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The extent of woody plant invasion in selected sites of the communally managed Molopo District, North West Province.

By:

Phemelo Ponatshego Mogodi

Student No: 16119886

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Supervisor: Prof. P. W. Malan

TABLE OF CONTENTS

Chapter 3: Woody plant invasion in the study area

Chapter 4: Soils in the study sites

Abstract

Woody plant invasion (bush encroachment) is a problem in the semi arid communal areas of the North West Province which had been affecting the Molopo Area as early as 1960. It affects the livelihoods of the communal farmer because it reduces carrying capacity and is a form of veld degradation.

The extent of woody plant encroachment was quantified at selected sites and reference sites in the Molopo District. There was a study site and reference site selected in a commercially managed area. Soil samples from these selected sites were also analysed for chemical and physical properties as well as nutrient content that could have an influence on the proliferation of the woody plants. Social surveys were also conducted to investigate the perceptions and influence of the affected communities towards woody plant invasion.

The prominent species identified in the area included *Acacia mellifera*, *Dichrostachys cenerea*, *Prosopis velutina* and *Terminalia sericea*. All of the study sites, except the benchmark sites, had woody plant densities of more than 2 000 TE/ha that according to Moore & Odendaal (1987), almost totally suppress grass growth.

It was clear from the data that the nutrient status of soils of encroached areas was higher than the benchmark sites although some of the differences were statistically insignificant. Organic carbon was higher at most of the encroached sites (71 % of the sites) where 80 % of the enriched sites had significantly higher organic carbon than that of the benchmark sites.

There is a need to develop small scale farming practices that are appropriate in terms of sustainable development in the local context.

Chapter 1: Introduction

1.1 Introduction

Woody plant invasion (bush encroachment) is the increase and invasion of indigenous woody plants in grazing lands (Bothma, 1989; Barnard & Newby, 1999; Hoffman & Ashwell, 2001) and is a big problem in South Africa, especially in semi-arid (average annual rain less than 600 mm) areas for ranchers and communal tribes. It is a form of ecological succession that follows veld disturbance. First woody pioneer plants such as *Acacia* species (e.g. scented thorn, sweet thorn, black thorn and umbrella thorn) invade what was previously open grassland. Seeds of these plants are dispersed by large herbivores and germinate readily, especially following good rainfall events (Hoffman & Ashwell, 2001). This results in extensive financial, socio-economical, ecological influences and implications in an area.

Bush encroachment is a fairly recent problem, having first been recorded in the 1920s and 1930s in savanna areas of the Northern Province and KwaZulu-Natal and in the 1940s in arid savanna of the Kalahari. Bush encroachment and the resulted bush thickening are problems affecting mainly cattle farming areas. Indigenous shrubs and trees encroach into former grassland areas, changing it to savannas, or the density of trees and shrubs in existing savanna areas increases. Both these processes reduce the relative amount of grass and, therefore, cattle production (Hoffman & Ashwell, 2001).

According to the United Nations Convention to Combat Desertification (UNCCD, 1995), land degradation is the reduction or loss of the biological or economic productivity in arid, semi-arid and dry sub humid areas resulting from land users or from a process or a combination of processes. The most important consequences of land degradation include:

- Soil erosion caused by wind and / or water.
- Deterioration of the physical, chemical and biological or economic properties of soil, and

- Long-term loss of natural vegetation

The misuse or overuse of land contributes to the destruction of land productivity and alters its carrying capacity. Indicators of land degradation include overgrazing of natural veld or pastures, urban development on productive agricultural land, alien invasive plants in grazing lands, the pollution of ground and surface water resources as well as the altering of the soil structure and chemistry of soil.

Rural communities experience adverse anthropogenic stresses e.g. physical restructuring, introduction of exotic and invasive species, the discharge of toxic material to air, land and aquatic habitats that are non-adaptable to the ecosystem and thus resulting in a process of degradation. These degraded ecosystems are characterised by the reduced efficiency of nutrient cycling and the increased dominance in exotic, smaller, short lived and other opportunistic species (Rapport, 1999; Hoffman & Ashwell, 2001).

The most comprehensive account of the problem of bush encroachment in South Africa was developed at a workshop held at Pretoria in 1980 (Pienaar, 1980; Hoffman & Ashwell, 2001). Officials from the Department of Agriculture met with scientists to estimate the extent of the problem, but their discussion was limited to the four provinces of the old South Africa and did not include communal areas. Of the 38 million hectares of veld analysed, less than 50 % was either affected by or vulnerable to bush encroachment. 4 % of this was heavily encroached upon and 19 % vulnerable to bush encroachment. The remaining 54 % were unaffected (Hoffman & Ashwell, 2001).

At the consultative workshop held in 1997 and 1998 (Hoffman & Ashwell, 2001), participants considered bush encroachment to be a problem in 42 % of the magisterial districts, particularly in the North West Province, Northern Cape, Eastern Cape and Northern Province. Participants from Gauteng and Western Cape did not recognise bush encroachment as a problem. About 50 % of communal districts and 38,5 % of commercial districts were affected (Figure 1.2)

Much attention in recent years has been given to the chemical and mechanical control, and eradication of undesirable bush species. However, significant results obtained from such methods of control show, that the problems might only be temporarily solved. The reasons being that the basic underlying principles are not fully understood. Little consideration has been given to characteristics of the woody plants that would effect their successful encroachment in grasslands.

This project will address the effects of the increase of indigenous woody plants, as well as their invasion on grazing lands in the communal areas**.**

1.2 Problem statement

The emphasis on bush encroachment in the Molopo Area was on *Acacia mellifera* (blackthorn) (Donaldson, 1967). Other encroaching species that have been identified in the study area were *Acacia hebeclada* (Candle acacia or Trassiedoring), *A. tortilis* (umbrella thorn or haak-en-steek), *A. karroo* (Sweet thorn/ Soetdoring), *Dichrostachys cinerea* (Sickle bush (Sekelbos)), *Prosopis velutina* (mesquite), *Rhus dentata* (Nana-berry or Nanabessie), *Ziziphus mucronata* (Buffalo thorn), *Grewia flava* (Brandybush, Wilderosyntjie), *Grewia occidentalis* (Cross-berry; Kruisbessie), *Terminalia sericea* (Silver terminalia. Vaalboom or Sand-yellowwood), *Tarconanthus camphoratus* (camphor bush or kamferbos) which are declared encroachers (Appendix 1).

Humans have contributed significantly in modifying the determinants of savanna systems i.e. directly or indirectly. The determinants of savanna systems may be primary (climate or soil) or secondary (fire and the impacts of herbivores) (Teague & Smit, 1992).

Madany & West (1983) and Skarpe (1991) concluded that overgrazing and overstocking were the main causes of bush encroachment. Ward (2005) suggested that factors such as climate change were responsible for the shift from savannah to woodland and that bush encroachment was widespread in areas with a single soil layer that have infrequent and light grazing.

Overstocking results in high grazing pressures and reduces the growth rate and reproductive potential of individual plants and so influences the competitive relations among the different species (Smit *et al*., 1999). Overgrazing, according to Van Vegten (1983), is the main cause of the increase in woody plants species in eastern Botswana. Skarpe (1990) concluded that densities of these woody species increased where grazing was heavy.

Mismanagement by man encourages bush encroachment and causes an increase in the woody plant densities and consequently leads to land degradation. Poor grazing practice, such as when domestic livestock at extremely high stocking rate, replaces indigenous browsers and grazers is contributing to this problem. The severity of encroachment increases during dry seasons because the negative effects of severe water stress are more evident on grass growth than on tree growth (Britton & Sneva, 1981; Smit *et al*., 1999). Sheep often uproot large numbers of *Themeda triandra* tufts when winter stocking rates are high.

1.3 Literature review

Bush encroachment is the process whereby a grass-dominated vegetation type is transformed into a woody species-dominated one and is recognised as:

- The invasion and introduction of woody species in areas where they originally did not occur.
- The increase in density of woody species in existing natural bushveld (Barnard & Newby, 1999; Bothma, 1989). Disturbance occurs due to natural or artificially caused disturbances in the ecosystem.

Bush encroachment is recognised as a dominant indicator of land degradation and is regarded as a serious problem throughout Sub-Saharan Africa (Hoffman & Ashwell, 2001). It reduces the capacity of large grazing areas by transforming habitats and reducing species diversity (Hoffman & Ashwell, 2001). Bush encroachment has occurred for a long time and seems to be increasing with time. About 13 million hectares of the veld in South Africa has been badly affected in 1956. About 33 % of Southern African savannah, bush and scrub vegetation had been dominated by woody species in 1983 (Barnard & Newby, 1999). The North West Province is among the worst affected areas in South Africa (Hoffman & Ashwell, 2001). It includes the Molopo region where the studies were conducted.

Bush encroachment is found mainly on previously overgrazed areas and old cropping lands (Hoffman & Ashwell, 2001). Non-agricultural practices that lead to bush encroachment are (Hoffman & Ashwell, 2001):

(i) Industrialisation;
(ii) Urbanisation;
(iii) Household activities

Trees and shrubs may form impenetrable thickets that are detrimental to the grazing capacity of the veld (Trollope, 1977). These thickets have the capability of storing precious water resources, as well as preventing passing through of livestock and movement (Barnard & Newby, 1999). Encroaching species decrease the grass production per hectare, thus reducing the grazing capacity of the area (Bothma, 1989). The absence of grass species, due to encroachment, encourages soil erosion (Hoffman & Ashwell, 2001).

Humans have been identified as the most powerful agent of change in the ecosystem (De Korte, 1984). They are responsible for the biotic and artificially caused environmental changes. Many of their activities result in the modification of the actual earth surface. Their impacts can be accidental or deliberate, direct or indirect. In some instances, human's activities have altered the volume, composition and structure of the organic components and consequently, the nature of the physical habitat (De Korte, 1984).

Overexploitation of the land by humans, which leads to encroachment, may be caused by overpopulation, lack of facilities and poverty in the communal areas (Hoffman & Ashwell, 2001). The increase in human population results in increased livestock (stocking rate), with a consequent decrease of grazing land. As a result, there is lack of grazing management. Man's livestock's grazing and browsing has a major effect on the extent of encroachment. Livestock deposit viable seeds in the droppings and the dung provides a favorable medium for germination. Woody plant invasion is most favored when grazing is heavy, because numerous animals browse the higher proportion of the seed crop, leave a higher number of droppings and overgraze the range so that the woody plants seedlings suffer less competition from grass (Detwyler, 1971). This decreases indigenous species variation and thus affects biodiversity.

1.3.1 Consequences of bush encroachment

Woody plant invasion jeopardizes grassland biodiversity and livestock grazing (Barnard & Newby, 1999). Invasion encouraged by livestock grazing is mainly due two factors namely:

(i) changes in climate
(ii) and human activities (Hoffman & Ashwell, 2001).

The increase in the atmospheric nitrogen also deposition favors the expansion of woody plants into grasslands (Barnard & Newby, 1999).

Although grasses are adapted to grazing, the "threats" to grasses are overgrazing and non-defoliation. Overgrazing is the repeated utilisation of the grass plant until the reserve nutrients in the roots are exhausted and the plants do not produce new seedlings. Defoliation has an influence on grass growth. The most palatable grasses are the first to be overgrazed (Van Oudshoorn, 1999).

As the grass cover and grass production decreases, the grazing capacity of the area decreases and leads to soil erosion. Bush encroachment is rapid and costly to control and more evident in communal areas than in commercial rangelands (Tainton, 1981; Barnard & Newby, 1999). Control measures include using fire, browsers, mechanical and chemical control (Tainton, 1999).

Woody plant invasion is determined by the specific invasive species involved as well as their densities. When the bush densities increase above certain thresholds (200 TE/ha), the following negative effects are experienced (Van Oudshoorn, 1999):

- High transpiration results in reduction in soil moisture, thus decreasing grass production and the consequent leading to soil erosion.
- The reduced grass production leads to a reduction in grazing capacity; these results in larger areas needed to sustain the livestock and the spread of encroachment to previously unaffected areas.
- Profitability of farming (sustaining communal communities) is reduced and affects the sustainability of livestock farming.
- The subsequent costs associated with controlling and managing the problem when the damage has been done.

1.4 Grass and tree interactions

Trees growing in the savanna affect herbaceous phenology, production and biomass allocation (root/shoot and leaf/stem) as well as species composition (Scholes & Archer, 1997). Trees have been viewed as competitors (Scholes & Archer, 1997; Smit *et al*., 1999) with grasses and having a negative impact. Positive tree-grass interactions have also been documented (Scholes & Archer, 1997; Smit *et al*., 1999).

Herbaceous productivity is often higher and often lower below the crowns of isolated trees than in the open (Belsky & Amundson, 1992). The growth and subsequent size of any individual tree is a function of the abundance of resources such as water and nutrients to which it has access (Belsky & Amundson, 1992).

Tree age, size and densities affect herbaceous production under and away from their canopies (Scholes & Archer, 1997). Tree age will influence soil properties and the microclimate can change as the tree canopy develops (Scholes & Archer, 1997). The positive or negative effects of trees on grasses may not be apparent until plants reach a specific age or size (Scholes & Archer, 1997). The effects of tree densities on grasses have been well documented (Moore *et al*., 1985; Moore & Odendaal, 1987; Scholes & Archer, 1999; Smit *et al*., 1999) whereby trees at high densities have been found to suppress grass growth.

In heavily grazed savannas, this competitive or facilitation effects of trees on grasses cannot be assessed because there are few differences between tree-crown and grassland zones (Scholes & Archer, 1997). In areas with high livestock densities or native herbivores, herbaceous production may be lower below tree crowns, because animals aggregate in the shade, trampling the plants thus leading to soil compaction (Belsky *et al*., 1993). However, small trees and thorny shrubs may protect understorey herbaceous plants by excluding herbivores (Belsky & Amundson, 1992) but not when they are so dense that there is no room for any herbaceous growth like in the study sites (Section 3.3).

1.4.1 Negative grass-tree interactions

Trees have a competitive advantage over grasses in that they can utilize surface water after overgrazing and deep water that the grasses cannot reach (Tainton, 1999). Some encroaching species are shallow rooted (e.g. *Acacia mellifera* and *Grewia flawa*) (Tainton, 1999; Smit, 1999). *Acacia mellifera* also has a deep root system (Smit, 1999).

Negative competitive interactions between woody and herbaceous plants involve available soil water as a determinant of dry matter production (Scholes & Archer, 1997;

Smit *et al*., 1999; Moleele *et al*., 2002). This implies that the herbaceous and tree components of savanna vegetation should suppress each other, although the results have been variable (Smit *et al*., 1999). Reduced production of the herbaceous components with increasing tree density has been reported by Moore *et al*., (1985) in the Kalahari (Mafikeng Thornveld) Thornveld and Shrub Bushveld (Smit *et al*., 1999). Increased grass production of between 220 % and 740 % was observed by Moore *et al*., (1995), following the application of arboricide (Tebuthithioron) that caused woody plant mortality. Clearing of woody plants in mixed savanna dominated by *Combretum apiculatum* and *Acacia tortilis* resulted in a small improvement in grazing capacity (from 9.1 ha/AU to 7.3 ha/AU) (Dye & Spear, 1982; Smit *et al*., 1999). The differences in response by the herbaceous layer to tree clearing are ascribed to differences in soil types and fertility as well as rainfall which are important determinants of the magnitude of the response to tree thinning (Dye & Spear, 1982; Smit *et al*., 1999).

This negative grass-tree competition is mainly for available soil water and nutrients (Moleele *et al*., 2002). The roots of woody plants are fundamental in their competitive interaction with grasses (Knoop & Walker, 1985; Smit *et al*., 1999). Roots determine the spatial distribution of water and nutrient uptake and can cause an increase or a decrease in resource availability. The roots of savanna woody plants often extend far beyond their projected crown radius (horizontal distribution) and lesser distances for herbaceous plants. Roots of *Acacia mellifera* can extend linearly up to seven times or more the extent of the canopy-spread (Smit, 1999; Smit *et al*., 1999). *Acacia mellifera,* which has a shallow and deep root system, competes directly with the grasses for resources (Smit, 1999). If a large proportion of the roots of trees are concentrated at a shallow depth, they will actively compete with the shallow rooted herbaceous plants for resources and suppress their growth (Rutherford, 1983; Knoop & Walker, 1985; Scholes & Archer, 1997; Smit *et al*., 1999; Smit, 1999). When considering the vertical distribution of roots, evidence exists to suggest that the roots of savanna trees are often concentrated at a very shallow depth (Rutherford, 1983; Knoop & Walker, 1985; Vetaas, 1992; Smit, 1999).

Roots of some species may penetrate to a considerable depth. The root distribution of *Acacia nigrescens* and that of grasses was found to be significantly deeper under tree canopies compared to that between tree canopies (Smit, 1999). No significant differences between root depths under *Acacia nigrescens* canopies and in the open were found (Smit, 1999). Testing for differences between tree species, it was established by Smit (1999) that *Acacia nigrescens* had a significantly low proportion of roots in the topsoil (< 350 mm) under tree canopies in comparison to species like *Combretum apiculatum* (Red bushwillow) and *Colophospermum mopane* (Mopane).

Moore *et al*. (1998) found that competition experiments are typically conducted at a small spatial scale and show that mature trees are competitively superior to grasses, while grasses tend to out-compete immature trees. Moore *et al*. (1998) also found that the suppressive effect of the grass layer on young trees in an area of a few hectares is weakened by overgrazing and absence of fire in a few years. Smit (1999) compared the root biomass of herbaceous and woody plants and found that in an *Acacia*-savanna, the density of the herbaceous roots is considerably higher than that of woody plants. Roots of herbaceous plants often form a dense tangled mass along the woody plant root distribution and even show over the surface soil A-horizon (Knoop & Walker, 1985). This distribution of herbaceous plants root systems has been used to explain the two layer hypothesis of Walker & Noy-Meir (1982). According to the model by Walker & Noy-Meir (1982), only grasses use the topsoil moisture, while the woody plants use the subsoil moisture. According to this model, removal of grasses, e.g. by heavy grazing, allows more water to percolate into the sub-soil, where it is available for woody plants. It was found that *Acacia karroo* trees are able to influence the vertical distribution of soil water up to a distance of 2.5 m from their stems (Smit, 1999).

Species differences exist in the vertical distribution of woody plant roots in relation to those of herbaceous plants (Smit *et al*., 1999).

1.4.2 Positive grass-tree interactions

Established trees create sub habitats ('islands of fertility') (See Chapter 4), which differ from those in the open, with subsequent influences on grasses (Belsky & Amundson, 1992). In the False Thornveld of the Eastern Cape, a consistent pattern of grass production around isolated *Acacia karroo* was found to exist (Stuart-Hill *et al.*, 1987; Stuart-Hill & Tainton, 1989). This pattern was characterised by high grass yields under and immediately south of the tree canopy and low yields immediately to the north of the canopy. The 'islands of fertility' were attributed to favorable influences by the tree (e.g. shade and tree leaf litter) (Stuart-Hill *et al.*, 1987; Stuart-Hill & Tainton, 1989; Scholes & Archer, 1997; Ludwig *et al*., 2001). The grass production patterns under tree canopies has been attributed to reduced water input associated with physical redistribution of rainfall by the tree and competition from the tree for soil water (Stuart-Hill *et al.*, 1987; Stuart-Hill & Tainton, 1989; Scholes & Archer, 1997; Ludwig *et al*., 2001). This led to the conclusion that grass production was greater where there were a few *Acacia karroo* trees than where there were no trees (Stuart-Hill *et al.*, 1987; Stuart-Hill & Tainton, 1989; Smit, 1999) e.g. 400 TE/ha (Moore & Odendaal, 1987). This implies that the presence of woody species at densities lower than 400 TE/ha (Bothma, 1989) that do not suppress grass growth for grass growth similar to the communal benchmarks (Figures 3.25) is encouraged. Smit (2004) recommended that selective tree thinning is encouraged rather than total clearing. That was because the intensity of tree thinning, the sizes of the trees which should be removed, as well the species to be thinned is important to achieve a balanced compromise between the reduction of the competitive effect of the trees on the herbaceous layer and the preservation of the positive influences which the trees have.

The presence or absence of grasses below tree crowns in the study sites is affected by differences in plant production dependent on the amount of solar energy and radiation that reach the ground and on below ground competition between the trees and understorey species (Belsky & Amundson, 1992). Herbaceous productivity has been recorded as much as twice as high below tree crowns as in the open in other savanna systems (Belsky & Amundson, 1992) which had climatic conditions that might be different to the study area.

1.5 Motivation

1.5.1 Purpose of Study

The purpose of the project is an initiative of the National Department of Agriculture supported by the DST-NRF Centre for Invasion Biology to determine the extent of bush encroachment as influenced by human activities in identified rangelands in the Molopo District. The findings will be used to assist government, local communities or any interested party in proper and efficient, land-use planning and management.

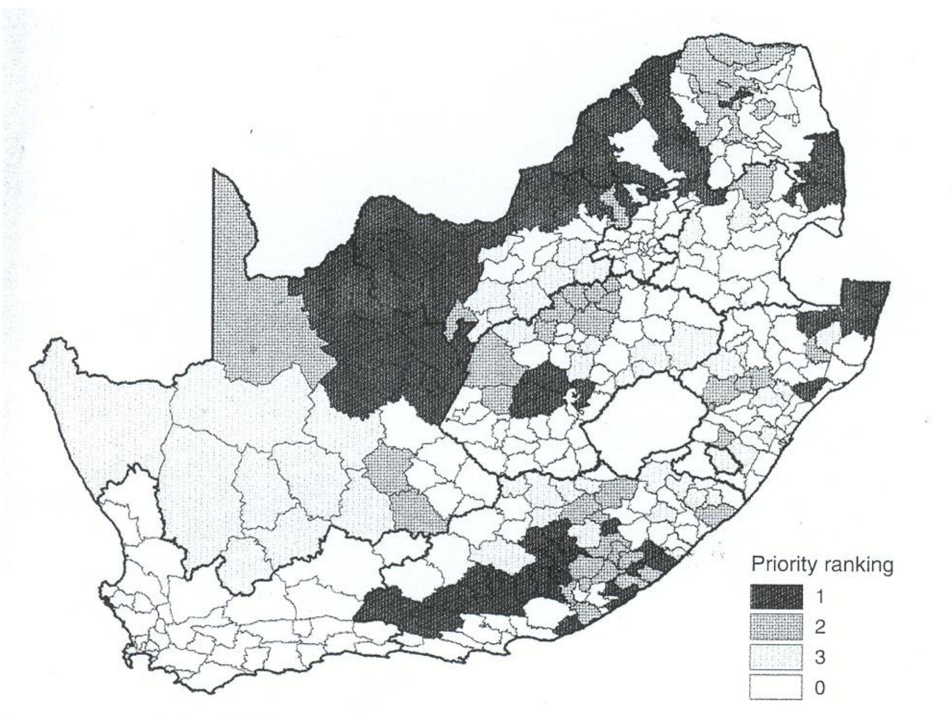

Figure 1.2 Location of the 154 magisterial districts in which participants perceived bush encroachment to be a 1st, 2nd or 3rd order veld degradation priority (Hoffman & Ashwell, 2001).

1.6 Aim and objectives

1.6.1 Aim:

The aim of this project is to determine the extent of woody plant invasion (bush encroachment) and its associated effects in selected communal villages in the Molopo Area (Figure 2.1).

1.6.2 Objectives:

- To asses the extent of bush densities in the communal lands.
- To determine the soil nutrient composition in the affected areas.
- To understand the factors that lead to woody plant invasion through social surveys on land-use practices.
- To research the availability of affordable, efficient and environmentally friendly methods of eradication of invading species.

1.7 Expected outcomes

- ❖ A quantitative analysis of bush density of the study area will be determined.
- ❖ A qualitative analysis will indicate the effect of bush encroachment on soil nutrient status.

Chapter 2: Study area and climatic conditions

2.1 Study area

The study area is situated in the semi arid savanna Biome in the North West Province South Africa. Barnes (1976) defined a “semi arid savanna” to include a range of physiognomic vegetation types of the tropical and sub-tropical summer rainfall regions of Africa. These regions, when degraded by over-use, have a closed herbaceous cover, mainly grasses, and a scattered to fairly dense population of deciduous trees or shrubs, or a mixture of both. Semi-arid savanna vegetation is primarily a reflection of moisture supply, which in turn is influenced by rainfall and local edaphic and topographic conditions, but may reflect also the intensity and frequency of fires (Barnes, 1976). The lack of fires burning veld results in the increase of the woody component and reduction of the grass component (Bothma, 1989).

