludwig *et al.*, (2004) & Abdallah *et al.*, (2008) stated that grass N content was higher due to soil enriched N, alluding to high correlation between soil N and plant N content.

Rothauge *et al.*, (2003) reported similar results of higher P plant content under tree, and suspected *Acacia eriolaba* tree for these differences among sub-habitat. Treydte *et al.*, (2010), in a study of grazing ungulate selection for grasses growing beneath trees in African savannas, also reported higher plant N and P content in under trees. According to Treydte *et al.*, (2010), savanna legume trees create patches of fertility referring to elevated soil nutrients and their effect on light and water availability in their direct surroundings there by improving the nutrient content of herbaceous layer.

2.5 Influence of *Acacia* trees on herbaceous plant species composition

Isolated legume trees contribute to vegetation heterogeneity, by charging the resource availability (Anderson *et al.,* 2001). According to Treydte *et al.,* (2010) in South Africa, large savanna trees can form "islands of fertility" by elevating soil nutrients and their effects on light and water availability in their surroundings, thereby creating highly fertile patches resulting in highly nutritious forage for grazing ungulates. In Tanzania, Ludwig, *et al.* (2004) established that species composition of the herbaceous layer under *Acacia tortilis* trees was completely different from the vegetation in open grassland. The distribution of perennial C3 grasses were ubiquitously distributed in sub-canopy and interstitial zones; whereas annual grasses were generally more abundant in the sub-canopy zone and indicated generally higher abundance in competition alleviation treatments in the sub-canopy patches. This response occurred despite limited overlap in the growth period of C3 grass and tree growth forms (Ludwig *et al.*, 2004). According to Ludwig *et al.,* (2004) the main factor causing differences in species composition was probably nutrient availability in the soil and shade. Forbs were 50% under-canopy and 20% in the open. In Tunisia, Abdallah *et al.,* (2012) reported that species plant cover and richness under *Acacia tortilis* and un-canopied sub-habitats was the same during the wet year, but significantly higher under woody cover compared to un-canopied surfaces during the dry year.

CHAPTER 3

Materials and Methods

3.1 Description of the study Area

3.1.1 Location and extent

The study was conducted at the Resettlement farms of Corsica (Latitude $23^0 26'03.99''$S, Longitude $18^0 10'26.29''$E), in the Khomas Rural Constituency. The farm is located 200km south-east of Windhoek at the border of Khomas and Hardap region in the Camel thorn Southern Kalahari Savannas of Namibia (Fig 1).

Khomas Region covers about 36 804,672 km^2. Most parts of the region are mountainous (Consulting Service Africa, 2005), dominated by the Khomas highland plateau (Mendelsohn *et al.*, 2009). Further towards the east, the highlands sub-merge gradually into the Kalahari sands in the intramontane plain of the Seeis and Nina, bordering with Blumfelde in the Hardap Region (King, 1967).

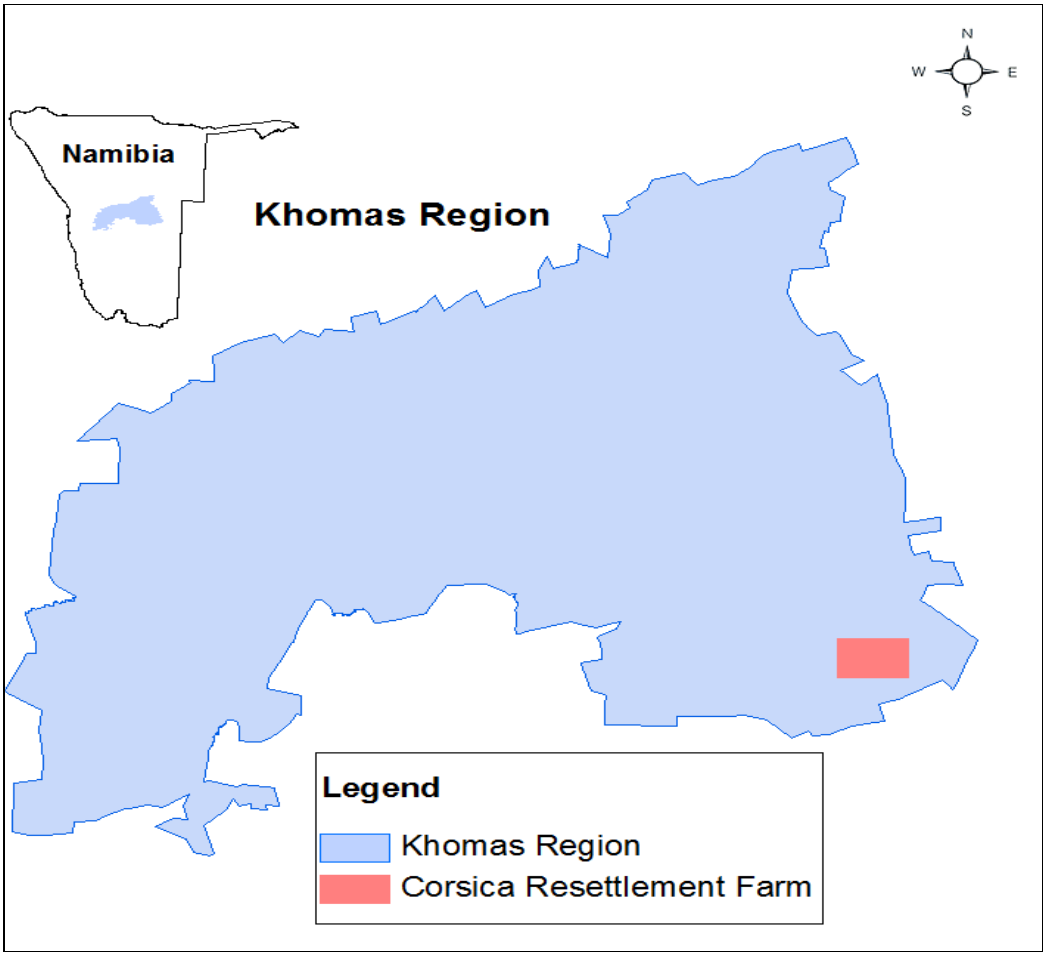

Figure 1: Location of Corsica Resettlement Farm in Khomas Region

3.1.2 Climate

Namibia's topography, river systems and soils, has been formed by climatic conditions (Mendelsohn *et al.*, 2009). Namibia spans a zone roughly between 17^o and $29^{\,o}$ South of equator. The relative positions of the system determine the rainfall, air circulation and temperature status for Namibia (Mendelsohn *et al.*, 2009). The Namibian climate is controlled by the Inter-Tropical Convergence Zone (ITCZ) and the Mid-Latitude High Pressure Zone (MLHPZ) in the Northern part of the country and the southern part of the country lies at the interface between the MLHPZ and the Temperate Zone (Mendelsohn *et al.*, 2009).

In the Khomas Region winters are generally cold with an average minimum temperature of 3° C (Joubert *et al.*, 2008); while summer averages maximum temperatures of about 29° C. Frost occurs between 10 and 20 nights per year (Mendelsohn *et al.*, 2009). The average annual temperature in the Khomas Region is 19.47 °C. In the Khomas Region, precipitation is highly variable and seasonal, 80% of the annual rainfall occurs between January and March (Joubert *et al.*, 2008). The normal annual rainfall average rainfall of this biome ranges between 300mm to 400 mm (Sweet & Burke, 2006). The Khomas average annual rainfall for 2012/2013 was 14mm (Namibia Meteorological Service, 2013). In May 2013, the President of Namibia, His Excellency President Hifikepunye Pohamba declared a countrywide State of Emergency due to drought that has impacted the country at large. Drought as defined by the Society for Range Management refers to "prolonged dry weather when precipitation is less than 75% of the average amount" (Society for Range Management, 1989).

3.1.3 Physical features, geology and soils

Most parts of the region are Mountainous (Consulting Service Africa, 2005), dominated by the Khomas highland plateau (Mendelsohn *et al.*, 2009). Further towards the east, the highlands sub-merge gradually into the Kalahari sands in the intramontane plain of the Seeis (King, 1967). Khomas Region, Otjozondjupa and Omaheke are the major freehold cattle farming areas in Namibia (Mendelsohn *et al.*, 2009).

Arenosols are the dominant soil type at the farm and the biome in general. According to Mendelsohn *et al.* (2009), Arenosols are formed from wind-blown sand and usually extend to a depth of at least one meter with sand generally making up more than 70% of the soil. The Kalahari Sand soils (Arenosols), are predominantly deep, structure-less and lacking in N, P and organic matter (Skarpe and Bergström, 1986; Dougill *et al.*, 1998).

3.1.4 Vegetation

Savannas are the dominant biome in Namibia, covering about 64% of the land surface of 824 269 km^2 (Moyo *et al.*, 1993). Due to the favourable physical and especially the vegetation characteristics of savannas, they are supremely suited for extensive livestock production (Rutherford & Westfall, 1994).

Corsica farm is situated in the camelthorn savanna that covers a large part of the eastern and central Kalahari basin. This biome east-central of Namibia is the country’s most important commercial beef producing region. Namibia’s traditional vegetation classification done by Giess (1971) identified 15 vegetation types, amongst others the camelthorn savanna. Mendelsohn *et al.* (2009) reclassified Namibia’s vegetation into 29 types, retaining the central Kalahari camel-thorn savanna as identified by Giess (1971) but grouping it into the larger biome of *Acacia* tree-and-shrub savanna.