The study area (Molopo District) (Figure, 2.1) is in the Kalahari Desert ecological zone (Department of Agriculture, Conservation, Environment & Tourism, DACET, 2002).

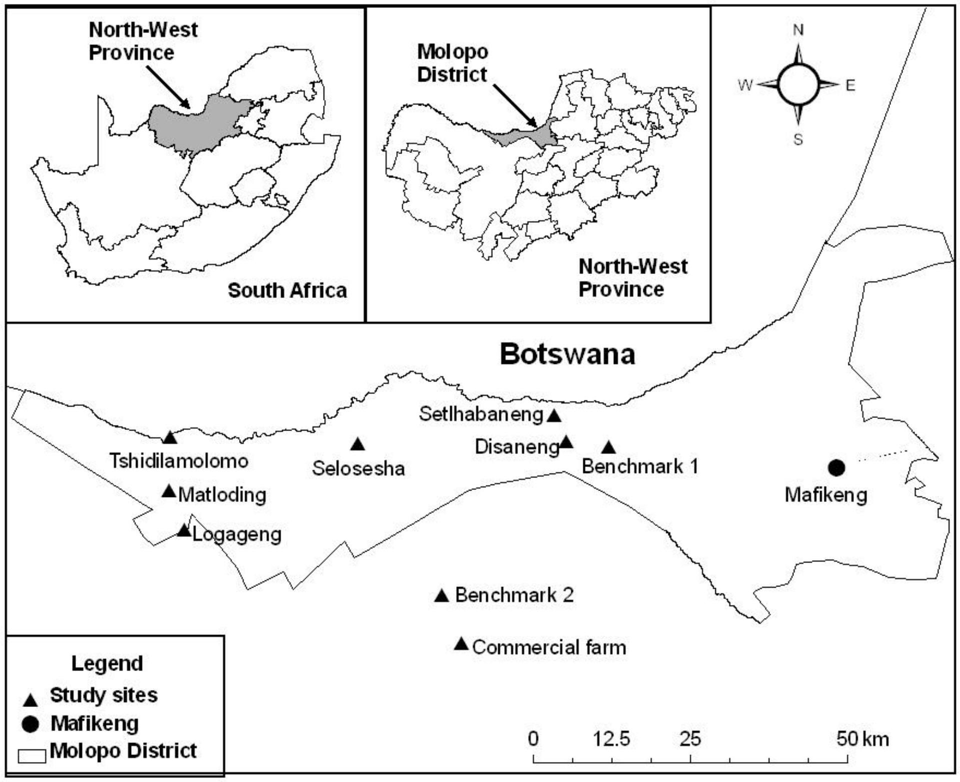

Figure 2.1 Map of study area

2.2 Climate

The climate of the Molopo study area is hot and semi-arid, characterised by high day temperatures during the summer months and much cooler winter months. The adverse effect, which the high maximum temperatures may have on the plants and animals, is reduced by the much lower temperatures experienced during the night. Like most other areas of South Africa, this region experiences dry and desiccating north-westerly winds which occur mainly during the spring and summer months. Although a few farmers in this area keep rainfall records, other meteorological data of great importance are unavailable (Donaldson, 1967).

2.3 Rainfall

Soil moisture has been cited as a primary determinant of savanna plant community structure (Scholes & Walker, 1993; Moleele *et al*. 2002). That is why rainfall is important.

The average rainfall per calendar year for the Molopo Area over the past 10 years has been recorded as 534.9 mm (Figures 2.1). The wettest months were December and January and the driest were June and July (Figure 2.1).

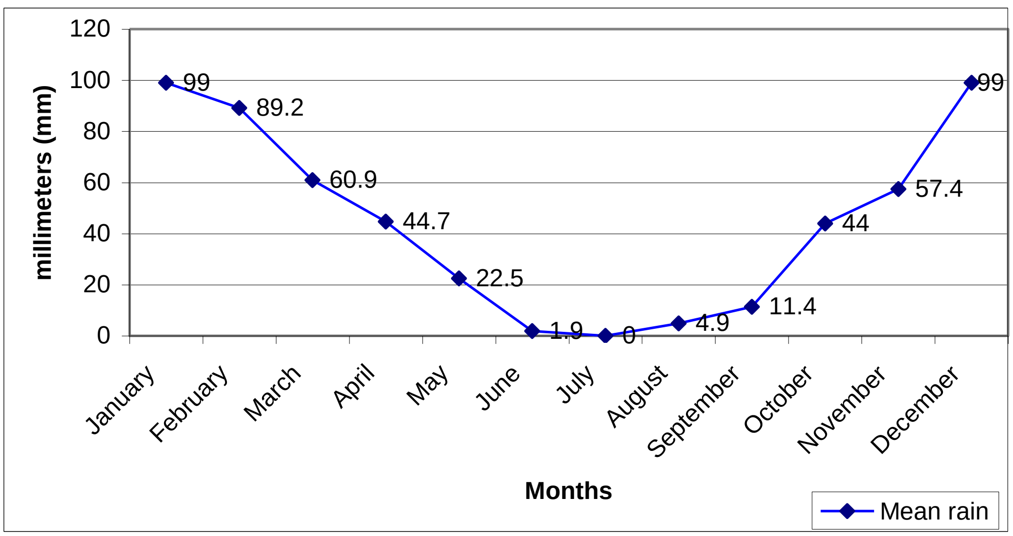

Figure 2.1 Average rainfall (mm) of Mafikeng (1996 – 2006) (South African Weather Service).

2.4 Temperature, evaporation and wind direction

2.4.1 Temperature

The importance of temperature is in enhancing plant growth and regulating the processes of photosynthesis and transpiration (Tainton, 1981). The average maximum temperatures go up to 30.2 ^{o}C in the hot seasons and to 20.8 in the cold seasons (Figure 2.2). These hot temperatures result in high evaporation rates of the region (City Council of Mafikeng-LDO's 1998 – 2004; South African Weather Service, 2008).The average minimum temperatures go from 17.7 ^{o}C in the hot seasons and to 4.2 ^{o}C in the cold seasons (Figures 2.2).

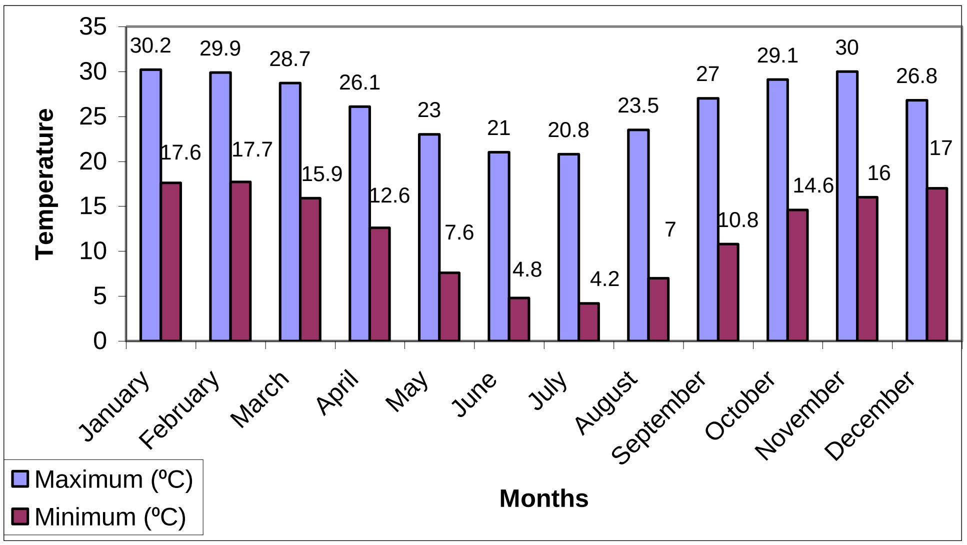

Figure 2.2 Average maximum and minimum temperature of Mafikeng (1996 – 2006) (South African Weather Service, 2008).

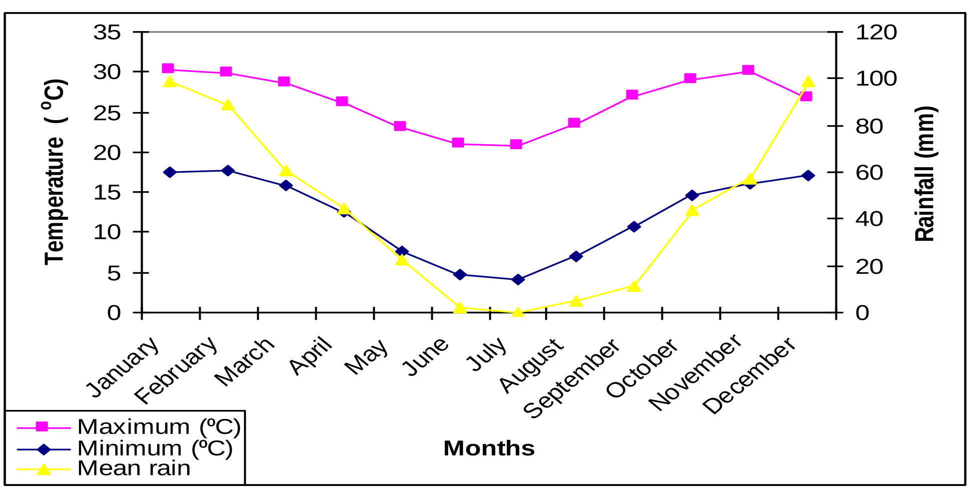

Figure 2.3 Climatic diagram for North West University (1996 – 2006) (South African Weather Service, 2008).

2.5 Geology

The geology of the area is considered important because it influences the topography and thereby influencing the climate, present materials, soil and vegetation (Van Riet, 1990; Bothma, 1996). The rocks found in the study area are of Andesite lava origin and Dolomites (Van Riet, 1990). The Andesite lava consists of Alendrige formations and Ventersdorp Super Groups. Dolomites are made of the Malami Super Group and the Transvaal Sequence. Most of the area is covered by a layer of red, silty, sandy transported soils, which varies in depth (Van Riet, 1990). Soil that develops from igneous rocks such as dolemite is poorly leached with a relatively high pH and therefore offers palatable grazing (Bothma, 1989).

2.5.1 Landscapes

There are large and small Andesite lava rocks on the terrain. This terrain type reduces the effect of erosion. The landscape represents undulating to steep slopes. Aspects, or the position in the landscape with regard to wind direction, are in areas with an undulating to steep topography (Bothma, 1989).

2.5.2 Soils

Soil is a natural resource. It results from complex interactions between climate, organisms, topography, parent material and time (Van der Merwe, 1973). According to Eloff (1984) the increase in rainfall from the west to east plays an important role in the geneses (development) of soil. Soil types found in the study area include Mispah, Hutton, Mayo, and Jabankulu (Van Riet, 1990). Different soil types as well as soil depth determine the productivity (yield) and the palatability of grazing in the long term. The yield of the material per unit area increases with soil depth. The most important characteristics are colour, texture and structure. Soil colour is attributed to the different forms of iron in the soil, the parent rock from which it has developed and the amount of organic material in the topsoil (Bothma, 1989). Mispah soil is shallow brownish red gravel fine sand, and is located on the A-horizon with depths of about 120 cm (Department of Agriculture, 1991). Red soils (as in Selosesha and Disaneng Villages) usually indicate good drainage and aeration (Bothma, 1989). Mayo soils are found along the river, and have a depth of approximately 80 cm. Jabankulu soils are also found along the river and are slightly moist with a dark grey colour (Van Riet, 1990). Grey colour of the soil is an indication of a high water table and/or waterlogged condition. For example, sandstone formations, which contain little iron, produce a light-coloured soil, while a dark-coloured soil can be the result of accumulated organic material (Bothma, 1989). The A-horizon easily washed away, exposing the erodable clayed B-horizon. Soil can hold water because of the pores between soil particles (Russell, 1997). Soil of the study area is described in Chapter 4.

2.5.3 Strata encountered

The soil profiles for the area are characterised with the overlying andesite as slightly moist, dark brownish red, loose to medium dense, open and voided grain structure. The sand is silty and fine containing scattered gravel and boulders. There are abundant termites' activities and burrows. The rocks are white to brownish red and of different sizes. The soft soil makes it easy for pigs to make burrows (Van Riet, 1990).

2.6 Vegetation of the study area

The veld type of Mafikeng is classified as mixed and more specifically dry *Cymbogon-Themeda* Veld (City Council of Mafikeng Land Development Objectives 1998-2003). The Central District Settlement Strategy identified that the effects of fuel woodcutting are very evident around the Greater Mafikeng Area (City Council of Mafikeng – LDO's 1998 – 2003).

Donaldson (1967) described how the sandy soils of the Molopo Area were transformed within 20 years from overstocking. Donaldson (1967) described how vegetation comprising open grassy plains dominated by the palatable and desirable grass species (e.g. *Anthephora pubescens*) with scattered trees (e.g. *Acacia erioloba* and *Boscia albitrunca*) changed to a dense tree-shrub savanna dominated by *Acacia recifens* and shrub-like thicket-forming plants such as *Acacia mellifera*, *A. hebeclada*, *Dichrostachys cinerea* and *Rhigozum obovatum* and a shrubby form of *Terminalia sericea*. Donaldson (1967) also described the understorey as sparse and comprises mainly *Stipagrostis uniplumis*, *Eragrostis lehmanniana* and *Schmidtia bulbosa* associated with *Aristida stipitata* and *A. graciliflora*.

Unpalatable grasses such as *Cymbopogon plurinodis* have thickened up where the area has been selectively grazed (Tainton, 1981). Degradation has taken the form initially of a depletion of vigor and so a drop in production, followed by the death of the perennials, and finally in the formation of bare areas covered by rocks and *Tragus berteronianus* where the area has been continuously overgrazed (Tainton, 1981). If these degraded areas are allowed to recover, it will be colonized by unpalatable karoo shrublets and by pioneer grasses, including *Aristida* (brittle grass) and *Chloris virgata*.

There are smallholdings such as the study sites Disaneng, Setlhabaneng, Selosesha, Tshidilamolomo and Matloding Disaneng Villages, where overgrazing is common as well as commercial farms such as the Neverset Farm (Figure, 2.1). The most common woody species in the study area is *Acacia mellifera* but there are other woody plants (Chapter 3) and variety of grasses. The vegetation is divided into four types namely: Vlei, Karee, Thorn veld and mixed veld (Van Riet, 1990).

2.6.1 Mixed veld

Mixed veld consists of grasses and clumps of trees and shrubs. Prominent grasses are *Cybopogon plurinodis* (turpentine grass), *Themeda triandra* (red grass), *Brachiaria nigropedata* (spotted signal grass), *Anthephora pubescens* (wool grass), *Elionurus muticus* (sour grass), *Aristida* species and *Eragrostis superba* (sawtooth love grass). Trees and shrubs include *Rhus ciliata* (sour karee), *Grewia flava* (brandybush), Aloe davyana, *Felicia filifolia*, *Lippia javanica*, *Acacia karroo* (sweet thorn), *Acacia tortilis*, *Acacia hebeclada* and *Ziziphus mucronata* (buffalo thorn) (Van Riet, 1990).

2.6.2 Vlei

The area lies along the dry Molopo River. The grass cover is dense with *Cymbopogon excavatus* as the most prominent grass. Other grasses include *Themeda triandra* (red grass), *Eragrostis* species (love grasses) and *Aristida congesta* (Van Riet, 1990).

2.6.3 Kareeveld

Kareeveld consists of mostly shrubs that border the vlei areas. The most prominent shrub is *Rhus ciliata* (sour karee). Other species include *Acacia karroo* (sweet thorn), *Ziziphus mucronata* (buffalo thorn) and *Grewia flava* (brandybush). Prominent grasses are *Cymbopogon plurinodis* (turpentine grass) and *Themeda triandra* (redgrass) (Van Riet, 1990).

2.6.4 Thornveld

Species that are descriptive of these areas are *Acacia tortillis* (umbrella thorn), *Acacia karroo* (sweet thorn) and *Acacia hebeclada*. *Acacia tortilis* is the most prominent species. Other species include *Ziziphus mucronata* (buffalo thorn), *Rhus ciliata* (sour karee), *Grewia flava* (brandybush) and *Aloe davyana*. Grasses are *Cymbogon plurinodis* (turpentine grass), *Themeda triandra* (Red grass), *Elionurus muticus*, *Aristida* and *Setaria* species (Van Riet 1990).

Chapter 3: Woody plant invasion in the study area

3.1 Introduction

The Savanna Biome represents 32.8 % of South Africa (399 000 km^2) according to Mucina & Rutherford (2006). According to Mucina & Rutherford (2006), the Savanna Biome represents 32.8 % of South Africa (399 000 km^2). The study area was situated in this biome and in order to understand woody plant it is necessary to understand the dynamics of the ecosystems in which they occur (Bergstrom & Kirchmann, 1998).

The determinants (primary and secondary) of savanna structure and function are water supply, nutrient supply, fire and herbivory (Scholes & Walker, 1993). Water supply and nutrients are considered as primary determinants while fire and herbivory are secondary determinants of savanna structure and function (Scholes & Walker, 1993; De Klerk, 2003). De Klerk (2003) described primary determinants as functions of a specific geographical region and beyond the farmer's control to a certain extent. Rainfall, together with soil moisture balance, has an overwhelming effect on vegetation structure, composition and productivity. Woody plants are viewed as establishing in large numbers during certain years rather than a gradual annual increase in density (De Klerk, 2003). The general view of increase in woody plant densities is that, at varying intervals, prolonged denudation of soils caused by droughts and grazing, followed by above-average rainfall years with frequent rainfall events, favors mass tree recruitment (De Klerk, 2003). Secondary determinants on the other hand, act within the constraints imposed by primary determinants and can often be directly modified by management (De Klerk, 2003). Exclusion of occasional hot veld fires, the replacement of most of the indigenous browsers and grazers by livestock, injudicious stocking rates, poor rangeland management practices and artificial water points are regarded as the major causes of bush encroachment (De Klerk, 2003).

Barnes (1976) had similarly viewed semi-arid savanna vegetation as primarily a reflection of moisture supply, which is influenced by rainfall as well as local edaphic and topographic conditions that may reflect the intensity and frequency of fires. The physical determinants of savanna vegetation which are biological interactions and individual species properties are unique to each spatial and temporal situation (Smit *et al.*, 1999). Past management practices (overstocking and overgrazing) added to the complexity by bringing about different kinds and degrees of modification (Teague & Smit, 1992). Determinants of savanna (Scholes & Walker, 1993) which are unique vegetation composition, nutrient composition, soils and past management practices (Teague & Smit, 1992; Smit *et al.*, 1999; Mucina & Rutherford, 2006) are noticed in the study area. Unique vegetation can be explained in terms of the different vegetation types within savannas (Mucina & Rutherford, 2006). This was noticed by the presence of some woody species being more prevalent in certain sites than others. Sites such as Selosesha had an almost pure stand of *Acacia mellifera*, while other sites such as Tshidilamolomo had *Prosopis velutina* which was not identified in other sites.

Management of savannas requires an understanding of the interactions of woody species with other components of the ecosystem (Bergstrom & Kirchmann, 1998) i.e. the biotic and abiotic. Whether there are too many woody species or not depends on different factors. That is, whether the woody species improve or reduce critical ecosystem functioning such as primary productivity, nutrient cycling and hydrological function or soil stability (Belsky & Amundson, 1992). This chapter aims at measuring the species composition and the structure of woody plant invasion that alter savanna structure in the selected study sites.

Woody plant invasion (bush encroachment) is the process whereby grass-dominated vegetation is transformed into a woody species-dominated one (Donaldson, 1967). Bush encroachment is caused by the increase in cover of usually indigenous trees and shrubs, usually in response to poor management practices (Hoffman & Ashwell, 2001). According to Whiteman & Brown (1998), there are two general types of shrub increase in rangelands; First, thickening of native shrubs in open savannas and grasslands leads to conversion to scrublands and is generally viewed as an acceleration of the existing successional processes. Second, invasion of exotic (alien) shrubs in open grasslands and savannas have the potential to drastically alter both economic and ecological function of the ecosystem.

Once the woody thicket is established, it may take decades to revert to an open savanna (Scholes & Archer, 1997). All veld types in South Africa are subjected to invasion by certain grass species, forbs, shrubs or trees (Bothma, 1989). Woody species can compete with herbaceous species for limited resources and facilitate their growth, increase soil erosion and deplete soil of nutrients but can also simultaneously enrich it (Belsky & Amundson, 1992) (See chapter 4).

3.1.1 Views of causes of bush encroachment

Proximate causes for woody plant displacement of perennial grasses are the subject of debate (Barnes, 1976; Teague & Smit, 1992; Archer *et al*., 1995; Brown & Archer, 1999 ; Smit *et al*., 1999; Ward, 2005; Briggs *et al*., 2007). Land-use practices such as shifts in land use and management, overgrazing and reduction in fire frequencies and landscape-level fragmentation have been implicated (Barnes, 1976; Teague & Smit, 1992; Archer *et al*., 1995; Brown & Archer, 1999; Smit *et al*., 1999; Ward, 2005; Briggs *et al*., 2007). Other factors that include indirect human influences such as climate change, increased N deposition and rising CO_2 concentrations have also been implicated (Barnes, 1976; Teague & Smit, 1992; Archer *et al*., 1995; Brown & Archer, 1999; Smit *et al*., 1999; Ward, 2005; Briggs *et al*., 2007).

According to De Klerk (2003), two important models can explain the causes of bush encroachment which are:

• **Walter's Two-layer Model**, which maintains that, if the grass layer is overutilised, it loses its competitive advantage and can no longer use water and nutrients effectively. This results in a higher water and nutrient infiltration rate into the subsoil. Such a scenario will benefit the woody component and bushes and allow it to dominate.

• **The State-and-Transition Model**, which recognizes that savanna ecosystems are dynamic in nature. Savannas are event-driven where rainfall and its variability plays a more important role in vegetation growth (and composition) than the intensity of grazing. It implies, therefore, that bush encroachment is not a permanent phenomenon and a savanna could be changed to its grass-dominated state by favorable management or environmental conditions.

Walter's Two-layer Model and The State and Transition Model encompass the two current paradigms in the function, ecology and management of arid and semi-arid rangelands, that is, the equilibrium and non equilibrium view of rangelands (Vetter, 2005).

In the equilibrium model, importance of biotic feedbacks such as density-dependent regulation of livestock populations and the feedback of livestock density on vegetation composition, cover and productivity is stressed (Vetter, 2005). Range management under this model centres on carrying capacity, stocking rates and range condition assessment (Vetter, 2005).

In the contrasting non-equilibrium model, rangeland systems are thought to be driven primarily by stochastic abiotic factors, notably variable rainfall, which results in highly variable and unpredictable primary production (Vetter, 2005). Livestock populations are thought to have negligible feedback on the vegetation as their numbers rarely reach equilibrium with their fluctuating resource base (Vetter, 2005).

Vetter (2005) suggested that most arid and semi-arid rangeland systems encompass elements of both equilibrium and non-equilibrium at different scales, and that management needs to take into account temporal variability and spatial heterogeneity.

Fire may have beneficial effects on grass establishment in that it inhibits invasions by undesirable woody plants (Barnes, 1976). In many vegetation types, regular fires every few years have the effect of preventing the establishment of seedlings of woody plants, and occasionally some established trees may be killed (Barnes, 1976; Trapnell, 1959). High-intensity fires played a major role in maintaining open savannas in the past (De Klerk, 2003). Veld fires were suppressed with the introduction of cattle farming and this is regarded as a major factor that contributed to bush encroachment (De Klerk, 2003). High-intensity fires are regarded as a prerequisite for effective burning. These fires depend largely on the amount and structure of the fuel (grass), its moisture content, the prevailing atmospheric humidity and wind speed. That is why fire is not effective where high bush densities occur, but it can serve as an effective management tool for modifying the structure of the woody layer and as an aftercare treatment. Because grass cover is poor in encroached sites, the use of fire to reverse bush encroachment is impractical, artificial and costly because thinning of the tree and shrub components is necessary initially (Donaldson, 1967; Barnes, 1976; De Klerk, 2003).

Due to a combination of long term drought, overstocking of domestic cattle, compression of wildlife habitat, harvesting of trees for fuel wood and poor agricultural practices, previously productive savannas have been or are currently being converted into unproductive deserts, eroded wastelands and dense thorn shrublands (Belsky & Amundson, 1992). High stocking rates of domestic livestock (grazers) and a decrease in game numbers (browsers) increased the pressure on the grass layer and declined the competitive advantage of a vigorous perennial cover, thus creating a more favorable environment for the woody component (De Klerk, 2003).

Invader bushes produced seeds in abundance and that created opportunities for the establishment of new generations of woody plants (De Klerk, 2003). Each generation was able to reach maturity and produced more seeds. Research findings indicate that the seeds of *Acacia mellifera*, for example, are not transferable from one season to another, but many of the other problem species (Appendix 1) (De Klerk, 2003) are. Factors like seasonal dormancy, hard seed testa and the presence of allelochemicals causes the seed content in the soils to gradually build up, resulting in several hundred to even several thousand seeds per square meter (De Klerk, 2003). The absence of ungulates in tandem with the suppression of fire further created favorable conditions for bush encroachment (De Klerk, 2003).

Factors beyond farmers' control characteristic of semi-arid regions (Mucina & Rutherford, 2006) are seen as having made a substantial contribution to the problem of bush thickening (De Klerk, 2003). These include poor rainy seasons or droughts, followed by years with above-average rainfall with frequent rainfall events (De Klerk, 2003).

De Klerk (2003) found that access to information regarding environmentally sound methods to carry out bush control programmes seems to be a serious problem, especially in the communal areas. Without proper post thinning management and monitoring, clearing of bushes could lead to even worse problems (De Klerk, 2003; Smit, 2004).

According to Moleele *et al*. (2002), the two main factors determining natural woody vegetation distribution (i.e. species and structure) in Botswana were rainfall and soil type which are non-equilibrium (Vetter, 2005) factors. It is suggested (Figure 3.1) that bush encroachment takes place as a result of the use of moisture by encroachers (relating to cattle density), high soil nutrient concentrations, low fire frequencies and high cattle selectivity (Moleele *et al*., 2002). This was confirmed by Scholes & Walker (1993).

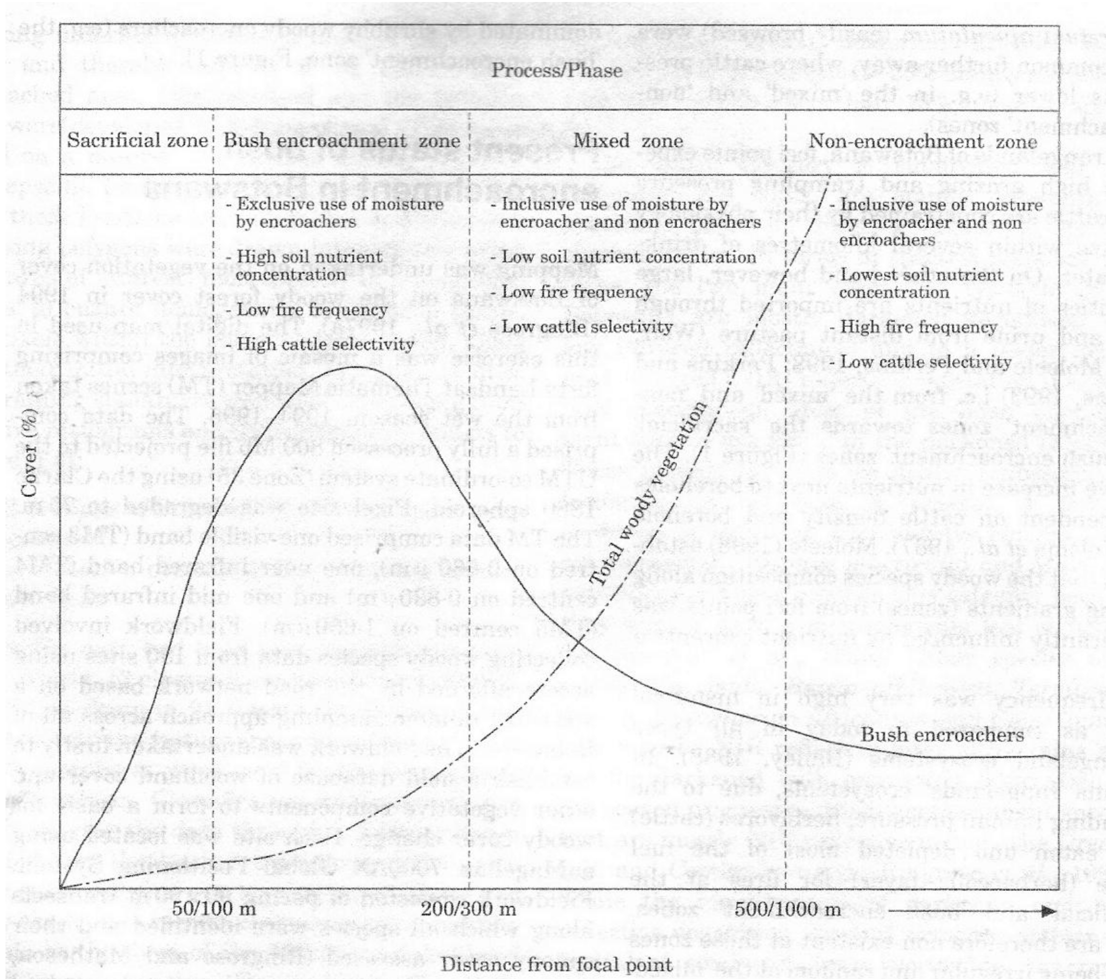

Figure 3.1 Four general phases related to bush encroachment around foci points in communal grazing pastures in south eastern Botswana (assuming homogeneous topography and no overlapping phases/ distances between foci points). The effect of the four interacting factors on each phase is also depicted (Moleele *et al*., 2002).

Ward (2005) suggested that bush encroachment is caused by other factors than the widely accepted "overgrazing and lack of fire" (Van Vegten, 1983; Perkins & Thomas, 1993; Tainton, 1999) by use of resource allocation models. According to the honeycomb-rippling model of Wiegand *et al*. (2002), bush encroachment can be a natural recruitment process in savannas that is independent of the source of disturbance that creates space for tree germination under ideal rainfall conditions (Ward, 2005; Wiegand *et al*., 2006).

Meyer *et al*. (2007) mentioned the patch dynamics models as described by Ward (2005) and Wiegand *et al*. (2006) as complementing, rather than excluding the accepted notion of overgrazing as cause of woody plant proliferation.

3.1.2 Implications of bush encroachment

Bush encroachment results in negative effects on the environment such as:

- a reduction in soil moisture due to a high transpiration,
- grass production is reduced,
- the reduced grass production leads to a reduction in the grazing capacity, and
- bush encroachment suppresses grass growth (Bothma, 1989) and thus decreases or alters the economic productivity (Belsky & Amundson, 1992; Whiteman & Brown 1998; Smit *et al*., 1999; National Department Agriculture, 2000; Higgins *et al*., 2007) of semi-arid grasslands (Donaldson, 1967) especially for communal subsistence farmers.

The three most important aspects according to De Klerk (2003) to properly asses the ecological implications of trees in the bushveld areas from an agricultural point of view are:

- Competition with herbaceous vegetation for soil moisture: Trees affect the soil moisture content by intercepting and redistributing precipitation. They reduce evapotranspiration by creating shade. Their roots penetrate deeply, and the intra-tree shading of leaves affects the rate of transpiration as well as inter-species differences in transpiration rates.
- Source of food for browsers: Available browse (Smit, 1989) refers to leaves, young twig material, bark, flowers and pods within reachable height.
- Creation of sub-habitats suitable for grasses.

Woody plant densities of 2 500 TE/ha decreased grazing potential by as much as 331 %, 149 % and 58 % in the Molopo Thornveld (where study sites are situated), the Mixed Vaalbos Thornveld and the Eastern Grass Bushveld, respectively (Richter *et al*., 2001). This was compared to sites with tree densities of less than 400 TE/ha (Richter *et al*., 2001). Moore & Odendaal (1987) claimed that densities of 2 000 TE/ha almost totally supress grass growth. Smit *et al*. (1999) suggested that removal of some or all of the woody species will result in an increase of grass production and thus grazing capacity. The results of woody plant removal may differ between veld types, depending on both positive and negative responses to tree removal and different interactions (Stuart Hill & Tainton, 1989; Scholes & Archer, 1997; Smit *et al*., 1999; Tainton, 1999; Simmons *et al*., 2007).

3.2 Methods

- **Method for describing woody plant composition and structure or variable quadrant method was used (Coetzee & Gertenbach, 1977).**

Knowledge of the severity of the problem in terms of its extent and intensity is necessary when dealing with phenomena such as bush encroachment for the development of a coherent management programme by both land managers and policy-makers (Whiteman & Brown, 1998).

The technique for describing woody vegetation composition and structure in inventory type classification, ordination and animal habitat surveys (Coetzee & Gertenbach, 1977) was used in this study to quantify bush encroachment in the study sites. Woody structure composition and structure were recorded per species, stem growth form, height class and canopy regime at different height levels. Quadrant size was determined independently at each height class to describe the density and distribution of plants (Figure 3.2). Figure 3.2 illustrates the procedure for e.g. 1 m tall plants. Figure 3.2 shows that 5 m x 5 m squares were large enough to include a 1 m plant in three quadrants but in the fourth, a 10 m x 10 m square is required to include such a plant. The quadrant size for 1 m tall plants was therefore four contiguous, nested, 10 m x 10 m squares, i.e. one square of 20 m x 20 m with an area of 400 m^2. The procedure was repeated to determine a suitable quadrant size for each height class. A specially designed data sheet was used to record the data (Appendix 2).

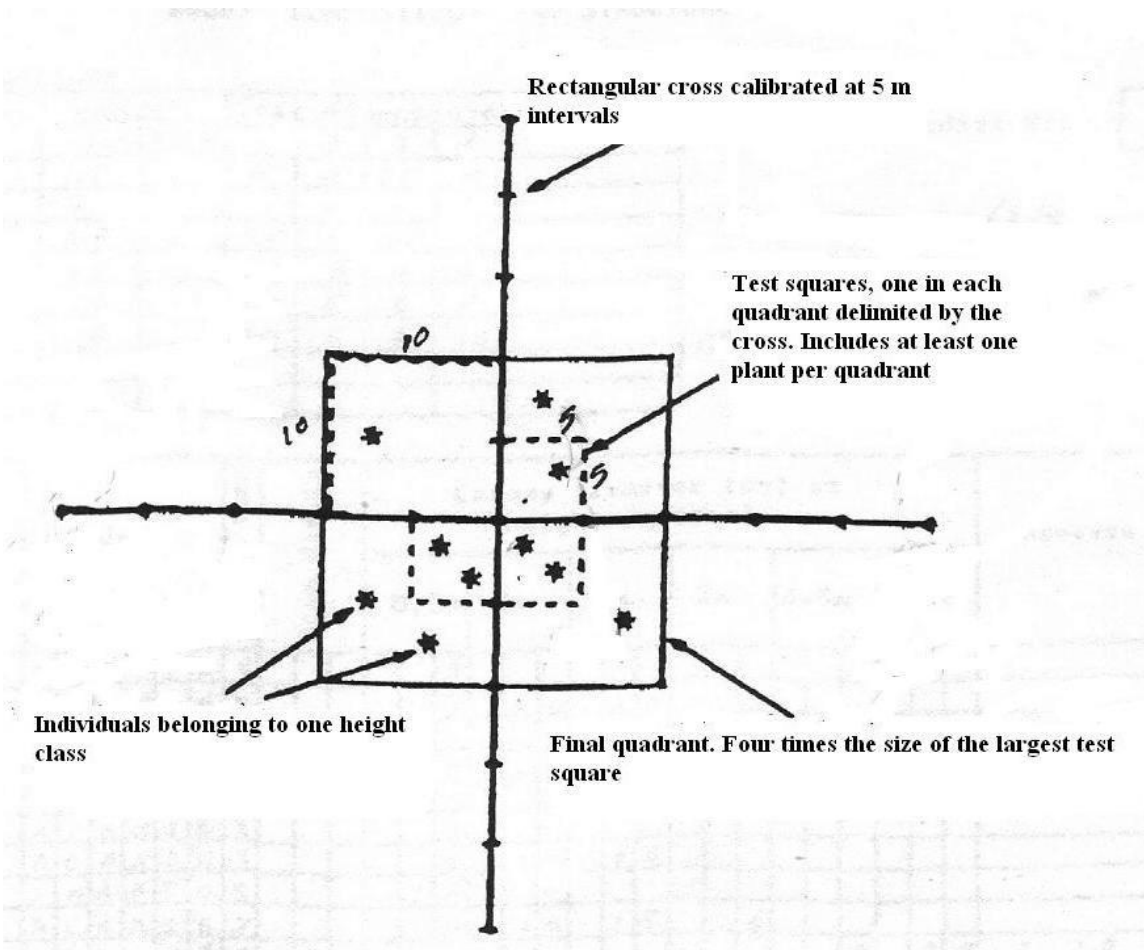

Figure 3.2 Procedure by Coetzee & Gertenbach (1977) for determining quadrant size for a height class, e.g. 1 m tall plants. Test squares are enlarged in steps until at least one plant is included.

Canopy regime at a height level was calculated from average maximum canopy diameters at that height level ($A = \pi.r^2$). Canopy cover is calculated as horizontal spread of the canopy diameters and is expressed as percentage of sampling unit area. Other woody species that are not considered encroaching species were counted because they contribute to the total woody species population and documenting them can help in understanding future trends in semi-arid landscapes.

Woody plant density was measured by tree equivalents per unit area (hectare). The term tree equivalent (TE) is widely used in South Africa to express the woody plant population in a currency or unit (Smit, 1992; Hardy *et al.*, 1999; Hagos & Smit, 2005). A tree equivalent is defined as a 1.5 m tall tree or shrub (Smit, 1992; Hardy *et al.*, 1999; Hagos & Smit, 2005). Therefore, a plant of 3 m in height represents 2 TE e.t.c.

The National Department of Agriculture (2000) declared some species as indicators of bush encroachment in South Africa (Appendix 1). Species like *Grewia flava* are considered encroaching at densities of 400 TE/ha and more (Donaldson, 1967). According to Moore & Odendaal (1987), a bush density of 200 TE/ha has no effect on grass production but the grass production will decline linearly with a further increase in bush density until a tree density of 2 000 TE/ha which almost completely suppress grass growth. From these observations by Moore & Odendaal (1987), a woody plant density above 200 TE/ha will be considered threatening. When calculating woody plant densities, emphasis should be put on encroaching species as declared by the National Department of Agriculture, (2000) because non-encroaching species like *Acacia erioloba* contribute to the total woody plant population.

Table 3.1 Indication of the extent of bush encroachment (TE/ha), (National Department of Agriculture, 2000) (Bothma, 1989; Moore & Odendaal 1987).

Tree equivalents per hectare (TE/ha)	**Extent of bush encroachment**
200-457	Encroached (grass production declines linearly)
458-714	Highly encroached (Grass suppressed further)
715-1099	Severely encroached (More grass suppression)
2000>	Grass growth almost totally suppressed

According to Tainton (1999) a benchmark site is one whose veld is in excellent condition in terms of management objectives. A benchmark is used for comparison or rating with veld in the same ecological zone or experiencing the same macroclimatic conditions to differentiate between the influences of climate and management (Tainton, 1999; De Klerk, 2003). The subjective selection of benchmark sites involves the selection of sites which are productive and stable and which would support long-term animal production while conserving the water and soil resources or exhibits the healthiest ecological processes and is best protected from erosion under the prevailing macroclimatic conditions (Tainton, 1999; De Klerk, 2003). According to De Klerk (2003), if the rangeland condition of the benchmark land is such that it could still be significantly improved through management, then it would be beneficial to fence off a representative area and manage it in such a way that the "healthiest" condition is achieved. Benchmark sites are selected in order to differentiate between the influences of climate and management (De Klerk, 2003). That is why two benchmark sites were selected in this study where two different management regimes were practiced (Figure 2.1, Chapter 2). One benchmark was in Disaneng Village (communally managed) while another was in Neverset farm (commercially managed) to detect any relationship between encroachment and land tenure.

Land tenure has been found to the single most important correlate of land degradation in South Africa (Hoffman & Ashwell, 2001). Communal rangelands in South Africa are generally viewed as being degraded, non-sustainable and non-productive while commercial farms are perceived to be at an opposite state (Tainton, 1999; Hoffman & Ashwell, 2001). Hoffman & Ashwell (2001) found that communal districts had significantly higher degradation indices for vegetation, soil and combined variables than commercial farming districts. These management regimes were compared to investigate and confirm the consistency of perceptions surrounding these types of land tenure systems. Higgins *et al*. (1999) found that there were changes in woody community structure and composition under contrasting land-use systems (commercial, communal and wildlife). Higgins *et al*. (1999) concluded that communal grazing management significantly changed the composition and structure of woody plant communities. These changes reduced current availability of natural resources and will continue to reduce resource production in the future. According to Hoffman & Ashwell (2001), whether land degradation should be blamed on the type of land ownership, is based on a number of assumptions which can be questioned.

3.3 Extent of woody plant invasion in Molopo Area study sites

The location of the study sites and reference sites is indicated in Figure 1.1 (Chapter 1) and described in chapter 2.

The significance of bush encroachment in the Molopo Area has been emphasised by Ebersohn *et al*. (1960) and *Acacia mellifera* was identified as the main encroacher (Donaldson, 1967). Other encroaching species such as *Dichrostachys cinerea* that is a declared encroaching species (National Department of Agriculture, NDA, 2000) are present in the Molopo Area including alien species such as *Prosopis* spp. In an estimate of the degree of *Acacia mellifera* infestation, Ebersohn *et al*. (1960) indicated that over 8 500 000 ha of veld in the Molopo Area has been encroached by *Acacia mellifera*.

3.3.1 Bush encroachment in the Disaneng Village (Benchmark)

This is site was chosen as natural veld and benchmark (Section 3.2). This site had a few large scattered trees and a thick grass layer. The benchmark was located within the same ecological zone as the research sites. The woody plant population was determined at 407 TE/ha (Figure3.4) locally.

Acacia erioloba was the most abundant woody species present at 278 TE/ha (Figure 3.3). The National Department of Agriculture (2000) does not consider *Acacia erioloba* to be an encroaching species. It is slow growing (Coates Palgrave, 1990). *Acacia erioloba* was first declared protected in South Africa in 1941 and again included on a revised list produced in 1976 that is still in effect (Seymour & Milton, 2003). It is declared a protected species, in terms of section 12 of the National Forests Act, 1998 (Act No. 84 of

1998). The law under section 12 of Act No. 84 of 1998 states that if a tree species is declared protected, "No person may (a) cut, disturb, damage, destroy or remove any protected tree; or (b) collect, remove, transport, export, purchase, sell, donate or in any other manner acquire or dispose of any protected tree, except under a license granted by the minister of Water Affairs and Forestry." The Act does not distinguish between dead and living trees. This implies that even removal of dead specimens is illegal without a permit. *Acacia erioloba* has a potential of suppressing growth of other acacias. This is because most acacias have been shown not to grow under canopies of other acacias (Tainton, 1999). *Acacia mellifera* which is the most problematic species in the Molopo District for decades (Donaldson, 1967) is an exception. It is able to grow beneath canopies of other acacias and was not identified at this site.

Woody species within the 0.5 m height class (maximum height of 0.5 m) were limited and occurred at 18 TE/ha (Figure 3.4). Large trees (with a maximum height of 6 m) were the most abundant (Figure 3.4). According to Scholes & Archer (1997) and Stuart-Hill *et al*. (1987), large trees are able to promote grass growth under its canopies but the nett result is dependent on tree density. Large trees in semi-arid regions have also shown to creating 'islands of fertility' below their crowns (Chapter 4) which could facilitate grass growth. According to Coates Palgrave (1990), large *Acacia erioloba* trees do not compete directly with the grasses because of their deep tap root systems.

From Figure 3.3, it is clear that encroaching species are absent within this site. No *Acacia mellifera* and other encroaching species such as *Dichrostacys cinerea* were observed. The other woody species observed were at ("non-threatening") levels in terms of Table 3.1) and important for biodiversity (Figure 3.3). There are abundant thick tall grasses, even in the presence of grazing.

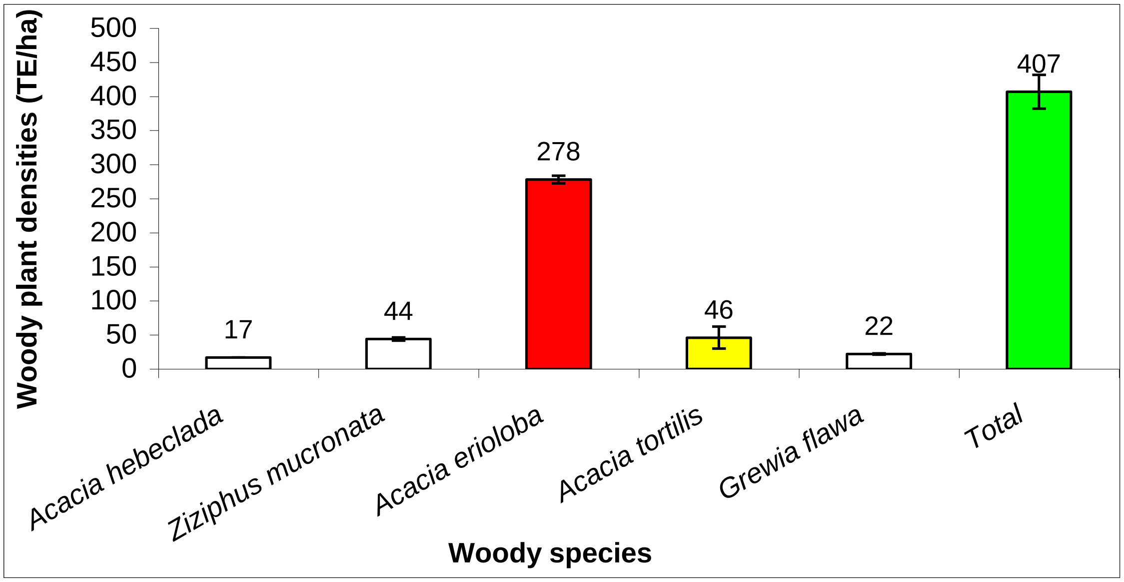

Figure 3.3 Densities of woody species in the Disaneng benchmark area.

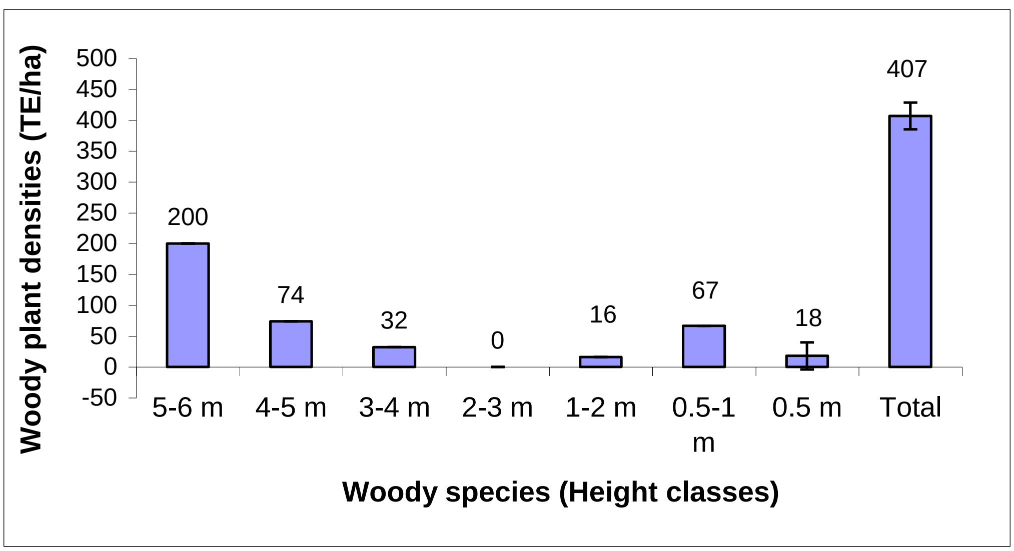

Figure 3.4 Bush encroachments in Disaneng Village benchmark according to height classes.