Vegetation types are strongly influenced by rainfall; however other factors such as soil types and landscapes also affect vegetation. In the long term vegetation is affected by climate.

The common species are *Boscia albitrunca, Catophractes alexandri*, *Acacia mellifera, Acacia hebeclada, Acacia erioloba* and *Phaeoptlium spinosum, Stipagrostis uniplumis, Stipagrostis ciliata* and *Acacia karoo* are the dominant species. Other grass species include *Schmidtia kalahariensis* and *Melinis repens* subsp. *repens, Enneapogon cenchroides,* dominating in disturbed veld. Cattle and goat production are the main enterprise at the farm.

3.2 Research design

Quantitative research was used. Purposive sampling method was used, because the researcher had to purposely select the isolated trees to investigate. Stratified systematic sampling was also used to identify and demarcate zones (i.e strata) and then sampled at specified distances within the zones (systematic). In this study there was also one primary factor (Tree), there were three sub-habitats (Tree crown zone, Outside tree crown zone, Grassland zone). The levels were the different distances in these sub-habitats. All *Acacia mellifera* trees in the study area formed the population. Five trees selected through purpose sampling formed the sample of the study.

3.3 Procedure

3.3.1 Selection of trees and tree height considerations

Due to the close proximity of the trees and the extensive shallow lateral root system of *A. mellifera* (Smit *et al.*, 1999), the outside tree crowns zone fall within the root zone of the trees. To avoid this only isolated trees located at least 50m from small trees and 80m from other trees were used in this study. In this study, only trees with heights above 2m were considered for sampling. According to Hagos & Smit (2004) evidence exists that soil enrichment under tree canopies is a slow process, implying that larger (older) trees are more important in terms of soil enrichment than newly established individuals. Five trees were sampled.

3.3.2 Transect lay out

All variables were determined and sampled in the same three sub-habitats (Hangos & Smit 2004); same distances and same transect lines (Fig 2). Two transects in opposite directions (North and South) were laid out per tree. Samples from the two transects were grouped per different distances to total 6 samples per tree as follows:

i) Tree crown zone: distance 1 m and 2 m from tree trunk (2 samples)
ii) Outside crown: distance 4m, 8m and 12m from tree trunk (3 samples)
iii) Grassland zone: distance greater than 50m from tree trunk (1 sample)

The outside crown zone is the area where the root system extends while the grassland zone is beyond the influence of the tree roots.

3.3.3 Data collection

To determine species composition, Quadrats (1m x 1m) were placed at different distances as outlined in above transect lay out. Herbaceous species were identified in the quadrat and recorded on an inventory form separately at different distances. To determine soil nutrients, a spade was used to collect soil samples in the same transect and quadrats where species composition was recorded. A garden shovel was used alternatively to a soil auger because the soil was dry and very sandy making it difficult to collect by a soil auger. Soil samples were taken per site at a depth of 0-30cm and analyzed for Total Nitrogen (N) and other elements such as pH; organic matter; available phosphorus (P); particle size distribution; exchangeable calcium (Ca); Potassium (K), Sodium (Cu), Magnesium (Mg). A total of 30 samples were collected (Tree crown zone: distance 1m and 2m from tree trunk (2 samples/tree); outside tree crown zone: distance 4m, 8m, 12m (3 samples/tree); Grassland zone: distance 24m from tree trunk (1 samples/tree); To determine herbage nutrients, all herbaceous plants in quadrats measuring 0.5 × 0.5m (Dagliesh and Foale, 2005) nested within the 1m x 1m quadrat (in (a) above) were clipped at 2cm above ground using a pair of secateurs in the sites where soil samples were collected. Assessment of species composition was done at the end of the rainy season (April to May) when species composition was best represented (Walker, 1976). Soil and herbage samples was prepared, processed and analyzed at the Ministry of Agriculture, Water and Forestry laboratory and Analytical laboratory using standard procedures (Association of Official Analytical Chemists, 1990; Goering and van Soest 1970).

3.3.4 Soil chemical analysis

A total 30 soil samples were prepared, air-dried and sieved to pass through a 2-mm sieve. The analyses included pH (H_2O); Texture by pipette method Miller and Miller, (1987) using the USADA classification system; available phosphorous (P) measured spectrophotometrically using Ohlsen method; available potassium (K), Magnesium (Mg), Calcium (Ca), Zinc (Zn), Manganese (Mn), Copper (Cu), Iron (Fe) and Sodium (Na) atomic absorption spectroscopy. Percentage of Organic matter was analyzed by Walkley and Black (1934). Soil total Nitrogen (Kjeldahl method) was analyzed at the Analytical Laboratory Services cc in Windhoek.

3.3.5 Grass nutrient analysis

Thirty (30) samples for nutrient analysis were air dried, milled to pass through a 1mm sieve and kept in air-tight plastic containers at the Ministry of Agriculture, Water and Forestry Laboratory Services for chemical analysis using *in vitro* fermentation in July 2013. Phosphorus (P) was determined using the modified colorimetry method of Cavell (1955). The level of Potassium (K) was determined by flame emission spectroscopy. The analysis of Calcium (Ca), Magnesium (Mg), Magnesium (Mn), Iron (Fe), Copper (Cu) and Zinc (Zn), was done by the method of atomic absorption flame spectrophotometer as modified by Association of Official Analytical Chemists, (1990). Plant Nitrogen (N) was through house method based on 93/28/EEC at the Analytical Laboratory Services cc in Windhoek.

3.3.6 Data analysis

All soil and plant nutrient data were first tested for normality using the Kolmogorov-Smirnov (K-S) Test and were confirmed to be normally distributed ($p>0.05$). To compare the means of soil N and N levels in herbaceous plants among the different distances from the tree, a One-way ANOVA test was used. To compare the amounts of other elements in grasses and soils in the three sub-habitants One-way ANOVA test was used.

To test whether herbaceous species composition differed along the distance gradient, a Hierarchical Cluster Analysis (HCA) was applied on species presence/absence (binary) data. The average linkage cluster statistic (Bray-Curtis similarity measure) was used in the analysis. A Pearson Bivariate Correlation was run to determine the relationship between soil total nitrogen and plant nitrogen along distances measured from *A. mellifera* outwards. All data collected were statistically analyzed using SPSS version 20.

CHAPTER 4

RESULTS

4.1 Soil properties

4.1.1 Soil texture

The results of soil particle size analysis confirmed the sandy (91.3%) type of soil with limited amount of clay and silt (4.8% and 3.9%, respectively). There were no significant differences ($p > 0.05$) in the soil particle sizes among sub-habitats, which was predominantly by sandy.

4.1.2 Comparison of soil Nitrogen (N) concentration at different distances

The amounts of total Nitrogen decreased significantly with distance from 337±24.61mg/kg at 1m, 211.4±7.44 mg/kg at 4m, 182±4.39 mg/kg and 180.4±1.82 mg/kg at 24m from the base of *Acacia mellifera* trees. One-way ANOVA confirmed that there was a statistically significant difference ($F(5,24) = 120.572$, $p < 0.01$) in amounts of total soil Nitrogen (N) among distances measured from the tree base outwards. Soil N at 1m, 2m, and 4m were significantly higher ($p < 0.01$) than at 8m, 12m and 24m. A Tukey *post-hoc* test revealed that there were no significant difference ($p > 0.05$) in N in soils at 1m, 2m and 4m, while the same applied to soil N at 8m, 12m and 24m (Fig. 2). Generally, amounts of total Nitrogen (N) concentrations were higher at distances closer to the tree and decreased along a distance gradient from the bases of the *A. mellifera* trees outwards. The variability in total soil N was less at distances 24 m and increased gradually to distances 1 m from the tree. Overall there was less variability in total soil N at different distances.

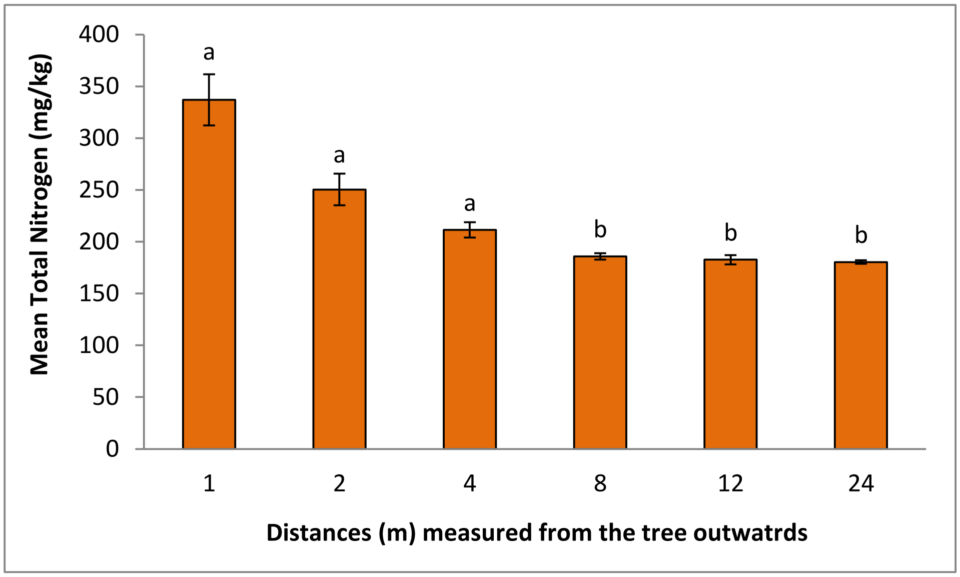

Figure 2: Comparisons of Nitrogen (N) concentrations at different distances from the bases of *Acacia mellifera* trees in Corsica Resettlement farm. Bars denote standard error of means. Bars not sharing a common superscript letter (a,b) are significantly different (p<0.05).