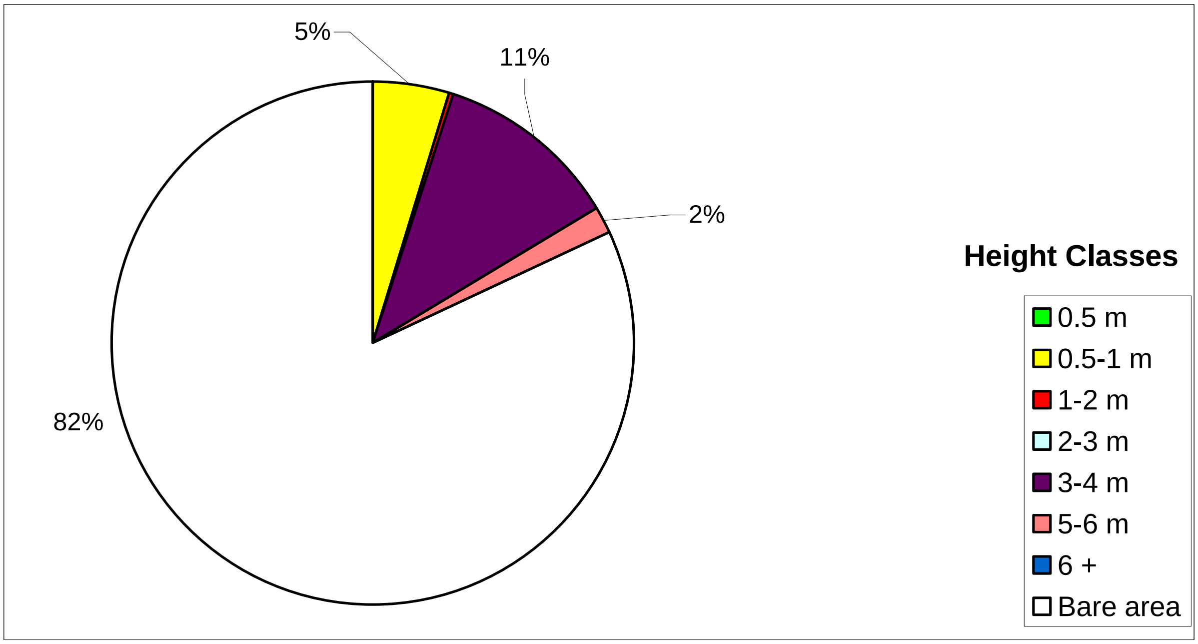

Figure 3.5 Canopy closure per hectare of species in different height classes in Disaneng benchmark.

3.3.2 Bush encroachment at Neverset benchmark

Woody plant population of Neverset benchmark which is situated in commercially managed area was recorded at 2 244 TE/ha (Figure 3.6). *Acacia erioloba* was the most abundant woody species present (Figure 3.6). It is a slow growing tree that is generally not considered an encroaching species and has nutritional value as fodder for livestock and used for various purposes by local people (Coates Palgrave, 1987; Smit, 1999; NDA, 1999).

Acacia erioloba has long taproots (Coates Palgrave, 1990; Smit, 1999) that make them able to grow harmoniously with grasses because they do not compete with them directly for resources. According to Scholes & Archer (1997) and Stuart-Hill *et al*. (1987), large trees are able to promote grass growth under its canopies but the nett result is dependent on tree density. This is observed in this site as there are grasses present. *Acacia erioloba* canopies provide excellent shade for both people and livestock in the semi-arid areas (Coates Palgrave, 1990). These trees were all within the 2-3 m height class (Figure 3.7).

Encroaching species that occurred in this site were *Dichrostachys cinerea* (encroaching at 476 TE/ha according to Table 3.1), *Acacia mellifera*, *A. karroo, Grewia flava*, *Tarchonanthus camphoratus* and *Terminalia sericea* (Figure 3.6).

Other woody species present included *Ziziphus mucronata*, *Grewia occidentalis* and *Ehretia rigida* occurred in this site (Figure 3.6). Tree-on-tree competition (Smith & Goodman 1986; Tainton, 1999) is species specific where in some, establishment is unaffected by a tree canopy while in others, establishment is limited to between canopy environments. Controlled access and rotational grazing is practiced here since it is a commercially managed farm.

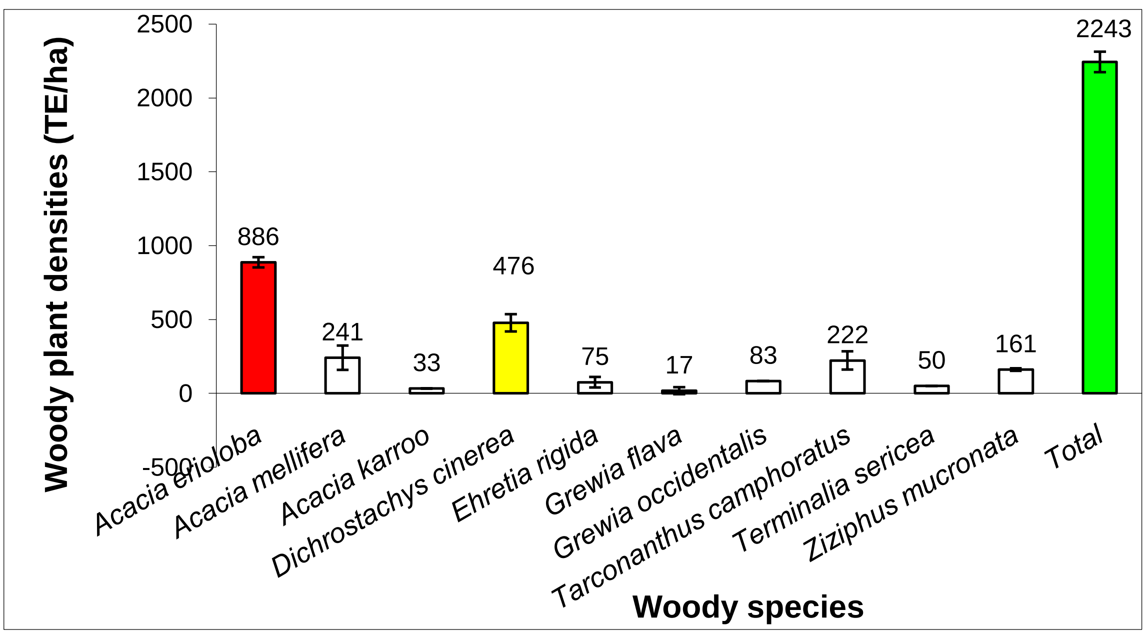

Figure 3.6 Densities of woody species in the commercial benchmark.

Trees within the 3 m height class were the most abundant locally (Figure 3.7). Their crowns covered the largest part of the soil surface at 6 % (Figure 3.8).

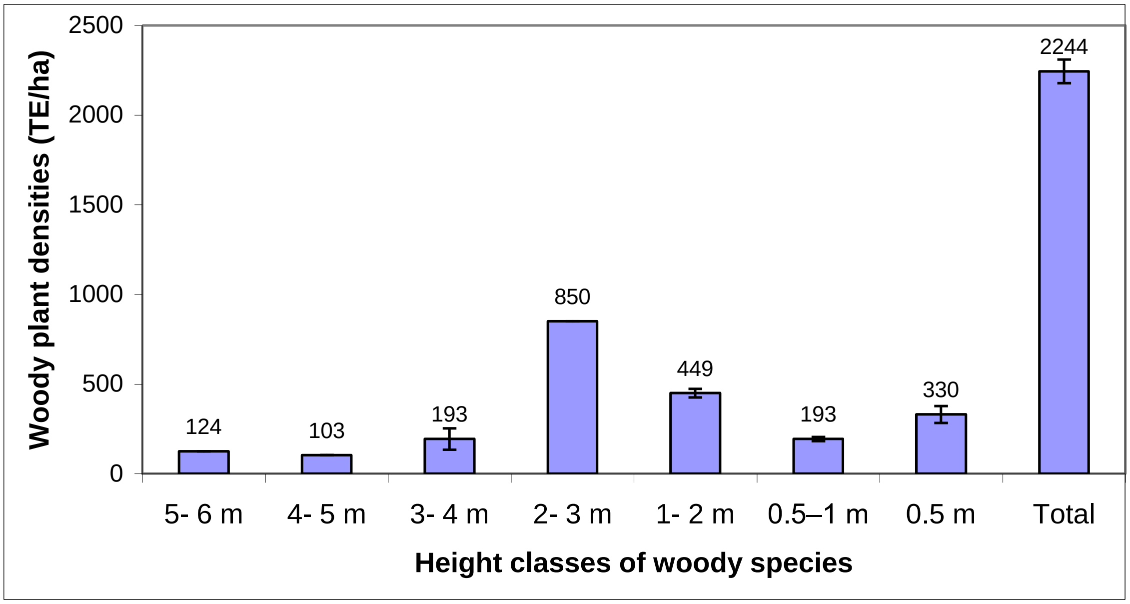

Figure 3.7 Bush encroachment in the commercial benchmark according to height classes.

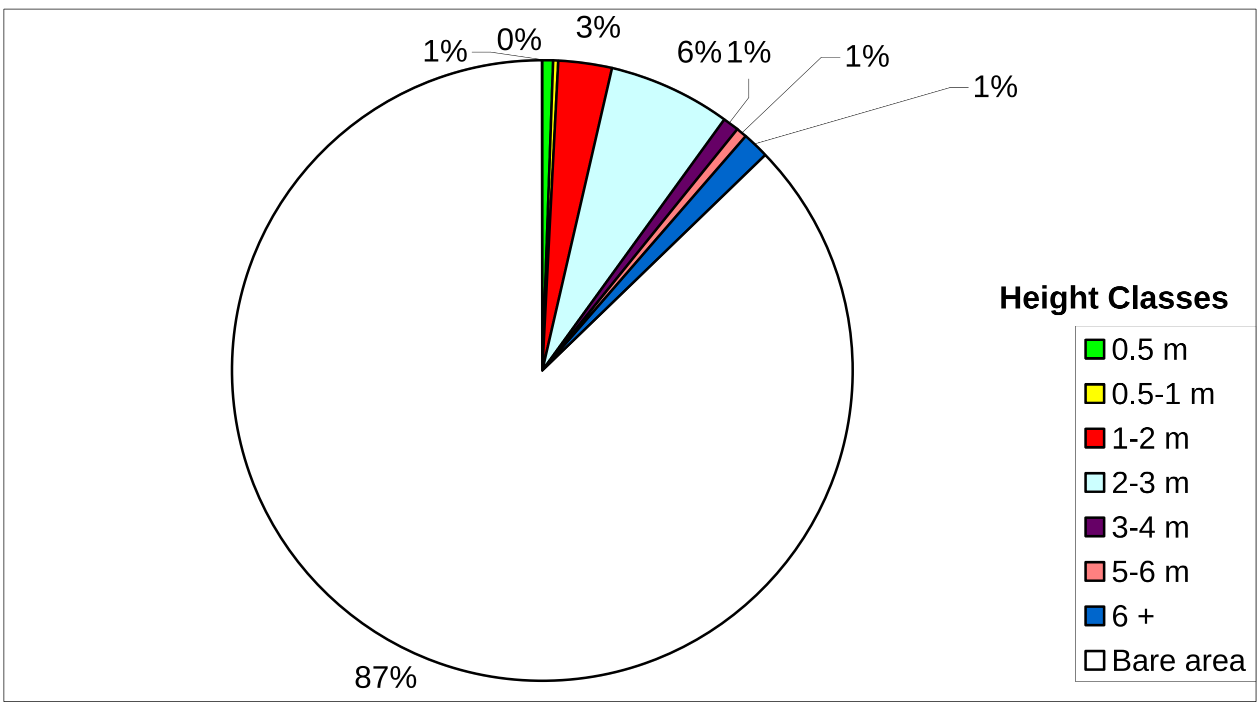

Figure 3.8 Canopy closure per hectare of species in different height classes in Neveset.

3.3.3 Bush encroachment in Disaneng Village

The density of woody plants was recorded at 3 530 TE/ha (Figure 3.10) which will almost completely suppress grass growth (Table 3.1). The woody species that contribute most to the woody plant composition in Disaneng were *Acacia mellifera* (1886 TE/ha) and *Dichrostachys cinerea* (1109 TE/ha) (Figure 3.9). Other woody species observed include *Acacia hebeclada*, *A. karroo*, *Ehretia rigida*, *Grewia flava, Ziziphus mucronata* and *Rhus dentata* (Figure 3.9). According to Obot (1988), their density can cause grass production to decline because total herbaceous biomass declines as woody plant density increases **(**Belsky & Amundson, 1992).

Acacia mellifera and *Dichrostachys cinerea* were the most prominent encroachers in this site at a combined density of 2 995 TE/ha (Figure 3.9). These species are known to cause impenetrable thickets and are indicators of overgrazing (Coates Palgrave, 1990). *Dichrostachys cinerea* is well spread over continents, extending from Australia, through Burma and India to all parts of Africa (Coates Palgrave, 1990). It also invades rapidly on overgrazed pastures, where grass cover has been reduced and has been found “difficult” to eradicate as it shoots again (coppice) from portions of roots or remaining stumps (Venter & Venter, 1996).

The absence of woody plants that have economic uses in this site such as *Acacia erioloba* (Coates Palgrave, 1990) make the site economically unproductive (Belsky & Amundson, 1992; Whiteman & Brown 1998; Smit *et al*. 1999; National Department Agriculture, 2000) for foraging since 4 155.8 m^2/ha or 42 % of this site is covered by canopies of woody species (Figure 3.11).

Woody species with a maximum height 0.5 m (0.5 m height class) occured at 2 063 TE/ha (Figure 3.10). This represented more than half of the total bush density in this site but 4 % of cover (Figure 3.12) but covers only 4 % of the soil surface (Figure 3.12).

There were a few large trees in this site (Figure 3.10). Woody species with a maximum height of 5 m (5 m height class) were present at 52 TE/ha (Figure 3.10). This represented 2 % towards the total canopy cover of the site (Figure 3.12).

According to Smit (1999), many acacias fail to establish beneath canopies of established individuals, irrespective of its species. *Acacia mellifera* is among the few exceptions of acacias which have shown to be able to grow under canopies of other *Acacia mellifera* (Tainton, 1981). Canopy morphology of woody plants contributes towards their proliferation (Tainton, 1981) because of light interception and as well as nutrients that build up directly below the canopies (Belsky & Amundson, 1992).

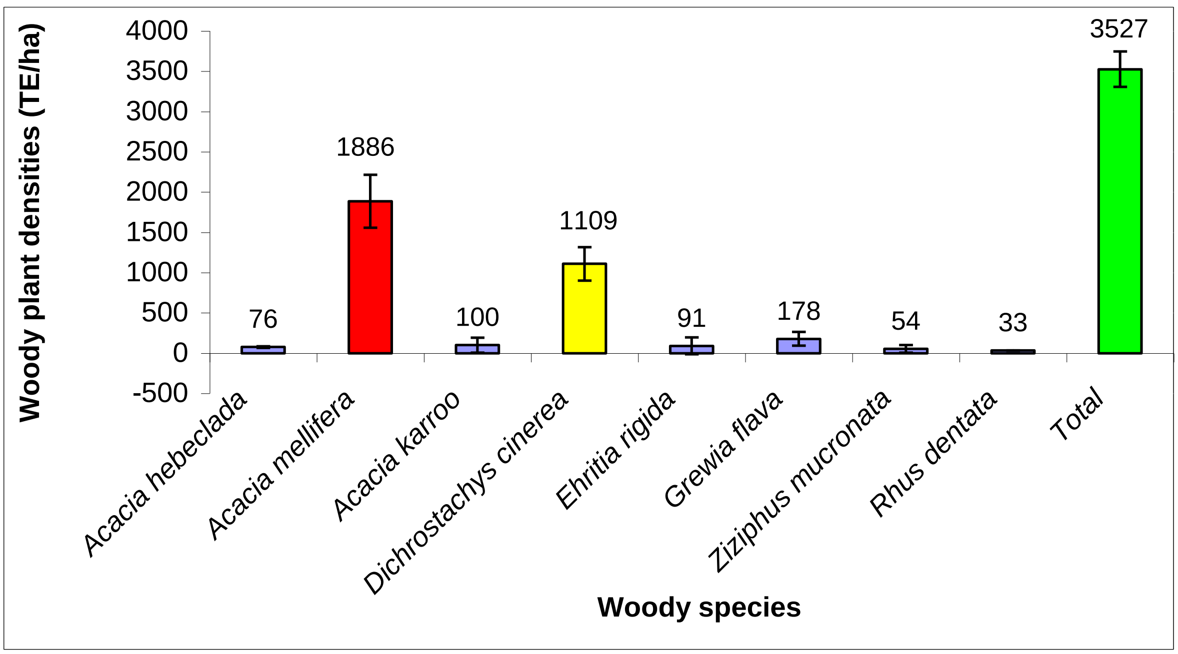

Figure 3.9 Densities of woody species in Disaneng Village.

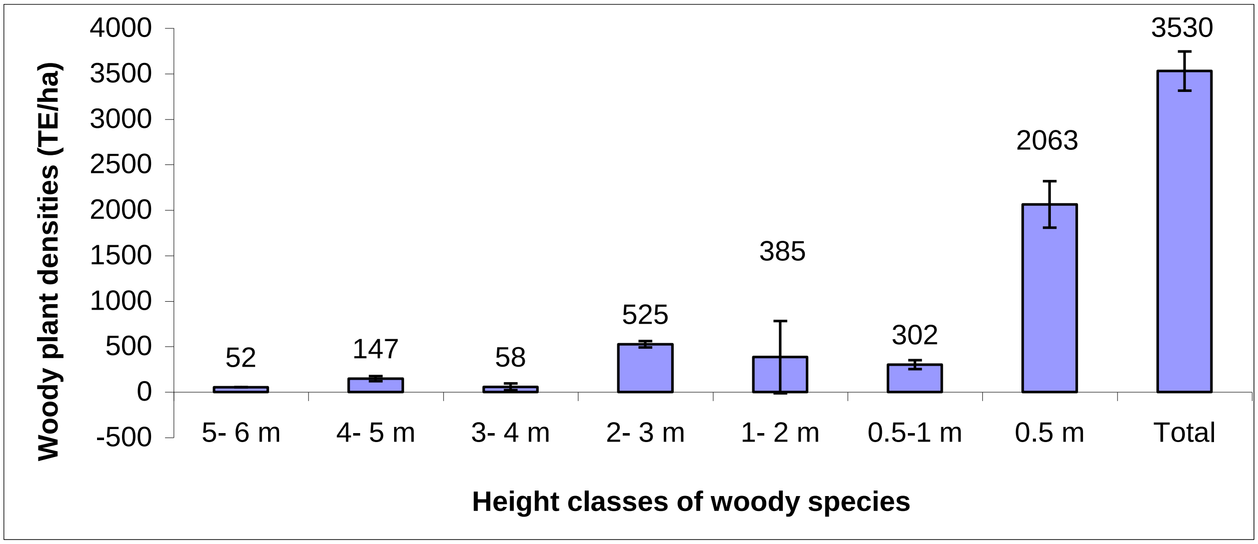

Figure 3.10 Bush encroachment in Disaneng Village according to height classes.

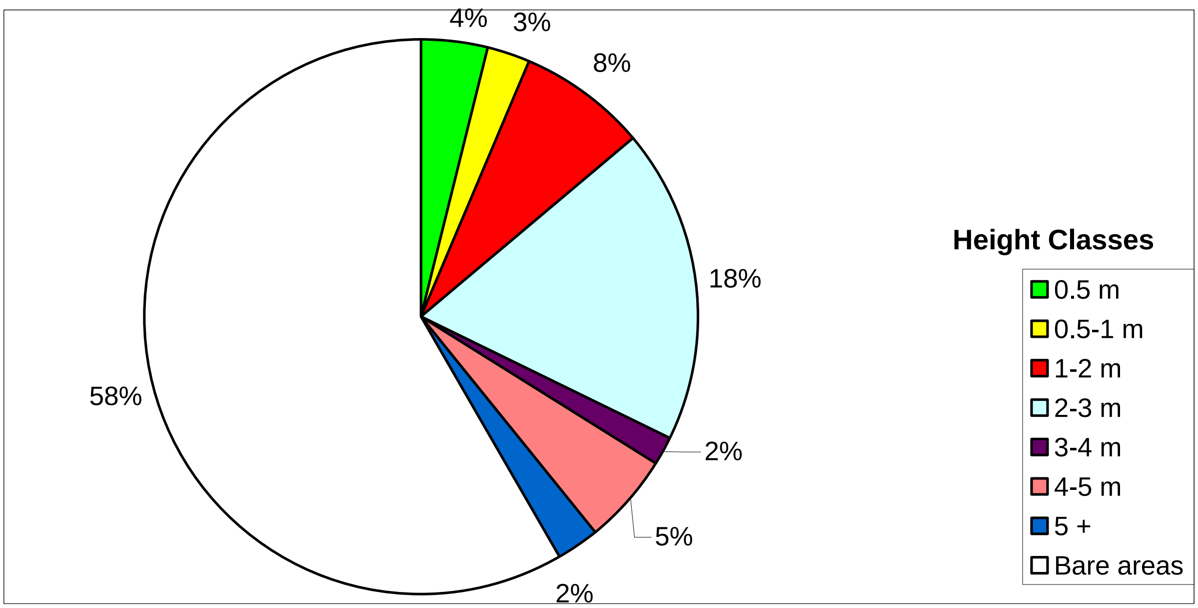

Figure 3.11 Canopy closure per hectare of species in different height classes in Disaneng Village.

3.3.4 Bush encroachment in Setlhabaneng Village

The total woody plant density locally was 3 104 TE/ha (Figure 3.12). This exceeds the density that according to Moore & Odendaal (1987), almost totally suppresses grass growth (Table 3.1).

The species contributing mostly to woody plant population in Setlhabaneng were *Acacia hebeclada* and *A. tortilis* (Figure 3.12). Other woody species observed include *Acacia karroo, Grewia flava* and *Ziziphus mucronata* (Figure 3.12). *Acacia hebeclada* recorded the highest density at 1 027 TE/ha (Figure 3.12) and together with *Acacia tortilis* at 932 TE/ha, it contributed to 60 % of the total woody plant population of this site (Figure 3.12). Grass growth was almost totally suppressed. *Acacia hebeclada* that grows in South Africa has a characteristic of growing low, normally not higher than 2 m. It usually occurs as a prostrate, spreading, multi-stemmed shrub with dense branches near ground level or with stems rising from branching underground stems and can achieve a diameter several times its height which is often reminiscent of a large flattened bush in appearance (Coates Palgrave, 1990). The spread cushion restricts movement of animals on the bush area and the thickness of this would restrict light for understorey vegetation. According to Belsky & Amundson (1992), the large flattened bush can have a positive role by intercepting rain and reducing splash erosion. *Acacia tortilis* was the second most prominent woody species in Sethlabaneng and occurred at 818 TE/ha (Figure 3.12). This woody species grows in a variety of soil types but show some preference to heavy, clayey soils (Coates Palgrave, 1990). Local soils were represented by Molopo sands (Low & Rebelo, 1996) as demonstrated in Table 4.2. *Acacia tortilis* is adapted to dry conditions and is often one of the first woody plants to establish on disturbed areas like old lands (Coates Palgrave, 1990). It also occurred along dry riverbeds and is cold tolerant (Coates Palgrave, 1990; Smit, 1999).

Acacia karroo occured at 467 TE/ha (Figure 3.12) locally and is one of the most widespread trees in Africa that occurred in a wide range of habitats (Coates Palgrave, 1990). Its presence indicated a sweet veld and since its uses are almost unlimited, it is considered an asset on farms as it provides excellent fodder with its leaves, flowers and pods (Smit, 1999; Coates Palgrave, 1990).

The total woody plant composition of this site of 3 104 TE/ha was less than the woody plant density determined at Disaneng Village (3 530 TE/ha) (Figures 3.10 & 3.13). The total canopy cover of this site was higher than that determined in Disaneng Village (Figures 3.5 & 3.8) that served as benchmark reference. Woody plants within the 0.5 m height class occurred in this location at 1 733 TE/ha (Figure 3.13). This contributed to 20 % of canopy cover in this site (Figure 3.14).

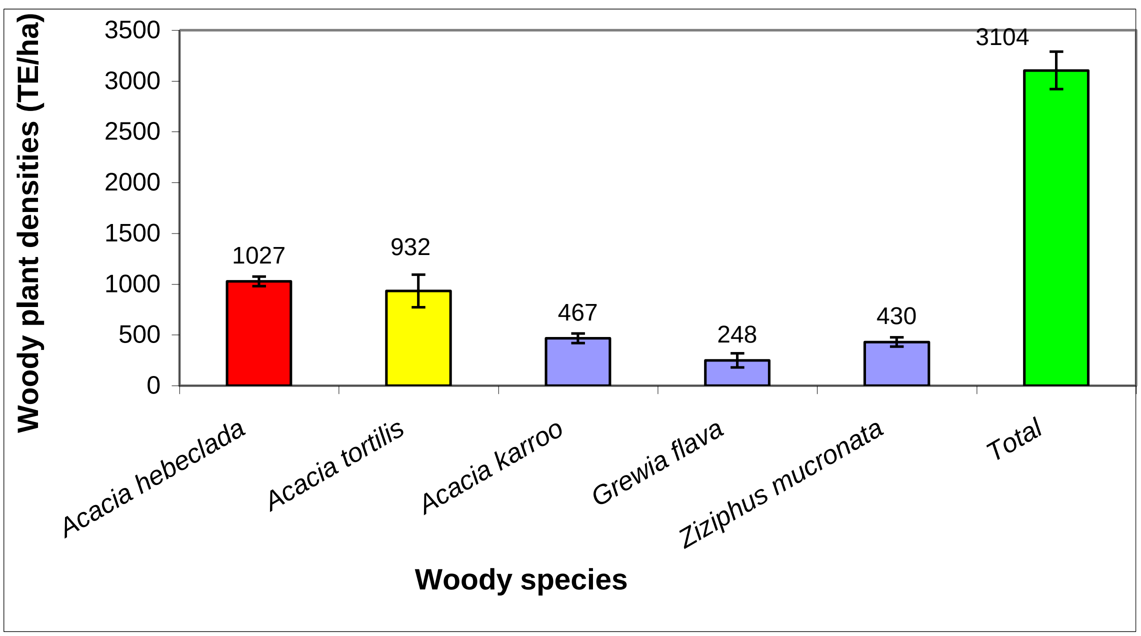

Figure 3.12 Densities of woody species in Setlhabaneng Village.

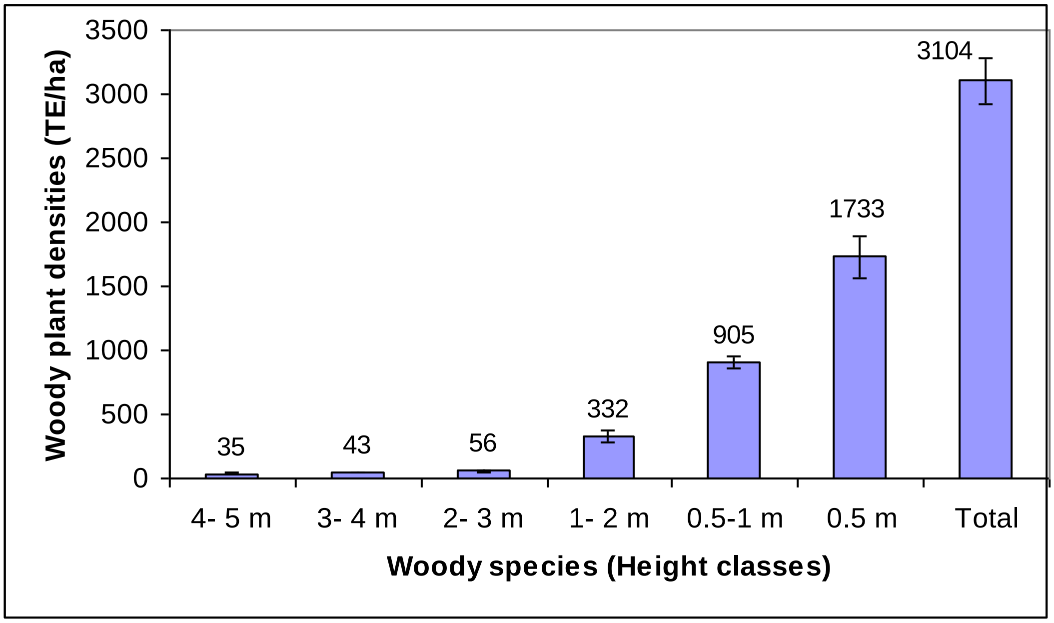

Figure 3.13 Bush encroachments in Setlhabaneng Village according to height classes.

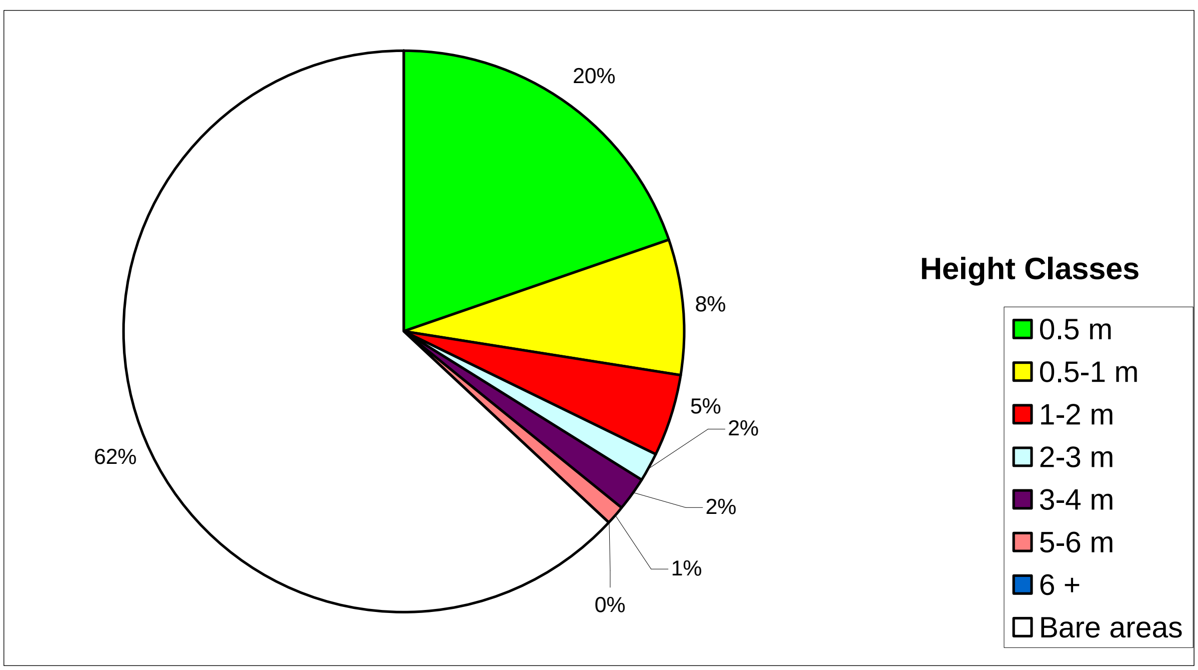

Figure 3.14 Canopy closure per hectare of species in different height classes in Setlhabaneng.

3.3.5 Bush encroachment in Matloding Village

Woody plants occurred at Matloding Village was 3 600 TE/ha (Figure 3.15, that is why grass was almost totally suppressed (Moore & Odendaal, 1987; Richter *et al*., 2001) at Matloding Village site. *Terminalia sericea* was the most prominent woody species present, occurring at 2 131 TE/ha (Figure 3.15). According to Moore & Odendaal (1987), it can almost totally suppress grass growth on its own at this level. Other woody species present were *Acacia hebeclada*, *A. mellifera*, *Buddleja saligna*, *Boscia albitrunca*, *Maytenus polyacantha*, *Dichrostachys cinerea*, *Grewia flava* as well as *Ziziphus mucronata*, but occur at lower densities (Figure 3.15). *Boscia albitrunca* (37 TE/ha) in this site (Figure 3.15) is important in the arid areas where the species often grows because both humans and animals use it (Coates Palgrave, 1990; Donaldson, 1967).

Since *Terminalia sericea* is the most prominent species and is not thorny, tha is why movement of animals between trees is possible. The BaTswana tribe (not necessarily the local BaTswana) potters (people that mould clay for art and other uses) use the silky, silvery leaf for glazing their wares and home remedies. The wood is yellow and hard and provides a useful general-purpose timber and is suitable for furniture and fencing posts (Coates Palgrave, 1990).

Woody plants with a maximum height of 3 m (3 m height class) had the highest densities at 1 000 TE/ha (Figure 3.16) and a canopy regime that covered 19 % (Figure 3.17) of Matloding site. The total canopy width covered 51 % area of this site (Figure 3.17). Shade under *Boscia albitrunca* can reduce sand temperatures by 21 ^{o}C (Eloff, 1984), thus trees' canopies reduce solar radiation and therefore temperatures and evaporation rates beneath canopies (Gubb, 1988).

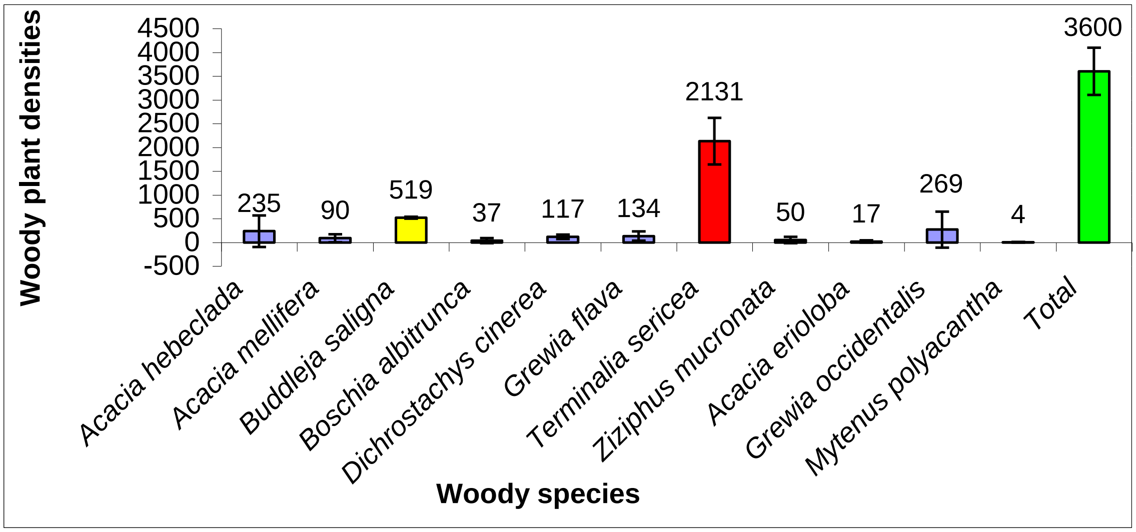

Figure 3.15 Densities of woody species in Matloding Village.

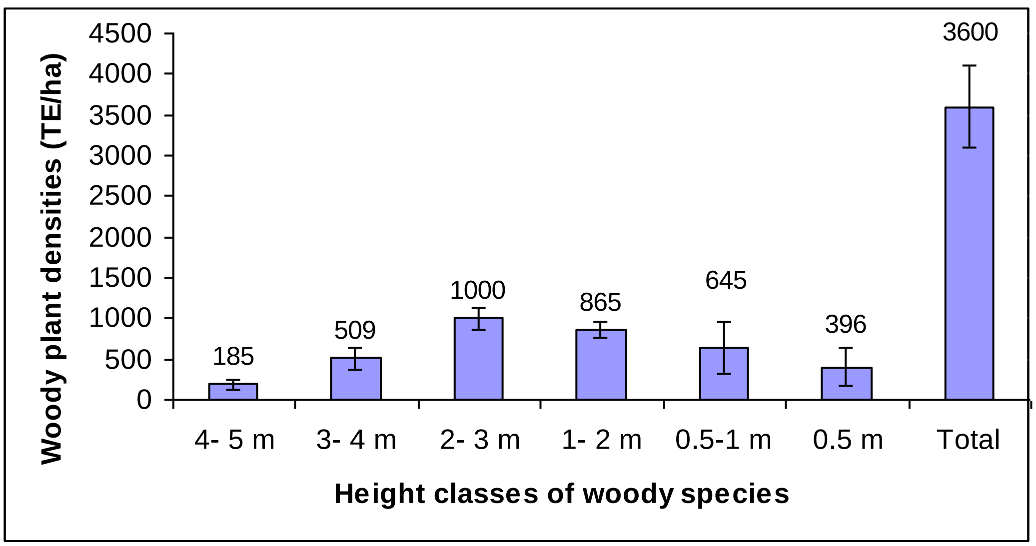

Figure 3.16 Bush encroachment in Matloding Village according to height classes.

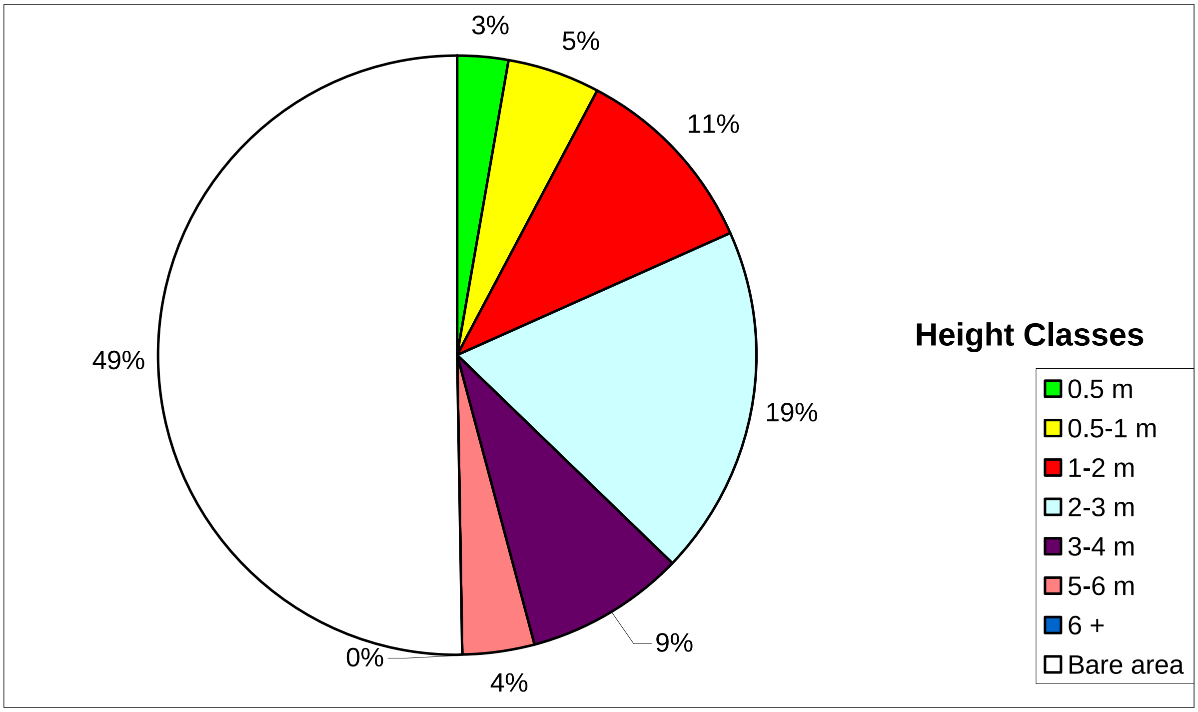

Figure 3.17 Canopy closure per hectare of species in different height classes in Matloding.

3.3.6 Bush encroachment in Logageng Village

The total density of woody plants in Logageng Village was 3 661 TE/ha (Figure 3.19) which almost totally suppressed grass growth (Table 3.1). The most abundant encroacher encountered locally was *Acacia mellifera*. *Tarchonanthus camphoratus*, *Ziziphus mucrunata* and *Ehritia rigida* also occurred but at lower densities (Figure 3.18). *Tarchonanthus camphoratus* (764 TE/ha) found locally (Figure 3.18) can be useful as a source of firewood for the locals because it burns even when green (Coates Palgrave, 1990).

Woody plants of 3 m, 2m and 0.5 m high covered the largest soil surface (Figure 3.20). 49 % of the soil surface at this site was covered by woody plants (Figure 3.20). Trees that are 3 m high contributed to 17 % (Figure 3.20) of the canopy cover.

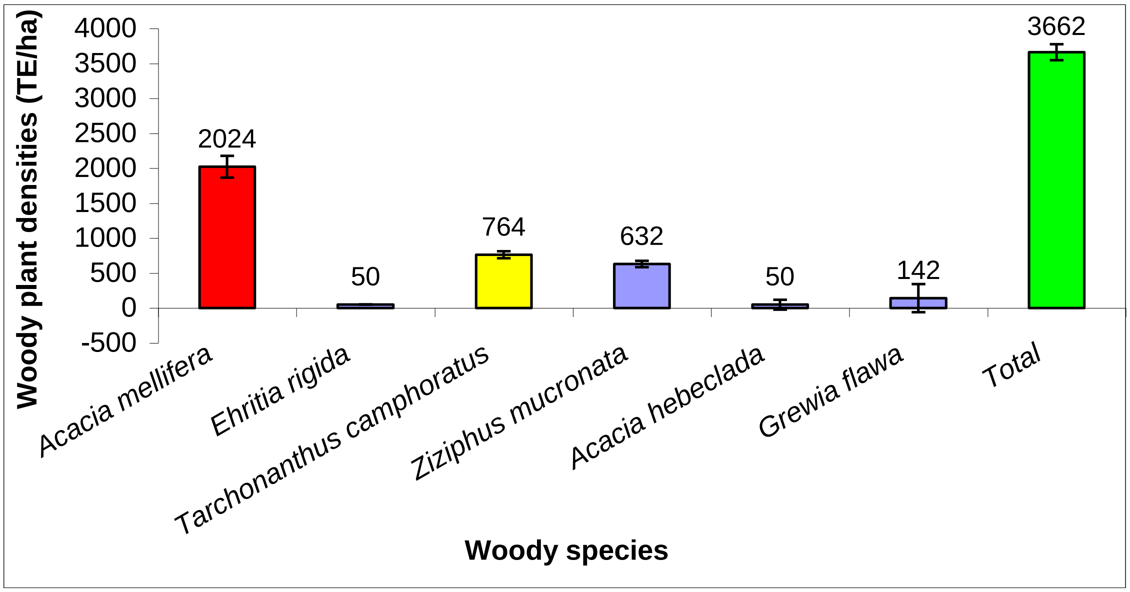

Figure 3.18 Densities of woody species in Logageng Village.

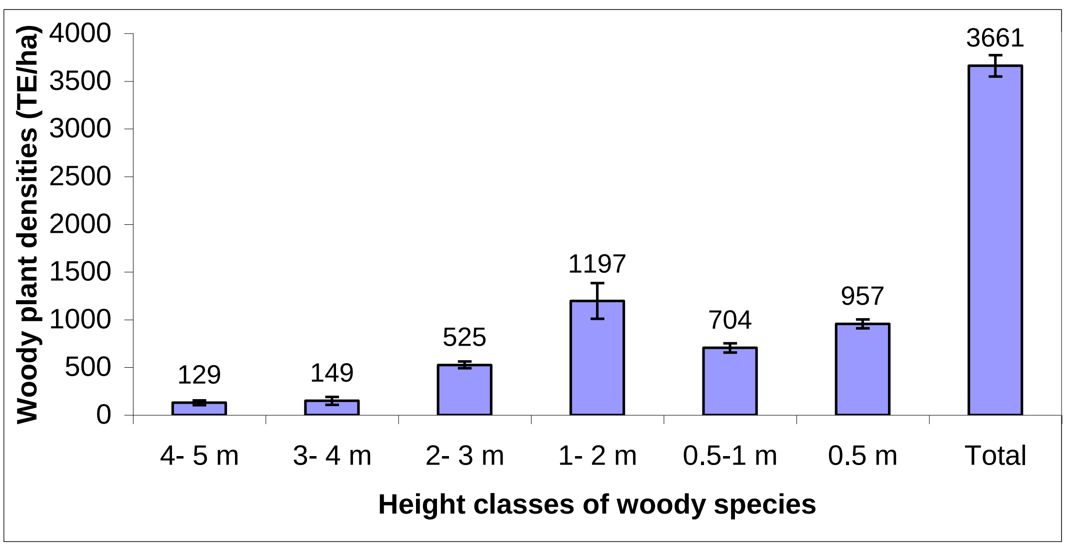

Figure 3.19 Bush encroachment in Logageng Village according to height classes.

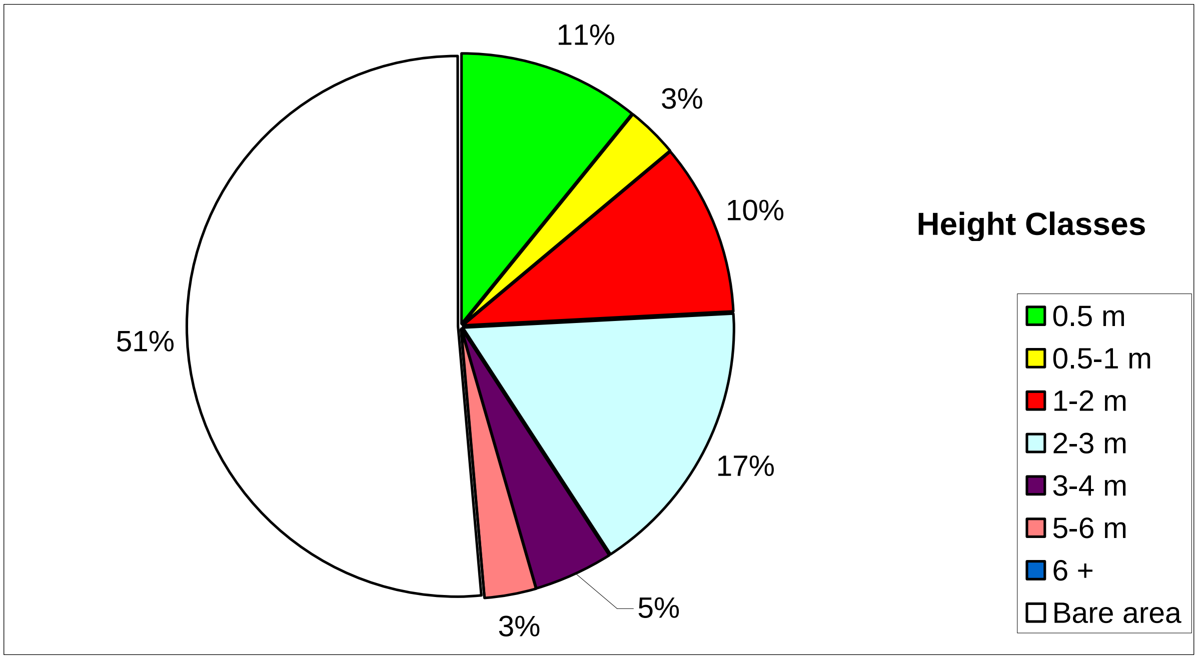

Figure 3.20 Canopy closure per hectare of species in different height classes in Logageng.

3.3.7 Bush encroachment in Selosesha Village

Woody plants in Selosesha Village occurred at densities of 7 000 TE/ha (Figure 3.21) and can be considered as severely encroached (Table 3.1) with the herbaceous layer almost totally suppressed (Moore & Odendaal, 1987; Richter *et al.*, 2001).

Unlike other study sites, *Acacia mellifera* was the only encroacher identified at this site. *Acacia mellifera* is the sole dominant encroacher locally, occurring at 6 967 TE/ha which represents 99 % of the woody plant composition of Selosesha. *Acacia erioloba* was the only other woody species present (Figure 3.21).

Trees with a maximum height of 1 m (3 484 TE/ha) were most evident in Selosesha followed by 2 m high trees (2 527 TE/ha) (Figure 3.22). This could be a result of intra-specific competition that suppresses growth of the trees (Tainton, 1999). Inter and intra-specific competitions have been regarded as a significant determinant of the structure and function of woody plant communities in African savannas (Fowler, 1986; Shackleton, 2002). Shackelton (2002) used the nearest-neighbour method to measure the presence or absence of competition among *Acacia* and broad leaved species in South African savannas. The results in terms of intra-specific competition revealed that 32 % of the sites tested had a significant correlation between nearest-neighbor distance and summed canopy volume of the two neighbors (55.6 % of *Acacia* species comparison and 21.4 % of the broad-leaved species comparison). Lower slope position and a smaller proportion of small stems were common among sites that lacked intra-specific competition.