4.1.3 Comparison of Soil Nitrogen concentration among sub-habitats

There was a significant differences in the mean total Nitrogen (N) concentration among sub-habitats ($F(2, 27) = 39.07$, $p<0.01$). The amounts of total Nitrogen decreased from 293.7±49.57 mg/kg under tree crown zone to 180.4±1.82 mg/kg in the grassland zone. A Tukey *post-hoc* test revealed that amounts of total Nitrogen (N) concentration were significantly higher under tree crown zone ($p<0.01$) than in other two sub-habitats (Outside tree crown and Grassland zone). There was however no significant differences ($p>0.05$) between outside tree crown and the grassland zone (Fig. 3). Generally, total nitrogen (N) concentration decreased with sub-habitats from the bases of the *A. mellifera* trees outwards. There was less variability in total soil N from the grassland zone compared to other zones. The tree crown zone exhibited more variability in data compared to other zones.

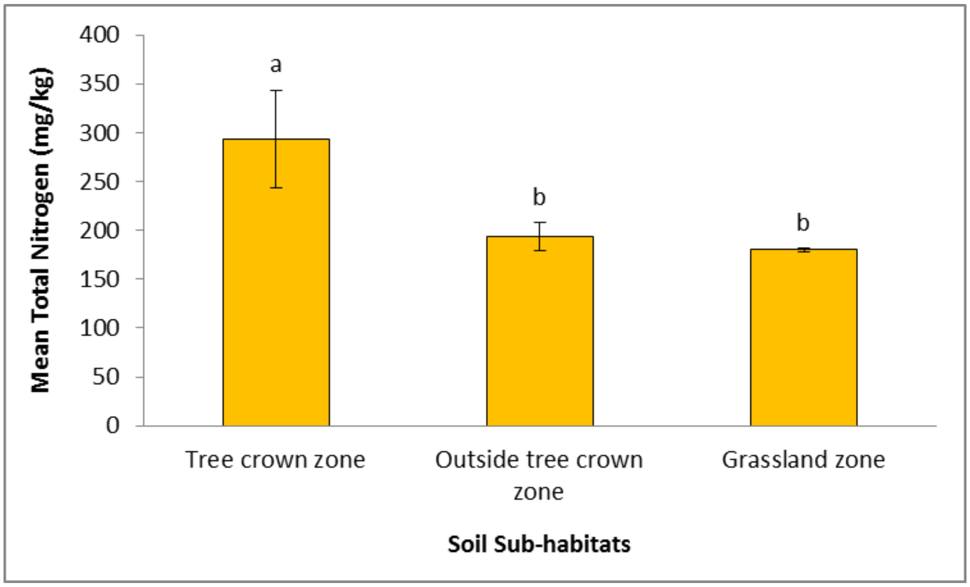

Figure 3: Comparisons of total Nitrogen (N) concentrations within sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars denote standard errors of the means. Bars not sharing the same superscript letter (a,b) are significantly different ($p<0.05$).

4.1.4 Comparisons of the concentration of other soil essential elements

4.1.4.1 Comparison of soil pH levels among sub-habitats

The pH levels tended to decrease from pH 6.79±0.48 under tree crown zone to pH 6.52±0.21 in the grassland zone. The One-way ANOVA test indicated that there was no significant difference ($F(2,27) = 0.637$, $p > 0.05$) in the pH levels among the three zones (Fig. 4). There was less variability in soil pH from the grassland zone compared other zones.

Figure 4: Comparisons of soil pHw levels among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars indicate standard errors of the means. The bars sharing the same superscript are not significantly different from each other ($p > 0.05$).

4.1.4.2 Comparison of Organic matter among sub-habitats

The amounts of organic matter (OM) significantly differed among sub-habitats (*F*(2,27)=9.093, *p*<0.05). The percentage of organic matter was high under tree crown zone 0.246±0.490 %, and 0.180±0.224 % in the grassland zone (Fig. 5). A Tukey *post-hoc* test revealed that % of Organic matter was significantly higher under tree crown zone (p<0.05) than in other two sub-habitats (Outside tree crown and Grassland zone). There was however no significant difference (p>0.05) between outside tree crown and the grassland zone (Fig. 5). Generally, organic matter decreased with sub-habitats from the bases of the *A. mellifera* trees outwards. There was less variability in organic matter (OM) of the outside tree crown compared to other zones.

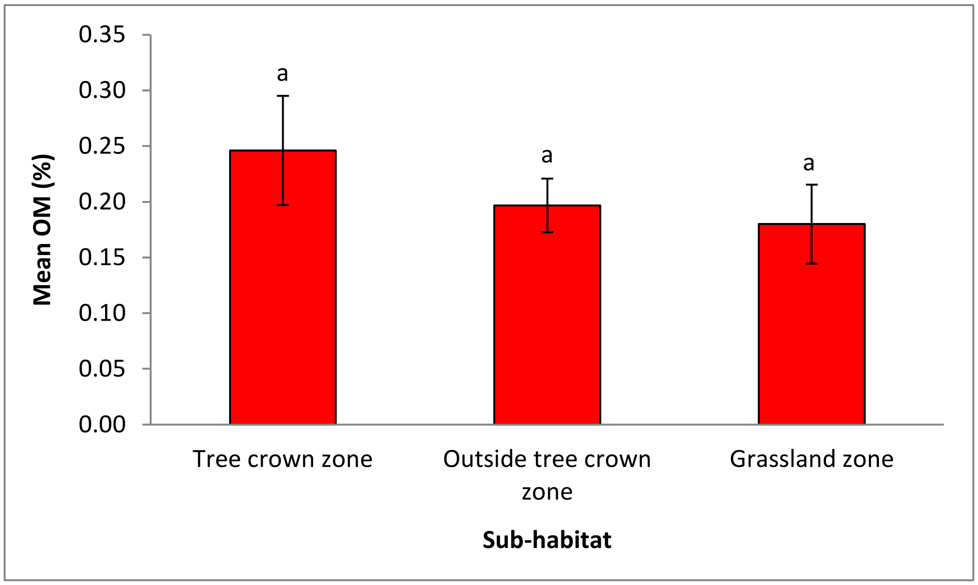

Figure 5: Comparison of Organic Matter (OM) among sub-habitats measured from *Acacia mellifera* trees in Corsica Resettlement farm. Bars indicate standard errors of the

means. The bars sharing the same superscript are not significantly different from each other ($p>0.05$).

4.1.4.3 Comparisons of Phosphorus (P) concentration among sub-habitats

The amounts of Phosphorus (P) tended to decrease from 0.260±.0190 ppm under Tree crown zone to 0.233±0.140 ppm in the grassland zone (Fig. 6). The test revealed that Phosphorus (P) concentration was not significantly different ($F(2,27)=0.325$, $p>0.05$) among the three zones. The grassland zone exhibited a much bigger variability than other zones. There was however less variability in Phosphorus (P) in soils from the tree crown zone compared to the other zones.

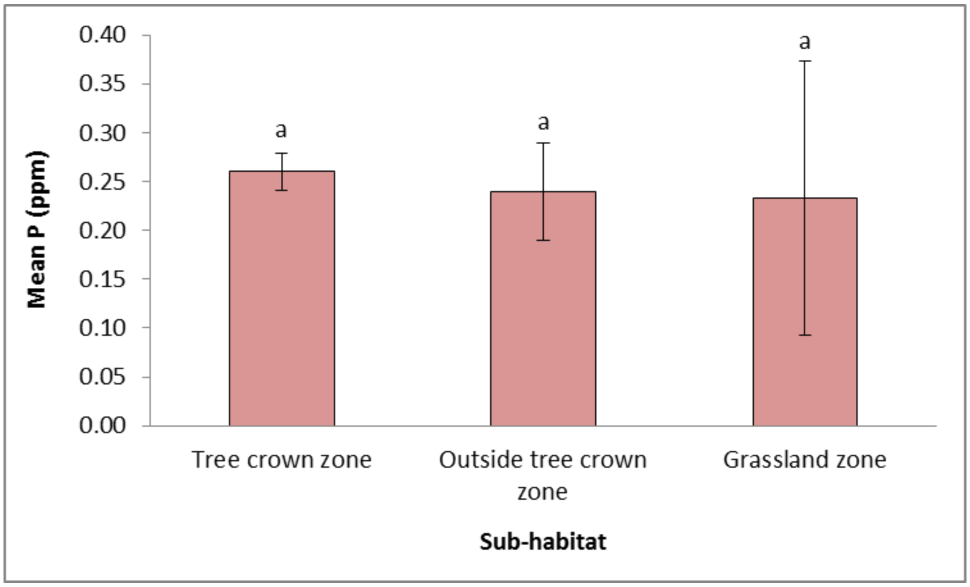

Figure 6: Comparisons of soil Phosphorus (P) concentrations among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement farm. Bars denote standard errors of the means. The bars sharing the same superscript are not significantly different from each other ($p>0.05$).