Invasion of *Acacia mellifera* in the savanna is an indicator of overgrazing (Coates Palgrave, 1990) and is characterised by a concentration of a number of plants in clumps or thickets, which appear to be contagiously distributed (Coates Palgrave, 1990). In the initial stages of invasion, these thickets generally consist of one or more large plants surrounded by younger plants of two or more height classes (Donaldson, 1967; Coates Palgrave 1990). *Acacia mellifera* subsp. *detinens* occurs as a multi-stemmed shrub of up to 3 m high, or occasionally a tree that can grow to a height of 7 m (Smit, 1999; Coates Palgrave, 1990). It has a spreading, rounded to flattened crown which may reach down to ground level. As a tree, it usually branches low down with a substantial horizontal spread that can well exceed its height (Smit, 1999). These trees spread very rapidly, both from seed and vegetatively so much that they can be a menace, forming impenetrable, tangled thickets (Coates Palgrave, 1990).

The shallow root system of *Acacia mellifera* competes directly with grasses (Smit, 1999) and at a density of 6 967 TE/ha (Figure 3.21) can completely suppress grass growth (Moore & Odendaal, 1987; Obot, 1988; Belsky & Amundson, 1992; Richter *et al*., 2001). Bothma (1989) stated that encroachment of *Acacia mellifera* in the Northern Cape has caused a 50 % decrease in the grass production. A characteristic feature of the vegetation growing in association with *Acacia mellifera* is the presence of a sparse understorey of forbs and an almost complete absence of grasses within the canopy spread (Arnold, 1964). This is followed by a sparse grass cover and the presence of juvenile *Acacia mellifera* in a zone approximately equal to twice its height (Arnold, 1964).

The area is densely encroached with 86 % (Figure 3.23) of the area covered by woody species which makes thoroughfare of animals limited. This can be exacerbated by the fact that there is no grass or forage matter to attract livestock and the sharp nature of the *Acacia mellifera* hooks. Moisture penetration into the soil and interception by *Acacia mellifera* has also been studied and demonstrated (Donaldson, 1967; Smit, 1999). Since overhead branches and leaves intercept rain and sunlight, there should be reduced rainfall, solar radiation, temperatures and evapotranspiration rates below tree crowns (Belsky *et al*., 1989; 1993; Vetaas, 1992) locally. The magnitude of such reductions depends on the density of overhead foliage, height of the crown above the ground, direction of storm events and the angle of the sun (Obot, 1988; Belsky & Canham, 1994).

Selosesha can be used to demonstrate how woody plants are agents of water loss in semi-arid landscapes due to their high transpiration rates (Donaldson, 1967). De Klerk (2003) described *Acacia mellifera* as "acting like windmills, pumping large amounts of water into the air every day". According to Donaldson (1967), it was evident that *Acacia mellifera* uses four to eight times more water than fodder bushes such as *Boscia albitrunca* and *Grewia flava* (Coates Palgrave, 1990). It was also evident from Donaldson's (1967) studies that an individual *Acacia mellifera* tree transpires 190 to 800 times more than individual grass plants.

According to Donaldson (1967), a 0.5 m high *Acacia mellifera* tree transpires 12.8 litres/day. This implies that the 3 484 *Acacia mellifera* trees with a maximum height of 1 metre (Refer to Figure 3.22) will transpire 38 400 litres of water daily in this site. Therefore, the total amount of water loss by *Acacia mellifera* in the local site will be 157 520.3 litres/day according to the calculations done by Donaldson (1967). These studies were conducted in the Molopo magisterial district that shares similar climatic conditions as the study sites (Chapter 2) but not exactly at the same localities.

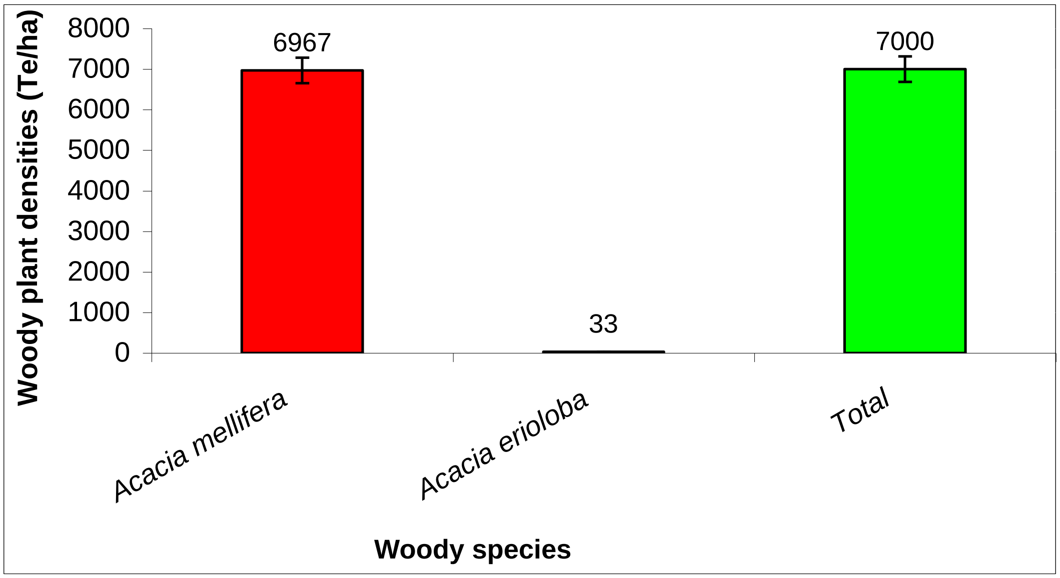

Figure 3.21 Densities of woody species in Selosesha Village.

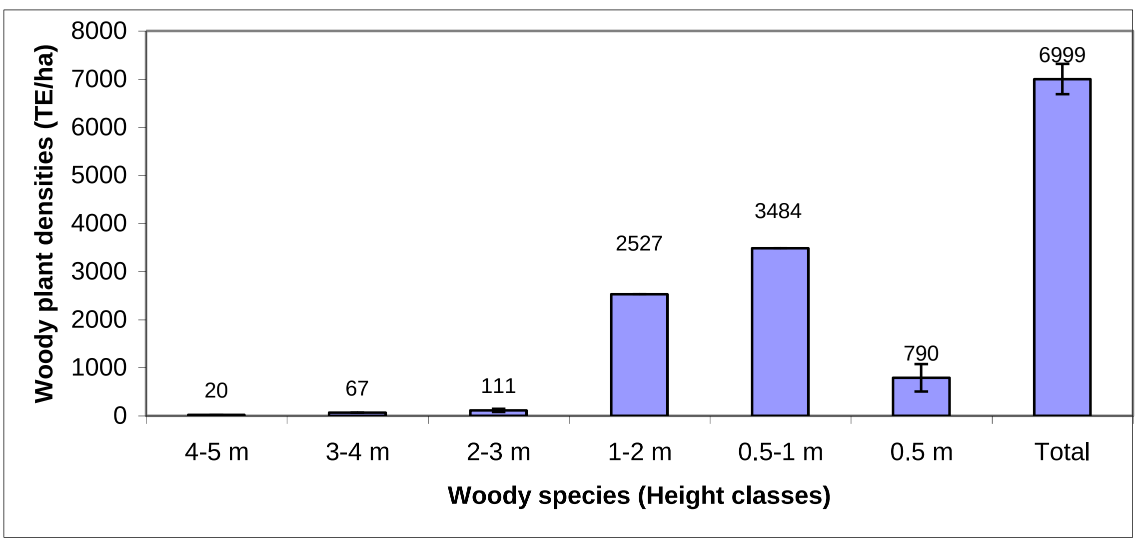

Figure 3.22 Bush encroachments in Selosesha Village according to height classes.

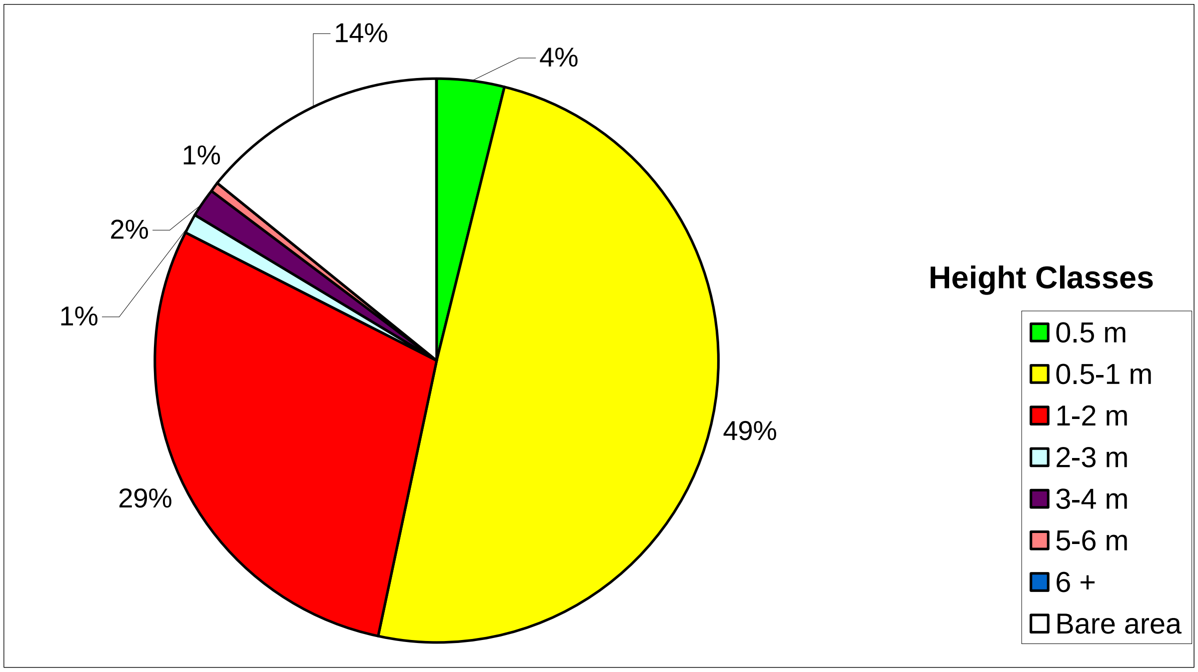

Figure 3.23 Canopy closure per hectare of species in different height classes in Selosesha.

3.3.8 Bush encroachment in Neverset Farm

Neverset is a privately owned commercial farm that was selected to compare bush encroachment as influenced by different land tenure management systems. *Acacia mellifera* is the most abundant encroaching woody species in the Molopo Area (Donaldson, 1967) and it has encroached in this site at 12 869 TE/ha (Figure 3.24). *Dichrostachys cinerea* and *Acacia hebeclada* are the other encroaching species that occurred at this site (Figure 3.24). The density locally was the highest recorded among all the sites that are being studied. The woody plant density in Neverset was 6.4 times more than the density indicated by Moore & Odendaal (1987) that will almost completely suppress grass growth.

The most prominent height class in terms of encroachment or woody plant densities were the small trees with a maximum height of 0.5 m at 11 154 TE/ha (Figure 3.25).

It was expected that Neverset would have the highest canopy closure among the study sites because it was the highest encroached site at 13 597 TE/ha (Figure 3.25). The results proved otherwise since it had a canopy closure less than that of Selosesha, Matloding and Logaganeng (Figures 3.23, 3.20 & 3.16) which were less encroached. The relatively low canopy cover locally was because the majority of trees (83 %) were 0.5 m high trees (Figure 3.25) whose canopy regime contributes to 3 % (Figure 3.26) of the canopy cover per hectare at the site. Trees with a maximum height of 0.5 m had a small canopy spread that averages 0.13 m^2/individual (Figure 3.26). Therefore they cannot contribute canopy cover as e.g. trees of 3 m and above that can have spread from 0.28 m^2 to up to 6.12 m^2 per individual (Table 3.8).

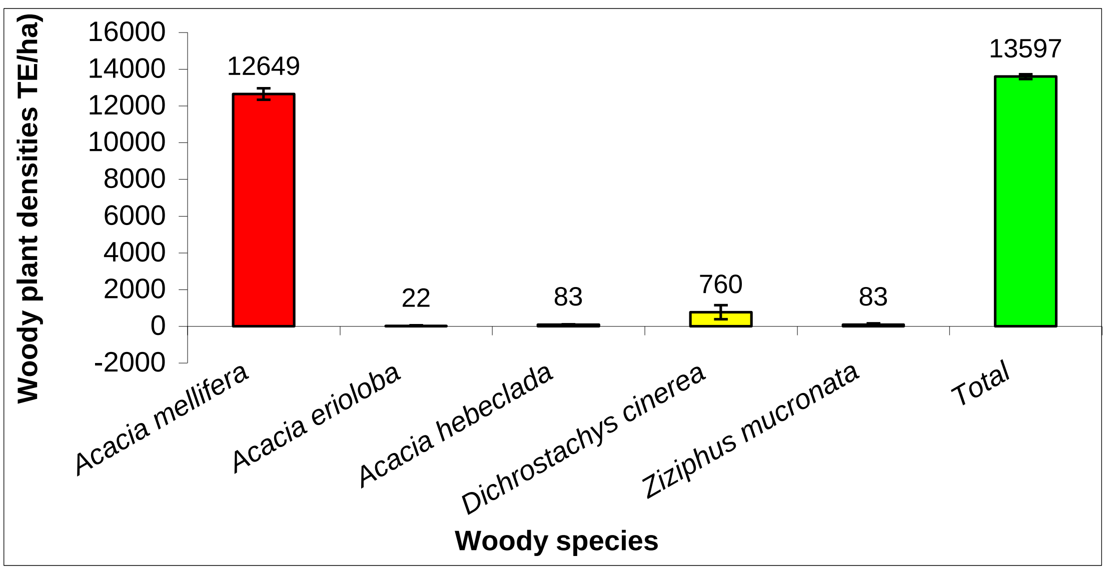

Figure 3.24 Densities of woody species in Neverset farm.

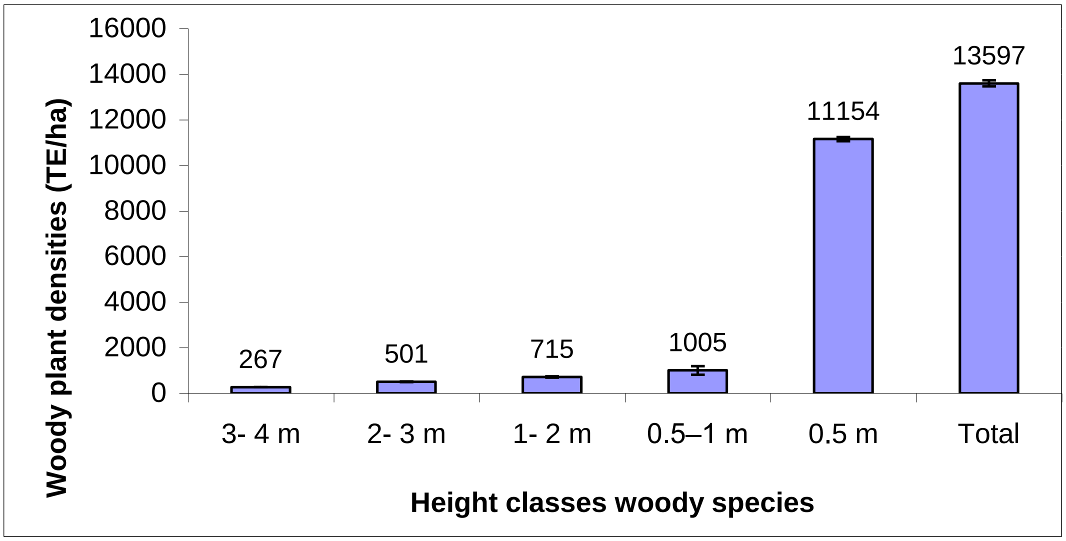

Figure 3.25 Bush encroachments Neverset farm according to height classes.

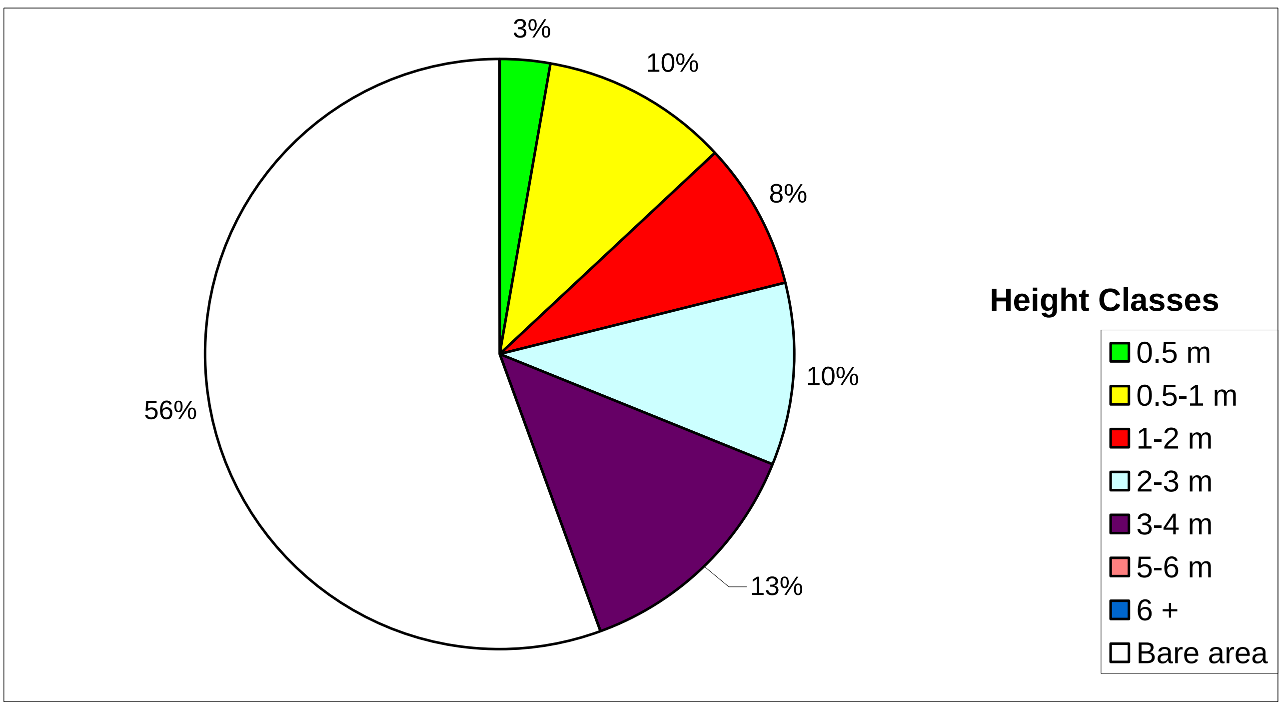

Figure 3.26 Canopy closure per hectare of species in different height classes in Neverset farm.

3.3.9 Bush encroachment in Tshidilamolomo Village

The woody plant density at Tshidilamolomo was recorded at 8 817 TE/ha (Figure 3.28) was the second highest recorded in the study. Woody plants occurring at these densities almost totally suppressed grass growth (Table 3.1). The dominating species in this site was *Prosopis velutina* (Figure 3.27). It is an exotic species that has been naturalized over considerable areas including the border regions of the North West Province (Coates Palgrave, 1990). The habitats of *Prosopis* are areas with relatively deep soil with ground water close to the surface, river banks, pans and depressions or 'leegtes' (Le Maitre 1999). According to Le Maitre (1999), *Prosopis* species is an 'aggressive grower' and can expand or its rate of spread was found to be approximately 18 % per annum or doubling in area in 5 years. This implies that the density of *Prosopis velutina* in locally will increase from 8 465 TE/ha (Figure 3.27) to 16 930 TE/ha in 2011 (5 years later).

Six species of *Prosopis* have been introduced in South Africa to provide fodder and fuel (Le Maitre, 1999). *Prosopis chilensis*, *P. glandulosa* and *P. velutina* have been hybridized and the hybrids are aggressive invaders which form impenetrable thickets (Le Maitre, 1999). *Acacia hebeclada* and *Grewia flawa* are the other encroachers identified locally but at occurred low densities (Figure 3.27).

Plants with a maximum height of 2 metres were present at 4 656 TE/ha, followed by 3 metre high trees at 3 200 TE/ha were the most prominent in this study site (Figure 3.28)**.** Plants within these height classes had had the widest canopies and measured at 33 % and 25 % of the area respectively (Figure 3.29). 71 % of the area was covered by canopies which was the highest canopy closure among all the study sites. This high canopy cover is attributed to the multi-stemmed shrub morphology of the *Prosopis* species.

Besides its invasive characteristics, *Prosopis* is a big problem in South Africa because of its extensive water use (Le Maitre, 1999). *Prosopis* species are phreatophytic plants, i.e. they obtain a significant fraction of their water requirements from the unsaturated soil zone (capillary fringe or vadose zone) above the water table (phreatic surface) (Jarrel &

Virginia, 1990). *Prosopis* is able to develop extensive root systems that can easily reach water tables at depths of 10 – 15 m. A maximum root depth of 53 m has been recorded (Le Maitre, 1999). *Prosopis* is highly adaptable to different geographic locations and is able to survive without using ground and deep soil water (Le Maitre, 1999).

Transpiration rates of *Prosopis* are directly related to water availability and limited by depth of water so that its transpiration will be less than the potential evaporation (> 2 350 mm per year) in the semi-arid areas (Le Maitre, 1999). Water use by *Prosopis* range from about 135 – 930 mm per year with the typical water use being from 350 – 500 mm per year (Le Maitre, 1990). From these estimates, the highly encroached Tshidilamolomo (Figure, 3.28) should be losing soil moisture which is limited in semi-arid landscapes (Hoffman & Ashwell, 2001; Tainton, 1999).

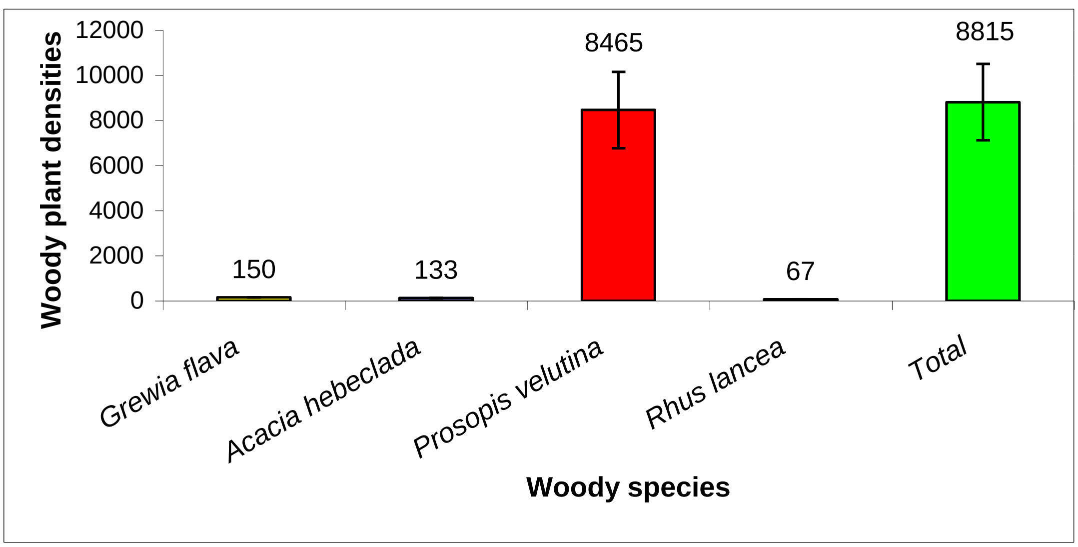

Figure 3.27 Densities of woody species in Tshidilamolomo Village.

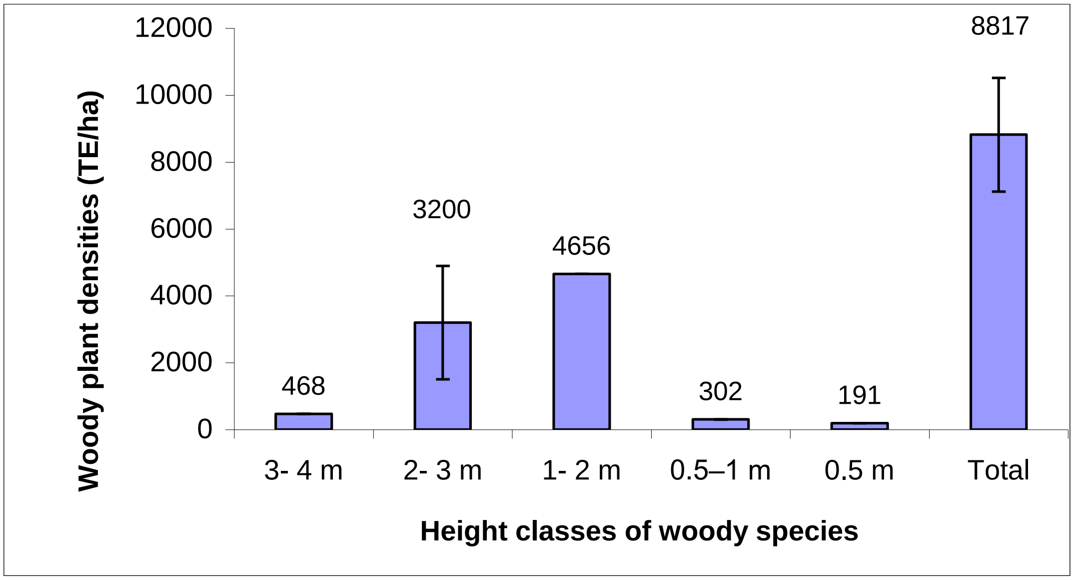

Figure 3.28 Bush encroachment in Tshidilamolo Village according to height classes.

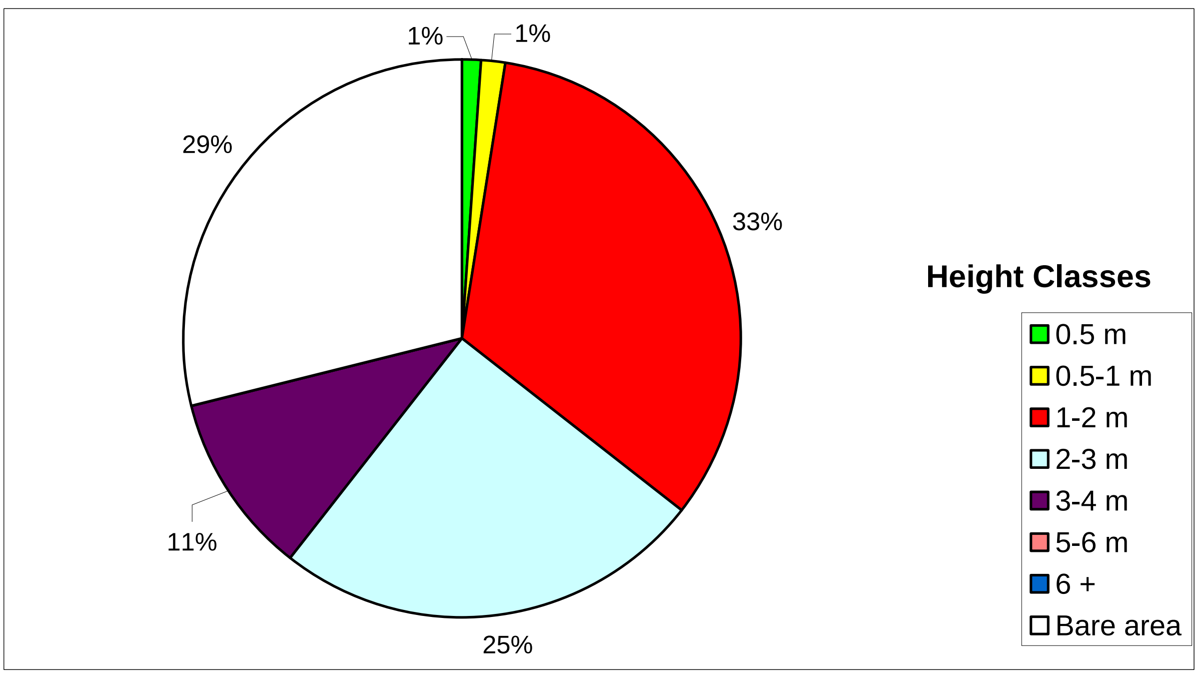

Figure 3.29 Canopy closure per hectare of species in different height classes in Tshidilamolomo Village.

3.4 Effects of woody species on arid landscapes

3.4.1 Soil nutrient enrichment by woody plants

Soil nutrient enrichment by trees and shrubs in arid and semi-arid communities is discussed in Chapter 4.

3.4.2 Interception of rain, wind and sunlight by woody plants

Overhead branches and leaves intercept rain and sunlight. Overhead branches and leaves reduce rainfall, solar radiation, temperatures, intercept rain and sunlight, and reduce evapotranspiration rates below tree crowns (Belsky *et al*., 1989; 1993; Vetaas, 1992). The magnitude of such reductions depends on the density of overhead foliage, height of the crown above the ground, direction of storm events and the angle of the sun (Obot, 1988; Belsky & Canham, 1994). Selosesha, Matloding, Tshidilamolomo all have woody thickets with canopy closures of more than 50 % (Figure 3.10, & Figure 3.22).

There are distinct below-crown areas of altered light, temperature, soil nutrient content, soil moisture and productivity that are determined by the way the species tree crowns are shaped (Belsky & Canham, 1994). *Acacia hebeclada* that grows in the region can have a crown (Coates Palgrave) that spread over a larger area than the other encroaching species.

Areas of reduced light and temperature are larger than the tree crown, extending north and south during different seasons. The size and location of the patches of enriched soil nutrients vary with slope and wind direction, while the size and location of soil-moisture patches vary with the size and location of soil-moisture patches vary with understorey productivity and the direction of ambient rainfall (Belsky & Canham, 1994).

Overhead shade may increase available soil N (Wilson & Wild, 1995) (See Chapter 4).

3.4.3 Species composition below and between tree crowns

Although plant species composition under the trees was not assessed in the study, plant species composition under tree and shrub crowns differs from that in the open (Tiedmann & Klemmendson, 1977; Weltzin & Coughenour, 1990; Menault & Cesar, 1992). Plant species composition is often altered below tree and shrub crowns, as shade-tolerant species invade these areas of higher soil fertility and lower evapotranspiration (Knoop & Walker, 1985; Amundson *et al*., 1995). In heavily disturbed sites, plant species compositional differences may disappear. A homogeneous woody species composition and a lack of species diversity often results when agricultural weeds and encroaching species replace native species (Belsky *et al.*, 1993).

3.5 Conclusion

There is acknowledgement that rangeland management in arid areas is complex and is influenced by spatial, bio-physical, social, cultural and economic factors at a multitude of temporal and spatial scales (Vetter, 2005).

The results are consistent with similar studies where it was found that dense woody trees resulting from overgrazing, rainfall patterns and other factors have a competitive advantage over grass (Moore *et al*., 1985). An almost total absence of grass was observed in the study sites except for the benchmark sites. All of the study sites, except the benchmark sites, had woody plant densities of more than 2 000 TE/ha that according to Moore & Odendaal (1987), almost totally suppress grass growth. This observation of grass growth suppression is a definite call for concern, since the communal rangelands being studied are intended for pasture use. The benchmark in Disaneng Village (Figure 3.3) was the only site with a woody plant density of less than 500 TE/ha and grass growth was evident. At the Neverset benchmark (Figure 3.6), the bush densities were slightly above 2 000 TE/ha. The species that contributes the most to the woody plant densities at this site (40 %) were *Acacia erioloba* which is slow growing and not considered an encroaching species (NDA, 2000).

Applying commercial carrying capacity norms to communal rangelands has been debated (Dikeni *et al*., 1996). Commercial beef farmers aim to make profit from meat production by controlling animal numbers and applying grazing management systems to ensure a "healthy" grass resource. Communal farmers, in contrast, have much broader livelihood strategies, of which livestock production may be a small part of (Chapter 5). Therefore, they aim to maximize animal numbers per area and focus on the maintenance and survival of the animals (Dikeni *et al*., 1996). Nonetheless, regardless of the farming objectives, caution should be taken to ensure that that the range is not degraded.

There is a research gap on the long-term quantitative biological and economic effects of high stocking rates under communal management systems (Dikeni *et al*., 1996). It is therefore important to know the extent (quantitatively) of woody plant encroachment in the affected areas so that appropriate restoration and treatment methods could be applied.

Chapter 4: Soils in the study sites

4.1 Introduction

Soil is described as a thin fragile layer of life supporting material that temporarily stores and recycles resources needed for plant growth (Plaster, 1992). Dokuchaev determined as early as 1883 that soil is a natural body with distinctive, repetitive and predictable properties that is the result of the conditions of their formation (Anderson, 2003). Soil has four important functions to supply plant needs, which are anchorage, water, nutrients, and oxygen for roots (Plaster, 1992).

Soil and climatic conditions are considered primary determinants of savanna condition and structure (Teague & Smit, 1992). It is thus important to investigate the quality of soil of the study sites.

Soil degradation in South Africa is most strongly related to the land tenure system and that soil degradation seems to be more severe in communal districts than in commercial districts (Department of Agriculture, Conservation, Environment & Tourism, DACET, 2002). South Africa's soils have been found to be sensitive and fragile (Garland *et al*., 1999).

Climate and topography have been implicated as predisposing the country to soil erosion, but that by far, the most influential factor in land degradation is poor farming and land husbandry by both commercial settler agriculturalists and communal farmers (Garland *et al*., 1999). A powerful causative link between land degradation and desertification has been pointed out by Garland *et al*. (1999).

Soil degradation causes have generally been focused on different forms of erosion and degradation. Other forms of non erosion soil degradation such as salinization, acidification, water logging, soil pollution, soil mining and compaction (Garland *et al*., 1999) also occur. All these forms of soil degradation may influence the desertification (in semi arid areas, See Chapter 1 location of the study area) process in one way or another (Garland *et al*., 1999).

Compaction results when pressure is applied to the soil surface e.g livestock trampling and heavy machinery. Belsky *et al*. (1993) found heavy livestock grazing around trees caused the formation of a hard soil crust. The pressure squeezes together soil particles, thus shrinking the pores between soil particles. Compaction reduces porosity and increases bulk density. Permeability declines, so that aeration and water infiltration becomes more difficult. Roots will thus have more difficulty growing through the denser soil. Soil compaction enhances harmful physical, chemical and biological processes which, because of inappropriate soil management, lead to soil degradation (Soane & Van Ouwerkerk, 2000).

It was established that woody plant invasion that results from overgrazing (hence trampling and compaction) (Smit *et al*., 1999) reduces the vigor and density of grasses and accelerated soil movement. It is because the wide spreading lateral root system and the open crown canopy of woody plants were found to be not effective in stabilizing the soil as compared to grasses. As the tree stand thickens, the effects of soil erosion become more prevalent while the roots of the perennial grass are often exposed and the surface becomes more irregular with bare patches (Smit *et al*., 1999).

Most forms of soil degradation modify physical and chemical soil characteristics (Garland *et al*., 1999). It would then be expected that persistent and long term degradation of most soil degradation types will affect both the plant species which can survive in an area and their rate of growth (Garland *et al*., 1999).

These events of overstocking as early as 1960 have led to the present day establishment of woody plants and hard compacted patches visible in the study area (Donaldson, 1967).

Woody plants have shown to facilitate microclimates and microhabitats directly below their crowns (Kellman, 1979; Belsky *et al*., 1989; Belsky *et al*, 1993; Isichei & Muoghalu, 1992). Therefore, they affect soil fertility.

According to Anonymous (2002), soil fertility degradation is the single most important constraint to food security in sub-Saharan Africa.

Two contrasting soil types within semi-arid savannas have been identified as dystrophic savanna soils (sandy soils) and eutrophic savanna soils (fine-textured soils) (Campbell *et al*., 1982).

Table 4.1 Characteristic features of dry savannas on fertile and infertile substrates (Scholes, 1990).

Feature		**Nutrient – poor**	**Nutrient – rich**
Soils	% Organic Carbon	0.2-1.0 1	1.0 - 3.0
	Mineralogy	Quartzitic or kaolinitic	Smectitic
	Sum of bases	<20 cmol (+)kg^{-1}	>20 cmol (+)kg^{-1}
	Parent material	Sands, sandstones, granites (upslope)	Basalts, dolerites, shales, granites (bottomlands)
Vegetation	Tree taxonomy	Combretaceae and Ceasalpinoideae dominate	Mimusoideae dominate
	Leaf type	Simple or compound	Compound
	Leaf size	>15 mm	1-15 mm
	Root: shoot ratio	High	Lower
	Grass palatability	Low	High
	Tree anti-herbivore strategy	Chemical (tannins, polyphenolics, etc.)	Structural (thorns)

	Woody biomass		15-25 Mg ha $^{-1}$	5-15 Mg ha^{-1}
	Herb layer water use efficiency		2-5 kg mm^{-1}	5- 10 kg mm^{-1}
	Litter layer		Conspicuous	Inconspicuous
Consumers	Herbivory	Mammal	Low	High
		Insect	Sporadic outbreaks	Continuously high
	Soil fauna		High, termite dominated	Low, ant dominated

According to Knoop & Walker (1985), soil moisture and soil nutrients are viewed as key environmental variables that regulate productivity and relative abundance of savanna vegetation. This is a non equilibrium view of semi-arid savannas according to Vetter (2005). Soil fertility influences aspects of semi-arid savanna vegetation structure and function such as species composition, morphology, forage chemistry and degree and type of herbivory as described in Table 4.1.

Nutrient (Table 4.2) enrichment, total excheangeable bases, cation exchange capacity (Kellman, 1979; Isichei & Muoghalu, 1992) and pH (Belsky *et al.*, 1989; Isichei & Muoghalu, 1992, Hagos & Smit, 2005) have been found to be higher under tree canopies than in the open spaces. The same was expected in the study sites since they had more canopy cover than the benchmark sites (See Chapter 3).

Human caused disturbances, such as cultivation and livestock grazing can either intensify or reduce the build up of nutrients below tree crowns (Belsky & Amundson, 1998). In the American south-west, decades of heavy grazing by domestic livestock have resulted in intense focusing of nutrients around the bases of small shrubs (Schlesinger *et al.*, 1990). In contrast, heavy livestock grazing around trees in Kenya caused the formation of a hard soil crust, showing few significant differences in soil nutrient status between below-crown and open-patch soils (Belsky *et al.*, 1993). The hard soil crusts are probably the results of compaction caused by the heavy livestock trampling. Ploughing of fields near trees and manual redistribution of tree litter may also reduce differences between below-crown and open habitats (Belsky & Amundson 1998). Archer (1996) suggests that changes in soil nutrient distribution subsequent to the establishment of woody plants may feed back to increase the likelihood of additional woody plant encroachment, increase the spatial heterogeneity of nutrient distribution and accelerate water and wind erosion.

Table 4.2 Nutrients essential for plants (Foth, 1984)

Nutrient	**Role in Plants**
	Macronutrients
Nitrogen (N)	Constituent of all proteins, chlorophyll, and in coenzymes, and nucleic acids.
Phosphorus (P)	Important in energy transfer as part of ATP. Constituent of many proteins, coenzymes, nucleic acids, and metabolic substrates.
Potassium (K)	Little if any role as constituent of plant compounds. Functions in regulatory mechanisms as photosynthesis, carbohydrate translocation, protein synthesis, etc.
Calcium (Ca)	Cell wall component. Plays role in the structure and permeability of membranes.
Magnesium (Mg)	Constituent of chlorophyll and enzyme activator.
Sulphur (S)	Important constituent of plant proteins.
Sodium (Na)	Essential for algae, not for higher plants.
	Micronutrients
Boron (B)	Uncertain but believed to be important in sugar translocation and carbohydrate metabolism.
Iron (Fe)	Chlorophyll synthesis and in enzymes for electron transfer.
Manganese (Mn)	Controls several oxidation-reduction systems, formation of O_2 in photosynthesis.
Copper (Cu)	Catalyst for respiration, enzyme constituent.
Zinc (Zn)	In enzyme systems that regulate various metabolic activities.
Molybdenum (Mo)	In nitrogenase needed for nitrogen fixation.
Cobalt (Co)	Essential for symbiotic nitrogen fixation by Rhizobium
Chlorine (Cl)	Activates system for production of CO_2 in photosynthesis.

Soil quality indicators are physical, chemical, and biological properties, processes, and characteristics that can be measured to monitor changes in the soil (Anonymous, 1996). Indicators of soil quality can be categorized into four general groups (Anonymous, 1996):

- Visual indicators, which may be obtained from observation or photographic interpretation. A few examples of potential locally determined indicators are: exposure of subsoil, change in soil color, ephemeral gullies, ponding, runoff, plant response, weed species, blowing soil, and deposition. Visual evidence can be a clear indication that soil quality is threatened or changing. The bare compacted patches at the study sites grounds were a visual indicator that their soil quality is threatened or changing.
- Physical indicators are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile.
- Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements/nutrients that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development (Table 4.2). The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions, such as the tendency for crust to form.
- Biological indicators include measurements of micro and macro-organisms as well as their activity, or byproducts. Earthworm, nematode, or termite populations have been suggested for use in some parts of the country. Respiration rate can be used to detect microbial activity, specifically microbial decomposition of organic matter in the soil. Ergosterol, a fungal byproduct, has been used to measure the activity of organisms that play an important role in the formation and stability of soil aggregates. Measurement of decomposition rates of plant residue in bags or

measurements of weed seed numbers, or pathogen populations can also serve as biological indicators of soil quality.

Snyman & Du Preez (2005) stressed the importance of maintaining rangeland in good condition and good soil quality to help ensure sustainable utilization of the grassland.

The objective of the study was to investigate and compare the nutrient status and chemical properties in the encroached study sites compared to the benchmark sites.

4.2 Material and Methods

4.2.1 Material

1. Soil Auger
2. Paper bags for soil collection

4.2.2 Methods (soil sampling and analysis)

Soil sampling in this study was conducted to investigate the effects of woody plants on soils under communal and commercial farming management regimes. Grass and forage crops, unlike other harvested crops are considered in terms of animal utilised economic benefit (Archer, 1995). This means that grass and forage crops are valued in terms of what is consumed by the rather than the field’s yield of a specific part of the plant (e.g. fruit) that is sold at a price (Archer, 1995).

The objective of soil analysis is to determine soil characteristics concerned with the property of soil fertility. Soil analysis is a tool used in the general assessment of soil properties in order to establish the agricultural (farming) value of the soil (Buys, 1974).

A soil auger and paper bags were used for soil sampling in each of the study sites. Soil from the A horizon was discarded because the organic matter from leaf litter was not required for analysis. The soil was collected and put into paper bags and put in a drying oven to prevent decomposition. The samples were taken around the randomly selected centre point of the study plot (Coetzee & Gertenbach, 1977). Two soil samples per site over two years (2006-2007) were sent to the Institute for Soil, Climate and Water of the ARC (Agricultural Research Council) in Pretoria for nutrient and chemical analysis.

Concentrations of exchangeable cations, potassium (K), calcium (Ca), Magnesium (Mg), sodium (Na) were determined by the ammonium acetate method (Bashour & Sayegh, 2007). Phosphorus was measured by the P-bray analysis method (Bashour & Sayegh, 2007).

Soil chemical analysis conducted included pH (H_20) (Bashour & Sayegh, 2007), resistance (R), electrical conductivity (EC) (Saturated water paste extraction method) (Bashour & Sayegh, 2007), cation exchange capacity (CEC) (Ammonium acetate extraction method) (Ellis & Mellor, 1995; Bashour & Sayegh, 2007), organic carbon (Org C) (Walkley - Black method) (Alvarez-Benedi, & Munoz-Carpena, 2005; Bashour & Sayegh, 2007) and total nitrogen (Total N) (Total N Dry combustion method) (Tan, 2005; Bashour & Sayegh, 2007). Sand %, silt % and clay % (soils texture) were determined by the Hydrometer method (particle size distribution – 3 fraction) (Lambe, 1951; Bashour & Sayegh, 2007).

4.2.3 Data analysis

The averages of all the variables of the soil samples were used for data analysis. All the data was exposed to analysis of variance (ANOVA) and standard error using a statistical analysis programme Microsoft Excel spreadsheets (Microsoft Office Professional Edition, 2003). Least significant differences (LSDs) were calculated from the appropriate standard errors and compared with the mean differences to determine significant differences.

4.3 Results and Discussion

4.3.1 Soil texture

Soil texture is a term commonly used to designate the proportionate distribution of the different sizes of mineral particles in a soil and does not include any organic matter (Brown, 2003). Soil texture is used in textural classification to determine the proportion or percentage of the three soils separates (sand, silt and clay) (Plaster, 1992). Soils usually have more than one separate but all three separates are usually found in most soils. That is, it is unlikely to find a soil whose texture is pure sand, silt or clay naturally. Any number of combinations of the three is possible, so scientists simplify the textures by dividing soils into textural classes (Plaster, 1992).

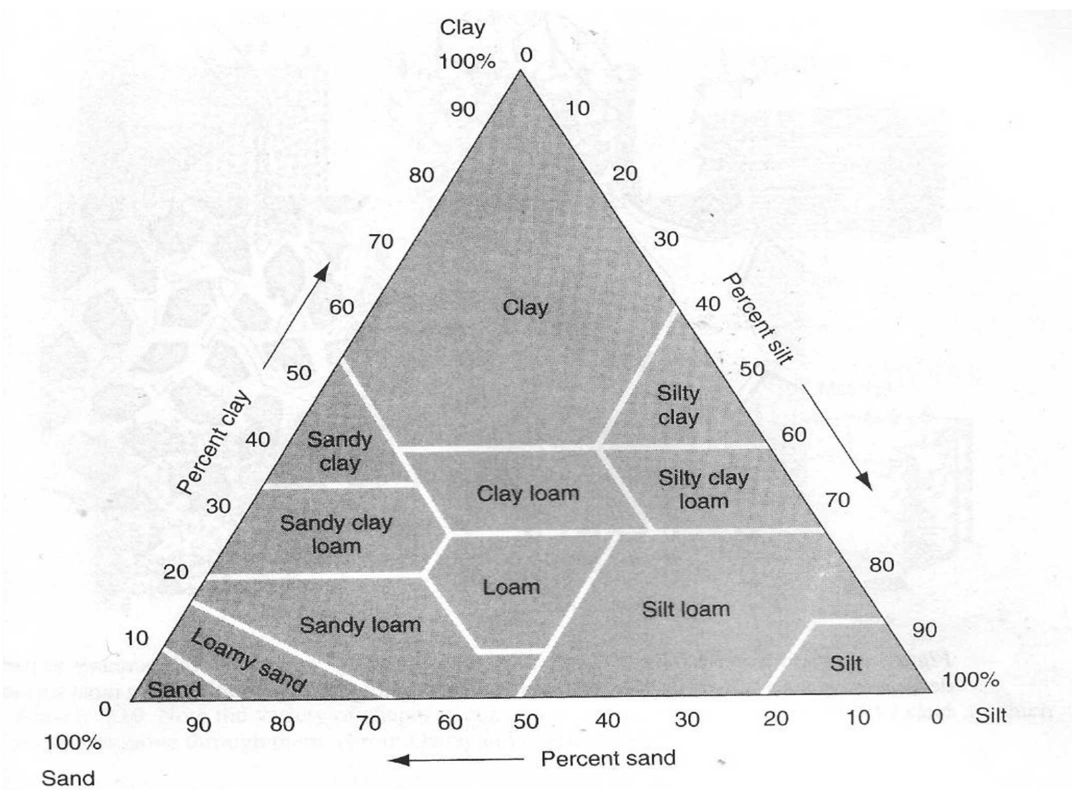

Figure 4.1 Soil texture designation based on percentages of sand, silt and clay (Owen & Chiras, 1995).

The soil texture designations of soil in the different study sites soils based on Figure 4.1, are shown in Table 4.2. This confirms that the soils of the Molopo Area are deep sandy to loamy sands of aeolian origin, underlain by calcrete (Low & Rebelo, 1996). Donaldson and Kelk (1970) and Acocks (1988) that described the Molopo soils as Kalahari sand which is consistent with Table 4.2.