4.1.4.4 Comparisons of Potassium (K) concentration among the sub-habitats

The One-Way ANOVA test indicated that there were significant differences in the amounts of Potassium (K) concentration among the different zones ($F(2,27)= 6.370$, $p<0.05$). The amounts of Potassium (K) decreased from 83.70±22.51 ppm under Tree crown zone to 61.00±6.04 ppm in the Grassland zone (Fig. 7). The Tukey *post hoc* test revealed that the amount of Potassium (K) in the Tree crown zone was higher than that of the Outside tree crown zone and the Grassland zone ($p<0.01$). The Potassium (K) concentration in the Outside tree crown zone did not significantly differ ($p>0.05$) from that of the Grassland zone. Generally, Potassium (K) concentration decreased with sub-habitats from the bases of the *A. mellifera* trees outwards. The tree crown zone exhibited a much bigger variability in soil K compared to other zones.

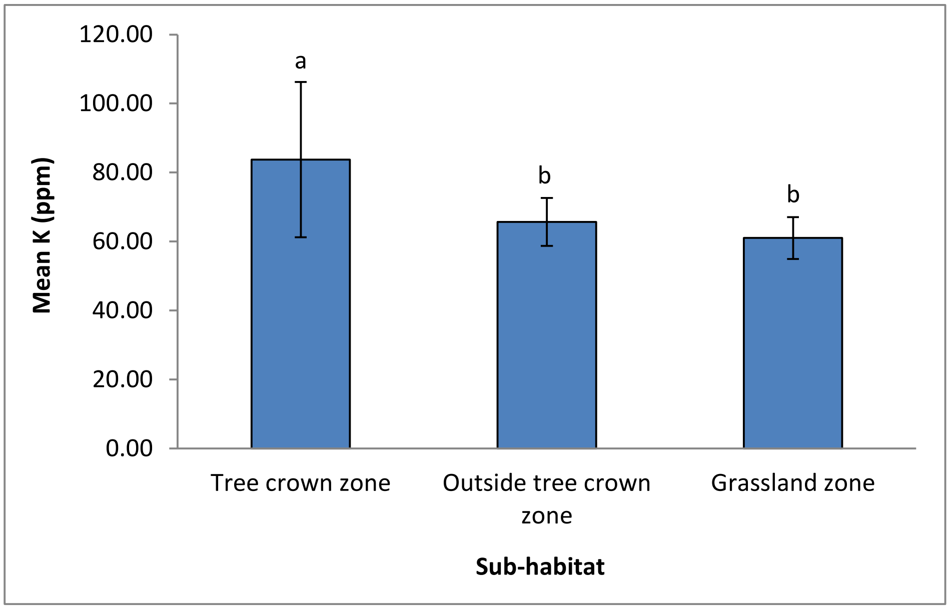

Figure 7: Comparisons of Potassium (K) concentrations within sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement farm. Bars denote standard

errors of the means. Bars not sharing the same superscript letter (a,b) are significantly different ($p<0.05$).

4.1.4.5 Comparisons of Calcium (Ca) concentration among sub-habitats

The amounts of Calcium (Ca) decreased from 212.50±31.17ppm under Tree crown zone to168.20±15.34 ppm in the grassland zone, moving outwards from the tree base (Fig. 8). Calcium (Ca) concentrations were significantly different among the different zones ($F(2,27)=9.524$, $p<0.01$). The Tukey *post hoc* test revealed that the concentration of Calcium (Ca) in the Tree crown zone was significantly higher than that of the Outside crown zone ($p<0.01$) and that of the Grassland zone ($p<0.05$). The concentration of Calcium (Ca) in the Outside crown zone was not significantly different from that of the Grassland. Generally, Calcium (Ca) concentration decreased among sub-habitats from the bases of the *A. mellifera* trees outwards. There was similar less variability in Ca among sub-habitats.

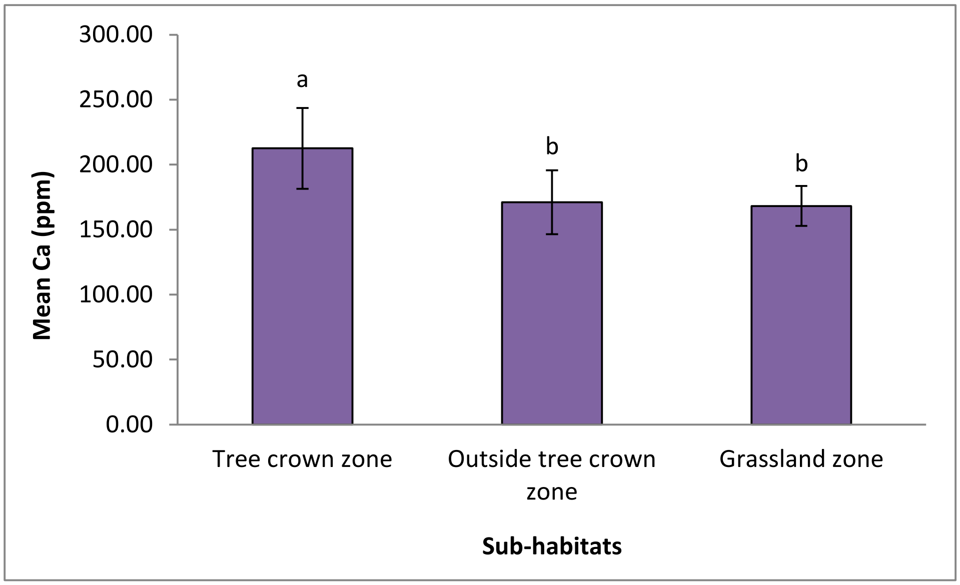

Figure 8: Comparisons of Calcium (Ca) concentrations among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars denote standard errors of the means. Bars not sharing the same superscript letter (a,b) are significantly different ($p<0.05$).

4.1.4.6 Comparisons of Magnesium (Mg) concentration among sub-habitats

The One-Way ANOVA test revealed that Magnesium (Mg) concentration was not statistically significantly different among the three zones ($F(2,27)=0.584$, $p>0.05$). The amounts of Magnesium (Mg) showed a trend of decreasing from 42.00±9.177ppm under Tree crown zone to 37.00±5.35 ppm in the grassland zone, moving outwards from the tree base (Fig. 9). The tree crown zone and the outside tree crown zone exhibited much bigger variability in soil Mg compared to the grassland zone.

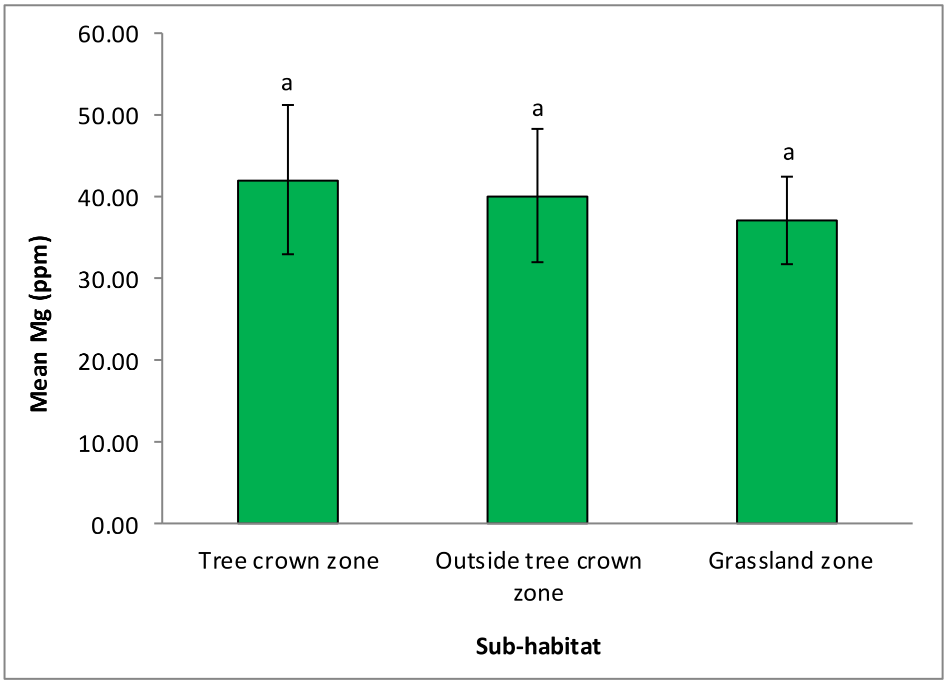

Figure 9: Comparisons of Magnesium (Mg) concentrations among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars denote standard errors of the means. The bars sharing the same superscript are not significantly different from each other ($p > 0.05$).

4.1.4.7 Comparisons of Sodium (Na) concentration among sub-habitats

The amount of Sodium (Na) concentration showed a decreasing trend from 3.80±1.32 ppm under Tree crown zone to 3.40±1.14 ppm in the grassland zone, moving outwards from the tree base (Fig. 10). The One way ANOVA test revealed that Sodium (Na) concentration did not differ significantly among the three zones ($F(2,27) = 0.154$, $p > 0.05$). There was much bigger variability in sodium (Na) in all sub-habitats.

Figure 10: Comparisons of Sodium (Na) concentrations among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement farm. Bars denote standard errors of the means. The bars sharing the same superscript are not significantly different from each other ($p>0.05$).

4.2 Comparison of amounts of nutrients in herbaceous plants

4.2.1 Comparison of plant Nitrogen (N) concentration at different distances

There was a significant difference in N concentration among distances from the tree base outwards ($F(5,24) = 22.590$, $p<0.01$). The mean plant Nitrogen (N) ranged between 1.28±0.130 g/100g at 1m, 1.06±0.114 g/100g at 4m, 0.860±0.055 g/100g at 12m and 0.82±0.045 g/100g at 24m (Fig. 11). A Tukey *post-hoc* test revealed that plant N at distances of 1m and 2m was significantly higher than plant N at distances of 4m, 8m, 12m and 24m ($p<0.01$). There was however no significant difference ($p>0.05$) in plant N at distances of 1m, 2m and 4m. Also, there was no significant difference in plant N at distances of 8m, 12m and 24m. Generally, plant Nitrogen (N) concentration decreased with distance from the bases of the *A. mellifera* trees outwards.

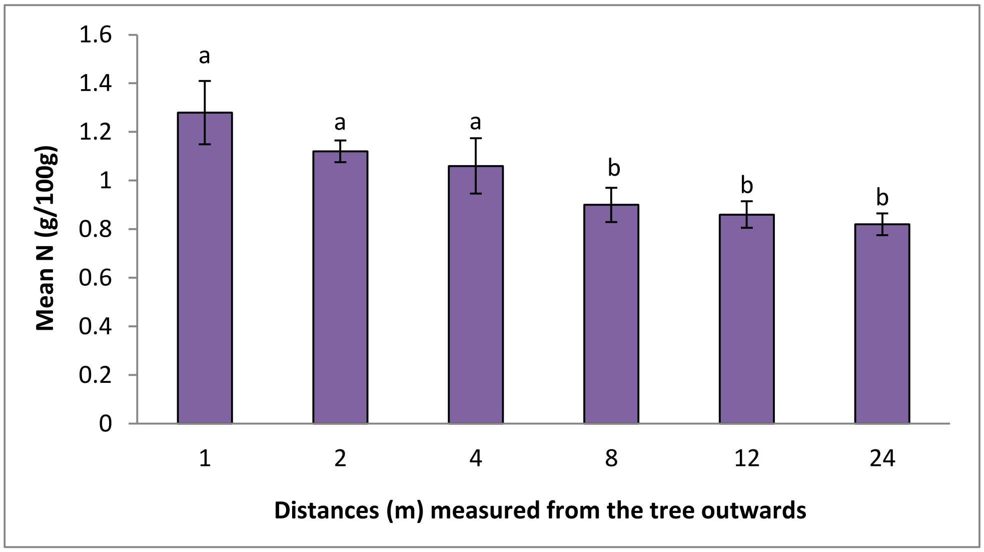

Figure 11: Comparisons of plant (N) concentrations among distances from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars denote standard errors of the means. Bars not sharing the same superscript letter (a,b) are significantly different (p<0.05).

4.2.2 Comparisons of plant Nitrogen (N) concentration among sub-habitats

The amounts of plant Nitrogen (N) decreased among distance from 1.2±0.125 g/100g under tree crown zone to 0.82±0.045 g/100g in the grassland, measured from the tree base of *Acacia mellifera* tree outwards (Fig. 12). One-way ANOVA test confirmed that there was a statistically significant difference in plant N among sub-habitats (*F*(2, 27) =

24.122, $p<0.01$). A Tukey *post-hoc* test revealed that Nitrogen (N) concentration was statistically significantly higher under Tree crown ($p<0.01$) than in other sub-habitats. There was no statistically significant difference ($p>0.05$) between Outside tree crown and that of the Grassland zone. Generally, plant Nitrogen (N) concentration decreased with sub-habitats from the bases of the *A. mellifera* trees outwards.

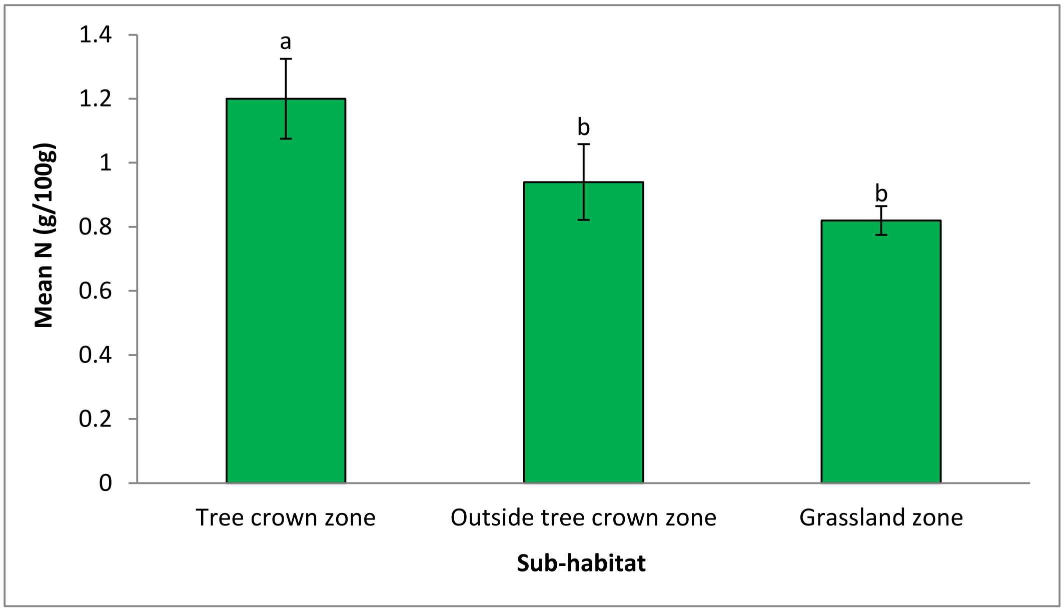

Figure 12: Comparisons of plant (N) concentrations among sub-habitats from the bases of *Acacia mellifera* trees in Corsica Resettlement Farm. Bars denote standard errors of the means. Bars not sharing the same superscript letter (a,b) are significantly different ($p<0.05$).

4.2.3 Comparisons of concentrations of other Plant essential elements

There were significant differences in amounts of plant Calcium (Ca) ($F(2,27)=34.839$ $p<0.01$), Phosphorus (P) ($F(2,27)= 31.219$, $p<0.01$), Potassium (K) ($F(2,27)= 38.533$, *p*<0.01), Copper (Cu) (*F*(2,27)= 15.120, *p*<0.01) among sub-habitats (Table 1). The amounts of Calcium (Ca) decreased within sub-habitats from 0.4756±0.026 ppm under Tree crown zone to 0.3106±0.032 ppm in the grassland zone, moving outwards from the tree base. Phosphorus (P) concentration decreased with sub-habitats from 0.103±0.0051a ppm under Tree crown zone to 0.067±0.0033 ppm in the grassland zone, moving outwards from the tree base. The amounts of Potassium, on the other hand decreased from 0.692±0.098 ppm under Tree crown zone to 0.370±0.060 ppm in the grassland zone. The amounts of Copper (Cu) decreased with sub-habitats from 13.28±3.862 ppm under Tree crown zone to 8.22±2.186 ppm in the grassland zone, moving outwards from the tree base.

The Tukey *post hoc* test revealed that Calcium (Ca), Phosphorus (P), Potassium (K), Copper (Cu) were significantly higher under Tree crown zone than in the Grassland zone (*p*<0.01). In all cases there were no significant differences (*p*>0.05) in the amounts of these plant elements among between the outside tree crown zone and the grassland zone.

The One way ANOVA showed that there were no significant difference (*p*>0.05) in the amounts of Magnesium (Mg), Manganese (Mn), Iron (Fe) and Zinc (Zn) among sub-habitats. Magnesium (Mg) concentration showed a trend of decreasing among sub-habitats from 0.067±0.017 ppm under Tree crown zone to 0.053±0.008 ppm in the grassland zone, moving outwards from the tree base. The means of plant Manganese (Mn) showed a similar trend of decreasing from 36.45±6.5391 ppm under Tree crown zone to 27.02±5.0883a ppm in the grassland zone, moving outwards from the tree base.

However, Iron (Fe) showed the opposite trend of increasing from 90.16±15.152a ppm under Tree crown zone to 99.93±11.96a ppm in the grassland zone. The amounts of Zinc (Zn) tended to decrease from 12.62±3.797 ppm under Tree crown zone to 7.80±2.242 ppm in the grassland zone, moving outwards from the *Acacia mellifera* tree base.

Table 1: Comparisons of amounts of various plant essential elements in herbaceous plant species among sub-habitats in Corsica resettlement farm.

Plant nutrients	**Sub-habitat**			**Significance**
	Tree crown zone	**Outside tree Crown zone**	**Grassland zone**	
Ca (%)	0.476 ±0.026^{a}	0.336±0.057^{b}	0.311±0.033^{b}	$p<0.01$
K (%)	0.692 ±0.098^{a}	0.471 ±0.062^{b}	0.370 ±0.060^{b}	$p<0.01$
Mg (%)	0.067 ±0.017^{a}	0.059 ±0.014^{a}	0.053 ±0.008^{a}	$p>0.05$
P (%)	0.103 ±0.005^{a}	0.074 ±0.014^{b}	0.067 ±0.003^{b}	$p<0.01$
Mn (ppm)	36.458 ±6.540^{a}	31.97 ±7.640^{a}	27.02 ±5.088^{a}	$p>0.05$
Cu (ppm)	13.282 ±3.862^{a}	6.746 ±2.396^{b}	8.22 ±2.187^{b}	$p<0.01$
Fe (ppm)	90.156 ±15.153^{a}	97.41 ±20.967^{a}	99.93 ±11.961^{a}	$p>0.05$
Zn (ppm)	12.624 ±3.797^{a}	9.29 ±2.883^{a}	7.804 ±2.241^{a}	$p>0.05$

4.2.4 Relationship between soil and plant Nitrogen concentrations

There was a positive correlation between plant nitrogen and soil total nitrogen, which was statistically significant (r = 0.871, n = 30, p<0.05). A scatterplot summarizes the results (Fig. 13) Overall, there was a strong, positive correlation between soil total nitrogen and plant nitrogen. Increases in soil total nitrogen concentration were correlated with increases in plant nitrogen content.

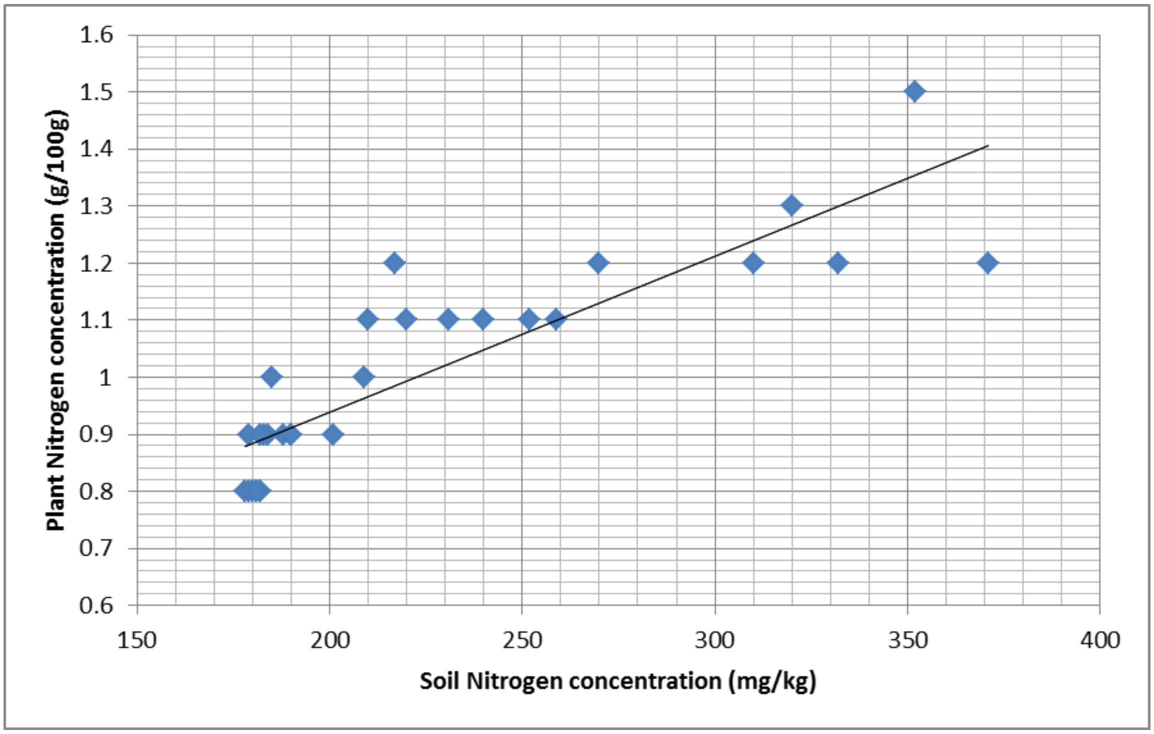

Figure 13: The relationship between soil total nitrogen and plant nitrogen in Corsica farm (as established by Pearson correlation analysis).

4.2.5 Relationship between other soil elements (P, K, Ca) and plant P, K, Ca concentration

There was a positive correlation between plant Ca and soil Ca (r = .525, n = 30, $p<0.01$) (Table 2); as well as between soil K and plant K (r = .435, n = 30, $p<0.05$) (Table 4). Phosphorus (P) did not correlate positively (r =.187, n = 30, $p>0.05$) (Table 3). Increases in soil K & Ca concentration was correlated with increases in plant K & Ca content, while increases in soil P did not increase with plant P.

4.2.6 Comparison of herbaceous plant species composition among sub-habitats

Based on the Hierarchical Cluster Analysis results, the dendrogram below presented the presence/absence representation of species composition among the three sub-habitats. Distances grouped under the same cluster give an indication of the presence of certain species at those distances and show absence of other species as well within the dendrogram. The Hierarchical Cluster Analysis (HCA) separated the quadrats into four (4) groups (Fig. 14) based on variations in the plant species (Table 5). Hierarchical Cluster Analysis showed that there were similarities between Cluster 1 and the rest = 78%; Similarity between Cluster 2 and Clusters 3 and 4 = 85%; Similarity between Clusters 4 and 4 = 86% (Fig 4.13).

Cluster 1 was an association of four distances mainly from the same tree (A) at 4m, 8m, 12m and 24m. The four distances recorded two common herbaceous species in the cluster. These species were *Stipagrostis uniplumis,* and *Stipagrostis ciliata.* These four distances are all from one tree and in the Outside tree crown zone and Grassland only.

Cluster 2: Consists of 10 quadrats from all trees, namely C 1m, C 2m, D 1m, D 2m, E 1m, E 2m, B 1m & B2m. This is one of the largest grouping mainly comprising distances from the under tree crown zone only. This cluster uniquely differed from the rest because forbs like *Aptosimum albomarginatum* and *Eriocephalus luederitzianus* were only recorded under trees. Other plant species include *Stipagrostis uniplumis,* and *Stipagrostis ciliata*, as well as the annual grasses *Schmiditia kalahariensis*.

Cluster 3: This was a very small cluster consisting of two quadrats from the same tree (B) at 4m and 12m. The two distances which also inhabits the Outside tree crown zone and Grassland zone only presented at least four plant species. These species includes the perennial *Stipagrostis uniplumis*, and *Stipagrostis ciliata*, as well as the annual grasses *Schmiditia kalahariensis* and *Melinis repens* subsp. *repens*.

Cluster 4: This is the largest grouping consisting of up to fourteen quadrats from 4 trees (B, C, D, & E). These distances include E12 m, E24 m; B8 m, B24 m, C4 m, C8 m; C12m, C24m, D4m, D8 m, D12m, D24 m, E4 m and E8 m. These distances occupy mostly the Outside tree crown zone and the Grassland zone only. Although the largest grouping, this cluster only recorded three plant species, namely *Stipagrostis uniplumis,* and *Stipagrostis ciliata,* as well as the annual grasses *Schmiditia kalahariensis*.

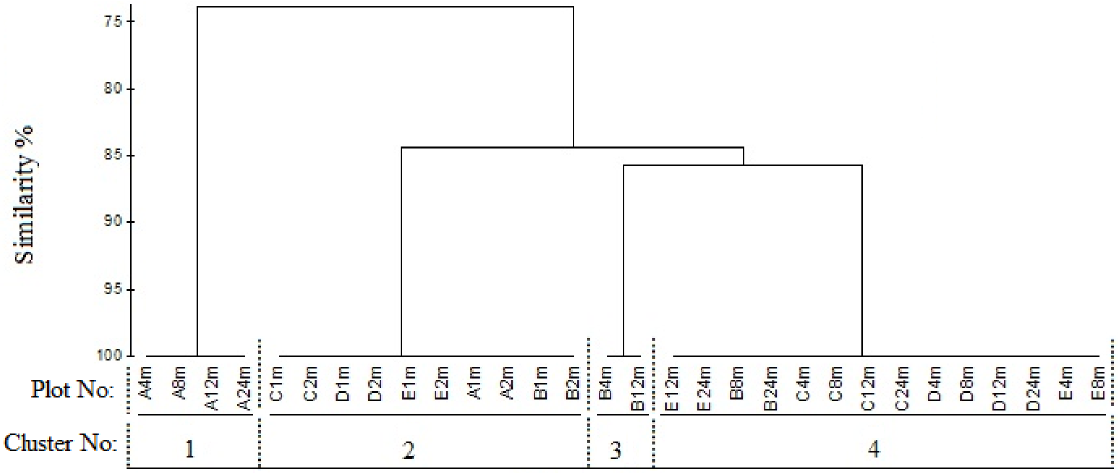

Figure 14: The Hierarchical Cluster Analysis dendrogram comparing the composition of herbaceous plants among the sub-habitats measured from *A. mellifera* tree bases outwards in Corsica farm.

CHAPTER 5

Discussion

5.1 Soil properties

5.1.1 Comparison of Soil Nitrogen concentration at different distances and sub-habitats

Total Nitrogen significantly differed ($p<0.01$) among distances and sub-habitats. Total Nitrogen concentration was higher under Tree crown zone (293.7±49.57 mg/kg) and distances in the Outside crown zone closer to the tree than in the Grassland zone (180.4±1.82 mg/kg). This increase under tree crown zone and beyond is the result of the N-fixation by *Acacia mellifera*. *Acacia mellifera* tree is a family member of Fabaceae subfamily Mimosoideae capable of fixing nitrogen. Some Legume trees have strains of symbiotic *Rhizobium* bacteria that form nodules on their roots and can fix atmospheric nitrogen gas (N2) in soil air and synthesize it into complex forms (Brady 1974).

Several other mechanisms could be responsible to these variations; the root system of *Acacia mellifera* that can extend laterally from 8m to 20m from the stem at 25cm depth (Adams, 1967). This, with symbiotic microbial activities, supports the theory of N enrichment under Tree crown zone and beyond (Ludwig, 2004). This is expected because according to Oyun (2007) greater number of nodules inhabits the upper soil layer than the deeper soil layer. The decomposition of these legume nodules also adds to

N enrichment under tree canopy and beyond because legume nodules have higher N concentration (Wardle and Greeenfield, 1991; Nygren and Cruz, 1998).

The enriched litter of *Acacia mellifera* leaf (Schulze et *al.,* 1991) could also add soil N improvement under Tree crown zone (Belsky, 1994). Contrary to Belsky (1994), animal droppings are not suspected to significantly add N to the soil in this study because the presence of the large *Acacia eriolaba* trees scattered through this arid oligotrophic savanna already forms focal points for animal activity because they supply better nest sites, shade and scarce food resources (Dean *et al.*, 1999) than *Acacia mellifera* trees. Schulze *et al.*, (1991) confirmed N-fixation in a study of estimating nitrogen fixation capabilities of *Acacia mellifera* trees on an aridity gradient in Namibia.

The low soil N in the grassland zone is an indication of lack of influence by *Acacia mellifera* tree in that sub-habitat. The grassland zone, dominated by grasses with poor N returns low N residues to this sub-habitat (Jones, 1971).

A similar study in South Africa, on poor Kalahari sands, Hagos & Smit (2004) also recorded higher N values under trees: 338mg/kg under trees, 204mg/kg outside and 184mg/kg in the grassland, alluding to the biological N fixation by *Acacia mellifera*.

In the semi-arid savanna of central Namibia dominated by *Acacia erioloba*, Rothauge *et al.*, (2003), recorded similar trends of higher N under trees than in the open. Abdallah, *et al.*, (2011) and Belsky *et al.*, (1989), David *et al.*, (2005) and Ludwig *et al*., (2004), also reported similar trends of higher Nitrogen concentration closer to trees than at distances in the Outside tree crown zone due to biological N fixation.

The Kalahari deep sandy soils are generally poor in N, P and organic matter (Skarpe and Bergström, 1986; Dougill *et al.*, 1998). There is abundant Nitrogen (N) in organic form (N_2) in natural rangelands which is not available for plants (Brady, 1974), while *A. mellifera* is capable of N fixation. The removal of these *Acacia mellifera* trees in the Camel thorn Kalahari savanna ecosystems will only impoverish such soils which inherently lack Nitrogen. Although *A. mellifera* is commonly found in the entire country, these finding cannot be generalized to other ecosystems other than those formed of deep Kalahari sands due to varying soil dynamics in non-sandy soils.

5.1.2 Comparison of the concentration of other soil elements

The means of pH levels under Tree crown zone were not significantly different ($p>0.05$) from that of the Outside tree crown zone and that of the Grassland zone. The study recorded pH 6.79±0.84 under crown zone and pH 6.52±0.21 in the Grassland zone. The reasons for the no significance difference could be due to less litter under trees. It is possible that herbivores could have picked the litter considering that a severe drought hit the country during the time of this study, given that pastures were poor due to drought. Areas under trees should normally have high litter than the grassland zone. The decomposition of litter and the root respiration dissolving in soil water forms a weak organic acid and therefore alter soil pH. The lack of moisture in dry seasons to allow for decomposition of organic matter and root respiration could explain the insignificant differences among sub-habitats.

Hagos and Smit, (2004) studying similar deep poor sandy soils and *Acacia mellifera* trees recorded no significant differences among sub-habitats. According to Hagos & Smit (2004) the exact reasons for lack of significant differences are not known, but argued that pH levels were supposed to be significantly high among sub-habitats with the high exchangeable cations under canopies. The reason being due to the positive association between increases in exchangeable cations and soil pH (higher base saturation) (Kennard and Walker, 1973)

The understanding and management of soil pH in our rangelands and ecosystems at large cannot be overemphasized as is the measurement and monitoring of the acidity or alkalinity of a soil. Soil pH is important in nutrient availability, and most nutrients require certain pH levels to be made available to plants.

The analysis of Phosphorus (P) revealed no significant differences ($p>0.05$) among the three zones. The study recorded 0.26±0.019ppm under tree crown zone and 0.233±0.140ppm in the grassland. This result is expected due to drought that hit Namibia for the 2012/2013 rainfall season. The slow decomposition of P bearing litter and the related mineralization of P at the surface due to insufficient moisture may explain the lack of significant differences among sub-habitats (Trudgill, 1988). Phosphorous generally originates from the weathering of parent rock. It is rapidly taken up by biomass and released when plants decompose (Knecht, 1998). Nutrients like P are likely to come from deeper soil layers (Ludwig *et al.,* 2004) because trees collect nutrients from deeper soil layers and laterally from areas beyond the canopy, which are then deposited below and beyond canopy through litter fall and leaching (Scholes and Archer 1997). The low mineralization of organic matter due to drought (which could have otherwise released Phosphorus during normal rainy seasons) is therefore the reasons for the insignificant differences in P levels among sub-habitats (Miles, J. 1986).

Results showed that organic matter significantly differed (p<0.05) among sub-habitats measured from the tree outwards. The organic matter was higher under tree crown zone (0.246±0.490 %), and decreased outwards to the grassland zone (0.180±0.224 %). These differences could be attributed to leaf litter, root decomposition of *A. mellifera* and the residue (leaf and roots) of the herbaceous layer under trees. Menault *et al.,* (1985) argued that root turnover is probably more important than litter accumulation in improving the soil fertility status under the canopy zone. The reason for the low organic matter in the grassland zone is because of the grass-dominancy layer in this sub-habitat. In the grassland zone, the main source of organic matter are grass materials (Kahi *et al.,* 2009), whereas the under tree crown zone benefits from the diversity of quality plant materials formed of foliage and the roots of both the trees, forbs and grass.

Similar results were recorded by Hagos & Smit, (2004) (under trees 0.822, and 0.612 % in grassland zone) and *Rothauge et al.,* (2003) (under trees 0.76, and 0.50 % in the grassland zone) who also confirmed significant differences in amounts of Organic matter among sub-habitats. The reason for the lower organic matter content reported in this study than the two researchers could be related to the low decomposition rate as a result of insufficient moisture due to drought that could have otherwise allowed for fast decomposition of plant materials.

Soil organic matter is a major component of biogeochemical cycles of the major nutrient elements, and the quantity and quality of soil organic matter both reflect and control primary productivity (Burke *et al.,* 1988). The amount of soil organic matter represents the balance of primary productivity and decomposition and as such is a sensitive and integrated measure of changes in ecosystem function (Burke *et al.,* 1988). Understanding the processes that control soil organic matter dynamics and their response to management is essential for informed use of agricultural land (Burke *et al.,* 1988).

Potassium (K), on the other hand was significantly higher ($p<0.05$) under Tree crown zone and decreased within sub-habitats outwards to the grassland zone. The reasons for these variations could be the reduced leaching and plant uptake during dry seasons. During the dry season, with reduced leaching and plant uptake, mechanisms like capillary rise can lead to K accumulation on the surface soils and even more under trees (Zwikel *et al.* 2007). The primary source of potassium in soil solution is the weathering of parent rocks. The uptake of K in plant leaf litter and high mobility of it is one of the secondary sources and the reason for an increased K under trees.

The fire regime in these areas that occurs every 2 to 4 years could also contribute to the K increase under trees than in the open. Volatilization of potassium (K) from the combustion of organic matter (tree leaves rich K) enriches the under tree crown zone significantly than the grassland zone.

The study on comparison of soil Calcium (Ca) concentration, revealed that there were significant differences ($p<0.01$) among the sub-habitats. The Under Tree crown zone recorded a higher Calcium (Ca) concentration and decreased in the Outside tree crown zone and the Grassland. The Calcium (Ca) concentration of the Outside tree crown zone was also significantly higher ($p<0.05$) than that of the Grassland zone. Magnesium on the other hand was not significantly different among sub-habitats ($p>0.05$). Reduced leaching during the period under study could be the reason for significant high values under tree. Magnesium can leach more easily than calcium, resulting in the lack of significant differences among sub-habitats. Both Calcium and Magnesium originate from parent materials, precipitated as secondary minerals, recycled to soil through litter, leaching and retained by soil particles (University of Hawai‘I, 2007). All soils contain calcium ions (Ca^{2+}) and magnesium (Mg^{2+}) cations (positively charged ions) attracted to the negative exchange sites of organic matter (cation exchange complex of the soil) (Sawyer, 2003). This could support the reason for higher Ca values under tree crown zone than in the grassland zone, while Mg could have leached to reach similar levels among sub-habitats.

The comparison of Sodium (Na) showed no significant differences among sub-habitats ($p>0.05$). The reasons for this could be related to the high concentration of calcium in the soil. Calcium just like magnesium ions generally competes for the exchange sites occupied by sodium there by reducing the amount of sodium that will be bound to soil (Hanson *et al*., 1999). Sodium is widespread in nature, and is found in all plant material in amounts large enough to be analyzed. Sodium is not a plant nutrient and therefore is not necessary for plant growth (Subbarao *et al.,* 2003). Sodium is removed through leaching, and not by plant uptake, there the reduced leaching during dry seasons could be responsible to this.

5.2 Comparisons of concentrations of plant nutrients

5.2.1 Comparisons of plant Nitrogen (N) concentration at different distances and sub-habitats

Plant N concentration at 1m & 2m (under the tree) and at 4m (outside crown zone) was higher than that at 8m & 12m in the outside crown zone and at 24m in the grassland. The high plant Nitrogen content at distances closer to tree base is related to the high soil Nitrogen under tree crown zone of *Acacia mellifera* trees. Soil enriched N grow N enriched plants (Perakis *et al.* 2006). A strong, positive correlation was established between plant Nitrogen (N) and soil total Nitrogen (N) (r =0.871, n = 30, $p<0.05$) in this study (Fig 4.20), indicating proportionate uptake of soil nitrogen by grasses in the different zones. Although done in temperate forestry, Perakis *et al.*, (2006) presented similar pattern of a strong correlation between soil Nitrogen and plant Nitrogen results (r= 0.71 $p < 0.001$) in the study of Coupled Nitrogen and Calcium Cycles in Forests of the Oregon Coast Range. This study indicated a decrease in plant Nitrogen concentration along a distance gradient from *A. mellifera* outwards.

5.2.2 Comparisons of other plant nutrients

Plant Calcium (Ca), Potassium (K), Magnesium (Mg), Zinc (Zn), Iron (Fe), Phosphorus (P) and Copper (Cu) were all significantly higher under canopy than in the other sub-habitats (p<0.01). Plant Magnesium (Mg), Manganese (Mn), Zinc (Zn) and Iron (Fe) were not significantly different among sub-habitats. These differences in plant nutrients under tree and the grassland are due to the nutrients available in the soil under tree. In this study a strong positive correlation was established between soil Ca and plant Ca (r = .525, n = 30, p<0.01); as well as between soil K and plant K (r = .435, n = 30, p<0.05). Nutrient concentration under tree is usually correlated to nutrients available in the soil (Belskey, 1992). However Phosphorus (P) did not correlate positively (r =.187, n = 30, p>0.05) (Table 4). Generally *A. mellifera* improved soil properties under trees thereby improving the plant nutrients under trees than in the grassland.

5.2.3 Comparison of herbaceous plant species composition among sub-habitats

Hierarchical Cluster Analysis showed that there were similarities between Cluster 1 and the rest = 78%; Similarity between Cluster 2 and Clusters 3 and 4 = 85%; Similarity between Clusters 4 and 4 = 86% (Fig 4.13).

The Hierarchical Cluster Analysis (HCA) revealed four (4) groups based on variations in the plant species composition (Fig. 4.10): Annual grass species (S*tipagrostis uniplumis*, and *Stipagrostis ciliata*) clustered in all the four groups is an indication of the dominance of these species in the area. S*tipagrostis uniplumis*, and *Stipagrostis ciliata* are the common grass species camel thorn savanna vegetation.

The under tree crown zone clustered forbs (*Aptosimum albomarginatum* and *Eriocephalus luederitzianus)*, *Stipagrostis uniplumis*, *Stipagrostis ciliata*, as well as the annual grasses *Schmiditia kalahariensis*. Nutrient availability under trees is the reason for these compositional differences between under tree zone and the open grassland zone. Factors like amount of light, water availability and interactions among them also contributed to these differences (Riegel, et al., 1995). The influence of mineral uptake characteristics of different species (Belsky, 1992) cannot apply in this case, since plant composition was reported to be different in all sub-habitats.

CHAPTER 6

Conclusions and Recommendations

6.1 Conclusions

This study was carried at the resettlement farm of Corsica in the Khomas Region. The main purpose was to determine the role played by *A. mellifera* on soil fertility, herbage quality, and botanical composition with reference to N-fixation. As hypothesized, the study confirmed that:

(a) Soil total Nitrogen concentration was higher under tree crown zone and some distances in the outside tree crown zone closer to *Acacia mellifera* trees than that of the Grassland zone. Generally total Nitrogen decreased along distance gradient measured from the base of *A. mellifera* outwards. The study point out to biological N-fixation by *A. mellifera*; shading that provide unique favorable conditions for bacterial activities and nodulation etc.; the rich N root nodule decomposition adding to these soil N; the N rich leaf litter; the root distribution pattern that extends many lateral roots with bacterial fixation activities within the rhizosphere beyond tree crown zone and in some distances in the outside tree crown zone (root zone) to be responsible for these variations. This led to the acceptance of Hypothesis (a).

(b) As it was hypothesized (Hypothesis (a)), Nitrogen (N) content of herbaceous (grass) layer was higher under tree crown zone than those further away due to enriched soil N by biological fixation of *Acacia mellifera* trees. Generally grass Nitrogen content decreased along the distance gradient from the base of *A. mellifera* outwards.

(c) As it was hypothesized (Hypothesis (b)), there was a strong, positive correlation between plant nitrogen and soil total nitrogen, which was statistically significant ($r = 0.871$, $n = 30$, $p<0.05$). Amounts of plant N increased with amounts of soil N due to its availability for uptake. This study therefore, accepts Hypothesis (b).

(d) Other soil elements (Organic matter, Ca, K, Cu) were significantly higher under trees than in the outside and the grassland zones due to soil enrichment by leaf litter this led to the acceptance of Hypothesis (c). However, other soil elements (pH, P, Mg, Mn, Na) did not differ significantly among sub-habitats, thus rejecting the Hypothesis (c) for these elements.

(e) Other plant elements (Ca, K, P, Cu) were also significantly higher under trees. This led to the acceptance of Hypothesis (c), while plant Mg, Mn, Zn and Fe did not differ significantly among sub-habitats, thereby rejecting Hypothesis (c) for these elements. *Acacia mellifera* creates some islands of fertility under tree crowns, where organic matter and other soil nutrients are high This could be responsible for the higher plant nutrients under trees.

(f) As it was hypothesized (Hypothesis (d)), herbaceous composition differed among sub-habitats. This led to the acceptance of Hypothesis (d). Overall, *Acacia mellifera* improved the soil, plant nutrients and influenced the herbaceous layer under tree crown zone and beyond.

6.2 Recommendations

6.2.1 Management recommendations

Recommendations for better management of *A. mellifera* to maximize the benefit from the N-fixation in these ecosystems include:

i. Thinning of *A.mellifera,* instead of clearing them, is recommended since the benefits of N-fixation by this species may be lost with tree clearance. It is important to maintain these islands of fertility in order to continue benefiting from browse for domestic livestock and game.

6.2.2 Recommendations for further research

(a) The study of the nodulation capacity of *Acacia mellifera* which this study did not cover, considering the specificity of rhizobia bacteria's to host legume plants, this aspect is very important and therefore, warrants further study.

CHAPTER 7

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Appendences

Table 2: List of recorded plant species at Corsica Resettlement farm

Stipagrostis uniplumis	Perennial
Stipagrostis ciliata	Perennial
Schmidtia kalahariensis	Annuals
Melinis repens subsp. *repens*	Annuals
Aptosimum albomarginatum	Forbs
Eriocephalus luederitzianus	Forbs

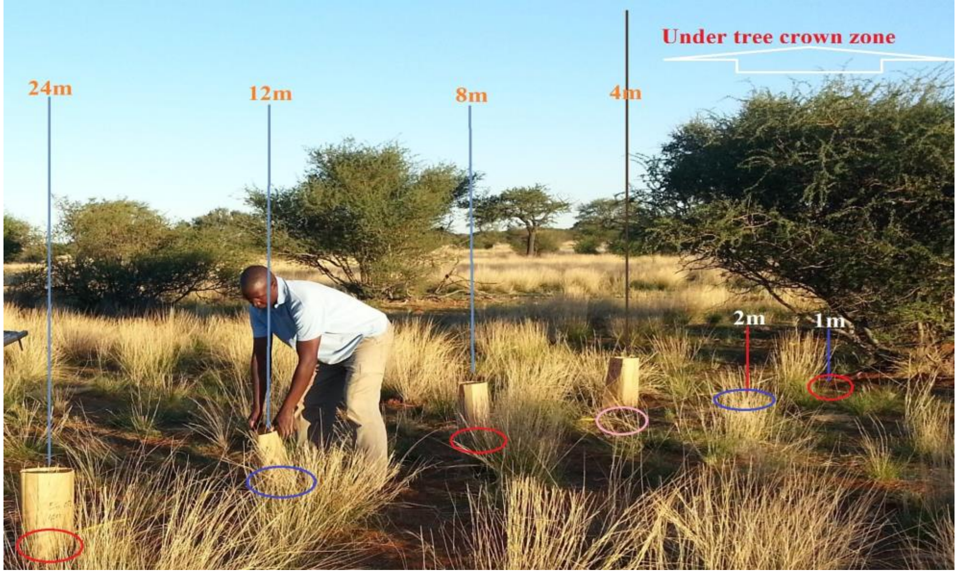

Figure 2: Lay out for sampling at Corsica Resettlement farm