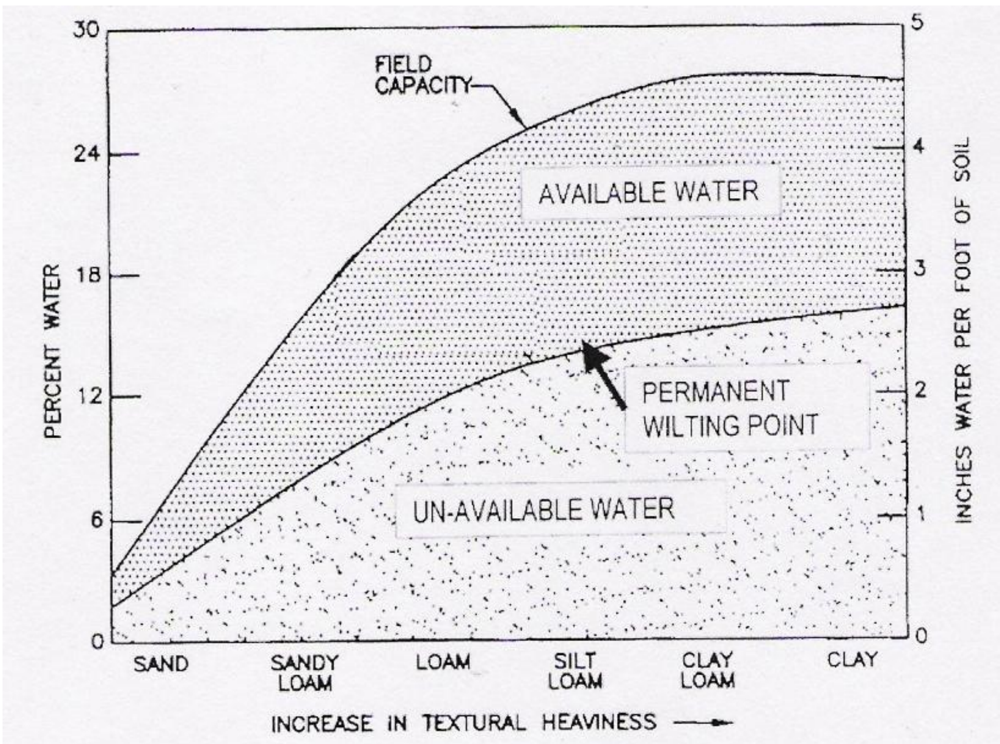

Figure 4.2 Relationship between soil texture and available water (Whiting & Toland, 2006).

According to Figure 4.2 and Table 4.3, the soils in Tshidilamolomo, Matloding and Benchmark 2 have the least available water. Disaneng and Logageng soil have higher available water than the former sites (Figure 4.2; Table 4.3). Setlhabaneng soil has the most available water (Figure 4.2; Table 4.3).

Water holding capacity is an important soil fertility function (Buys, 1974). The water requirements of plants are not only determined by the need for liquid, but water is also a medium through which plant roots feed, i.e. extract nutrients food (Buys, 1974). There is a relationship between soil texture and available soil water (Figure 4.2). This is because the pore space created by soil texture and structure primarily determines a soil's ability to hold water. Water coats the soil particles and organic matter and is held in the small pore spaces by cohesion (the chemical forces by which water molecules stick together) as air fills the large pore spaces. Water fills the pore spaces at saturation. It fills the smaller pore spaces while air occupies the large pore spaces at field capacity. At the wilting point, plants cannot extract additional water from the soil (Whiting *et al*., 2006).

Table 4.3 Soil texture designations of study sites

	Sand %	**Silt %**	**Clay %**	**Soil texture Designation**
Study site				
Disaneng	86.2 %	5.8 %	8.0 %	Loamy sand
Setlhabaneng	59.2 %	20.8 %	20.0 %	Sandy loam
Selosesha	80.94 %	7.06 %	12 %	Loamy sand
Tshidilamolomo	90.16 %	3.84 %	6 %	Sand
Matloding	89.8 %	2.2 %	8.0 %	Sand
Logageng	85.1 %	4.9 %	10.0 %	Sand / Loamy Sand
Neverset Farm	80.2 %	3.8 %	16.0 %	Loamy sand
Benchmark 1	86.4 %	3.6 %	10.0 %	Loamy sand
Benchmark 2	89.9 %	2.1 %	8.0 %	Sand

According to Figure 4.2, available water is field capacity taking away wilting point. Field capacity is the maximum amount of water a soil can hold, but excluding the gravitational water that drains away. Soil cannot be wetter than field capacity unless it is water-logged. Wilting point is that moisture content which is so low that plants wilt permanently and dies (Buys, 1974). The process of weathering and profile development (involving organic as well as inorganic parts of the soil) are greatly affected by water. The movement of materials dissolved in water results in loss of horizons of loss and accumulation, which give the soil a distinctive profile and may brand it as fertile or infertile for plant growth.

Water is also a responsible agent for soil erosion that is observable from gully formations in Selosesha (Figure 2.1**)**. Many of the physical properties of the soil, such as its structure are affected by water so that soil-water relations play an important role in tillage and in the design and performance of roads and buildings (Marshall, 1982).

Soil texture is important in determining the retention of exchangeable cations and soil P in different savanna types due to adsorption by cation exchange complexes (Kellman, 1985). Kellman, (1985) found that deep sandy soils (similar to study site's) with low cation-exchange capacities had low retention potentials. Percolation in these deep sandy soils is being more concentrated in the macropores that bypassed the surface-soil solutions and thus reduced leaching.

Soil texture also affects soil organic carbon (Van Noordwijk *et al.*, 1999; Anonymous, 2007). According to Van Noordwijk *et al.* (1999), even slight differences in soil texture such as those at the study sites (Table 4.3), can result in differences in soil organic matter of the sites. It is thus recommended that the soil organic carbon of Disaneng, be compared with that of Selosesha,Logageng, Neverset farm and Benchmark 1 (Table 4.3). While the soil organic carbon of Tshidilamolomo should be compared with that of Matloding. Even then, the pH differences (Figure 4.4) could contribute to differences in the study sites soil organic carbon (Figure 4.7).

4.3.2 Soil pH in study sites

pH refers to the hydrogen ion concentration [H^{+}]. The pH of soils in the various study sites was moderately acidic to neutral (Figure 4.4). Hagos & Smit (2005) recorded higher soil pH (although statistically not significant) away from the tree canopies than beneath the trees. Isichei and Muoghalu (1992), on the other hand, recorded, significantly higher soil pH in tree vicinities than in open grasslands. pH values of soils in Disaneng, Selosesha and Neverset Farm (Figure 2.1) had no significant ($p > 0.05$) differences with the benchmark sites (Figure 4.4). Woody plant density (See Chapter 3) at Selosesha was 3 104 TE/ha while that of Selosesha and Neverset Farm was 6 999 TE/ha (Figure 3.15) and 12 869 TE/ha (Figure 3.18) respectively and the benchmark sites recorded 407 TE/ha (Figure 3.24) at the communal benchmark and 2 244 TE/ha (Figure 3.27) at the commercial benchmark. Soil pH was significantly ($p < 0.05$) higher at Setlhabaneng, Tshidilamolomo and Logageng while it was significantly ($p < 0.05$) lower at Matloding (Figure 4.3). Woody plant densities at these sites (See Chapter 3), was 3 104 TE/ha, 8 817 TE/ha and 3 600 TE/ha respectively. The pH of study sites (Figure 4.4) was found to be moderately acidic as expected of leached sandy soils (Table 4.3).

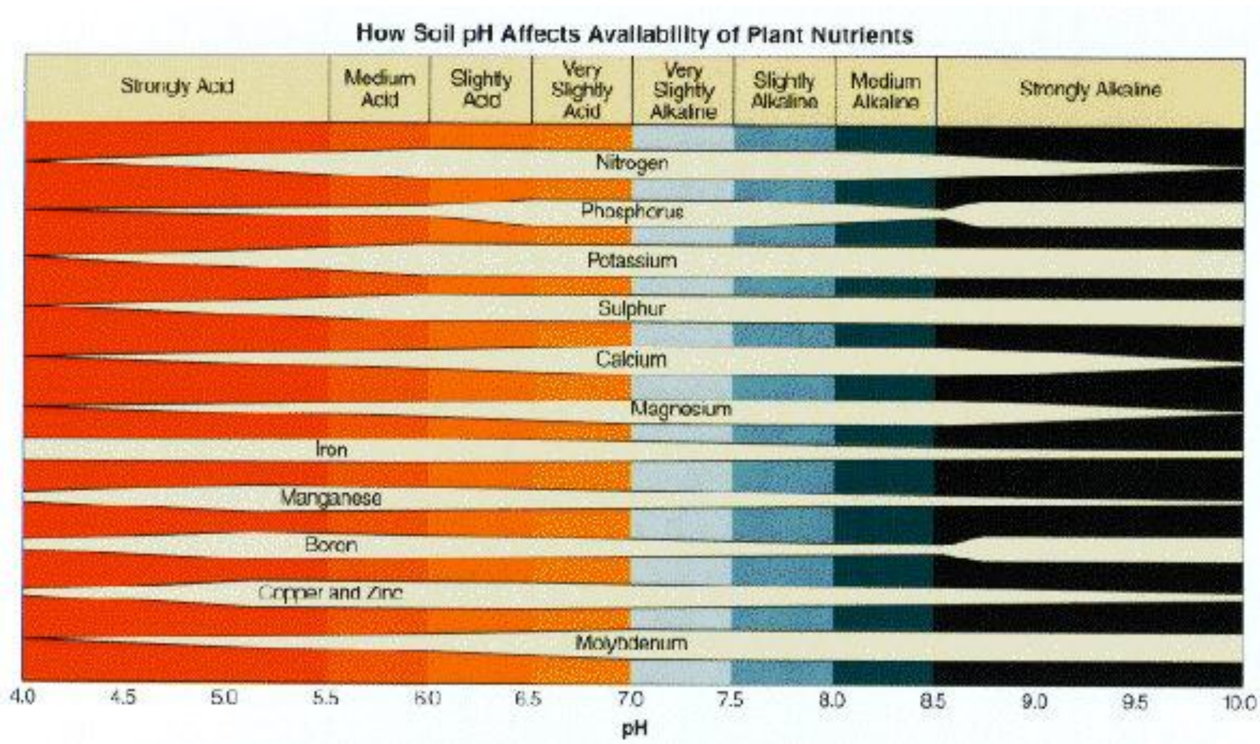

Figure 4.3 The general relationship between soil pH and availability of plant nutrients, the wider the bar, the more the availability (Foth, 1984).

At pH levels below 4, direct root injury may occur. When pH is below 4, root development into subsoil is unlikely, even though other toxicities are not an overriding factor (Archer, 1985). None of the study sites soils had a pH below 5 (Figure 4.4). The greatest general influence of pH on plant growth could be its effect on the availability of nutrients (Figure 4.3) (Archer, 1985; Foth, 1984).

Different woody species have been found to influence pH changes. Belsky *et al*. (1993) found significant pH differences under canopies of *Adansonia digitata* (baobab) and *Acacia tortilis* than in the open. Soil pH was significantly lower under *Acacia* canopies compared to that of baobab trees.

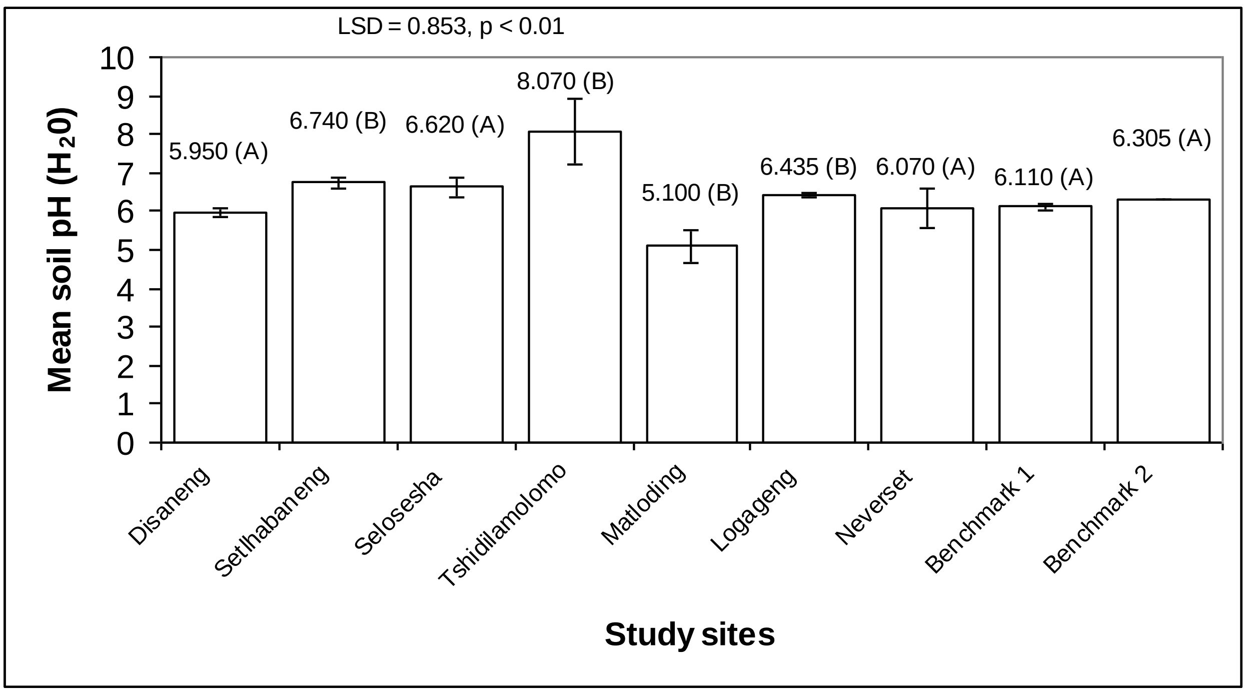

Figure 4.4 Mean pH of soil in Disaneng and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences.

Many studies have been conducted that relate increases in the percentage of calcium in plants, with increasing soil pH (Foth, 1984). This pattern of increased soil Ca can be observed in soils of the study sites (Figures 4.4 & 4.10). Soil pH and the presence of free calcium carbonate influence the soil chemistry and various physical and biological aspects of the soils. The rate of organic matter decomposition is much slower in acid conditions (Archer, 1985). Acid in permanent grassland soils frequently builds up a thick surface root mat because of lack of biological activity. Worm activity is much less in acid conditions (Archer, 1985). Soil pH also affects soil organic carbon (Van Noordwijk *et al.*, 1999; Anonymous, 2007). This can be seen in Figure 4.7.

Some important soil borne plant diseases are influenced by pH and liming (Archer, 1985). An increase in acidity will increase the adsorption of most soil acting herbicides. The result is much poorer weed control at the normal application rates (Archer, 1985).

4.3.3 Soil (P) phosphorus

4.3.3.1 Soil (P) phosphorus from soil in the study sites

There were no significant ($p > 0.05$) differences in the soils of the study sites compared to the benchmark sites except for soil of Tshidilamolomo (Figure 4.5) which was found to be ($p < 0.01$) higher than all sites. Extractable phosphorus (P) of soils under tree and shrub crowns is normally higher than that of soils in open spaces (interspaces) or between individual crowns (Belsky *et al*., 1989, 1993; Young, 1989; Belsky, 1992; Vetaas, 1992; Isichei & Muoghalu, 1992, Hagos & Smit, 2005). *Prosopis velutina* (95 % of recorded species in Tshidilamolomo, See Chapter 3) can result in the significantly high ($p < 0.01$) P content in its soil. Available phosphate should be greatest at the benchmark sites, Setlhabaneng, Selosesha, Logageng and Neverset farm because their soil pH is between 6 and 7 (Figure 4.4). Phosphate availability is generally greatest between pH 6.0 and 7.0 (Archer, 1985). The relationship between the labile pool and the soil solution depends particularly on soil texture and pH. In calcareous soils, precipitation of calcium phosphates is a major factor limiting solubility (Archer, 1985).

Plants take up phosphorus in smaller amounts than nitrogen or potassium (Archer, 1985). Phosphorus (P) plays a major role in biological metabolism. In comparison to other macronutrients required by biota, phosphorus is least abundant and commonly is the first element to limit biological productivity (Wetzel, 1983). Orthophosphate is the only directly utilisable form of soluble inorganic phosphorus. Phosphate is extremely reactive and interacts with many cations (e.g. Ca^{2+}) to form, especially under oxidising conditions, relatively insoluble compounds that precipitate out of water. It is thus important that the level of cations e.g. (Ca^{2+}, Fe^{2+}) be monitored since phosphate is extremely reactive and interacts with them to form insoluble compounds, which precipitate out of the water and cannot be utilised by plants (Wetzel, 1983). This limits biological productivity of the soil. Availability of phosphate is also reduced by adsorption to inorganic colloids and particulate compounds (e.g. clays, carbonates, hydroxides) (Wetzel, 1983).

Due to its strong specific adsorption in soils, phosphorus behavior is dominated by the low concentrations in the soil solution. This results in relatively poor mobility of phosphorus in soils, compared to cations or non-absorbed anions. The low concentration of orthophosphate maintained in the soil solution (often less than 1 mg/1 phosphorus) coupled with the considerable crop demands that diffusion of ions to the root surface is important in determining uptake. The main source of plant-available phosphorus is generally termed the labile pool. This provides fairly rapid exchange with the soil solution, maintaining the solution concentration. The remaining fraction is the non-labile pool. This contains the large quantity of insoluble phosphate, which is only very slowly released into the labile pool. The various organic and inorganic phosphates constitute these labile and non-labile pools. There is no clear distinction by which particular forms can be designated as in one pool or another. In general, the labile pool can be considered as orthophosphate adsorbed on the surfaces of clays minerals, hydrous oxides and carbonates plus iron and aluminium phosphates. The relationship between the labile pool and the soil solution depends particularly on soil texture and pH. In calcareous soils, precipitation of calcium phosphates is a major factor limiting solubility. Phosphate availability is generally greatest between pH 6.0 and 7.0 (Archer, 1985).

Generally the concentration of phosphorus in the plant xylem is 100 to 1000 times more than in the external soil solution, indicating an active energy demanding uptake process. Once inside the plant, these phosphorus anions are rapidly metabolised into organic compounds and move freely in both the phloem and xylem transport systems. Movement can also occur in inorganic form. Phosphorus occurs in numerous forms, such as phosphorylated sugars and alcohols and as phospholipids that have a wide range of functions. The main function is in energy transfer as adenosine triphosphate (ATP). This contains high-energy pyrophosphate bonds which are formed during photosynthesis and which, on hydrolysis, release this energy to drive other plant processes including active nutrient uptake (Archer, 1985).

Nutrient retention of soil P has been found to differ in different types of savannas due to contrasts in soil properties which determine adsorption by cation exchange complexes (Kellman, 1985).

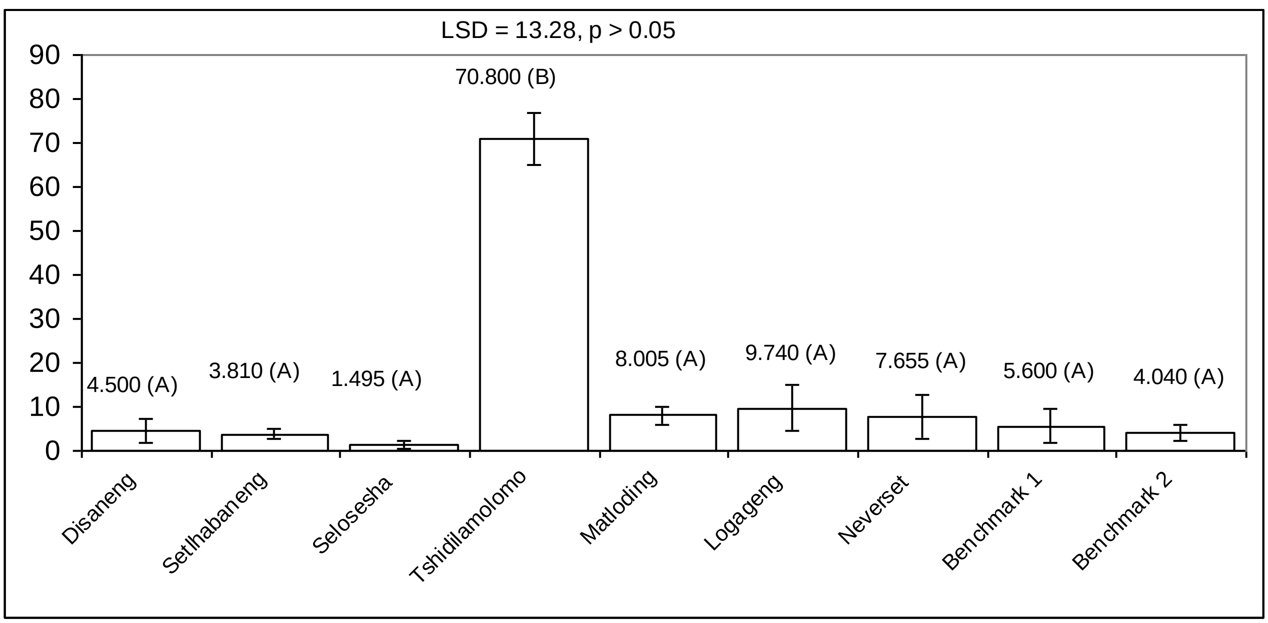

Figure 4.5 Mean (P) phosphorus from soil in study area and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences.

Belsky *et al*. (1989, 1993) found no significant differences in extractable soil P under trees canopies of *Acacia tortilis* and *Adansonia digitata*. Significant differences were found in some of the other soil nutrients and moisture availability was also found to have influence. Therefore, according to Belsky *et al*. (1989, 1993), different woody species can influence nutrient sequestration and moisture availability under their canopies differently but further studies and evidence is needed. These influences could account for the high soil P in Tshidilamolomo soils (Figure 4.5).

4.3.4 Organic carbon in soils of the study sites

Highly significant ($p < 0.01$) differences in soil organic C were recorded in Selosesha, Setlhabaneng, Matloding, Logageng and Neverset Farm when compared to the benchmark sites (Figure 4.7). It was to be expected that the soils of areas invaded by woody plants would have higher concentrations of organic carbon than sites with few woody plants (Chapter 3). This is because soil organic carbon beneath woody plant crowns is normally higher than away from crowns (Belsky *et al*., 1989, 1993; Young, 1989; Belsky, 1992; Vetaas, 1992; Isichei & Muoghalu, 1992; Hagos & Smit, 2005). Only soils in Matloding had significantly ($P < 0.05$) lower soil % organic C than the study benchmark sites (Figure 4.7). Soil organic carbon in Disaneng and Tshidilamolomo had no significant ($P > 0.05$) differences with the benchmark sites and was recorded at 0.255 % and 0.310 % respectively (Figure 4.7).

Soil organic carbon (SOC) is the carbon associated with soil organic matter and is part of the natural carbon cycle (Figure 4.6; Chan, 2008). According to Chan (2008), soil organic matter is the organic fraction of the soil that is made up of decomposed plant and animal materials as well as microbial organisms, but does not include fresh and undecomposed plant materials, such as straw and litter, lying on the soil surface. Much carbon is added to the soil from root material as well and depends at the rate which microbes break down organic compounds (Anonymous, 2007). Soil carbon can also be present in inorganic forms, e.g. lime or carbonates in some soils in the drier areas (Chan, 2008).

Soil organic carbon is important for all three aspects of soil fertility, which are chemical, physical and biological fertility (Chan, 2008). It is also important in a rangeland ecosystem functioning since it improves soil structure and thereby enhances water infiltration and reduction of soil erosion through aggregate stabilization (Snyman & Du Preez, 2005). Increases in soil organic carbon (SOC) can also improve soil health and can help to mitigate climate change (Chan, 2008).

Soil organic carbon according to Chan (1998) affects:

- Soil nutrient availability due to the decomposition of soil organic matter releases nitrogen, phosphorus and a range of other nutrients for plant growth.
- Soil structure by holding the soil particles together as stable aggregates improves soil physical properties such as water holding capacity, water infiltration, gaseous exchange, root growth and ease of cultivation.
- Biological soil's health as a food source for soil fauna and flora. Soil organic matter plays an important role in the soil food web by controlling the number and types of soil inhabitants which serve important functions such as nutrient cycling and availability, assisting root growth and plant nutrient uptake, creating burrows and even suppressing crop diseases.
- The effect of harmful substances e.g. toxins, and heavy metals, by acting as buffers (lessening their toxic effects), e.g. sorption of toxins and heavy metals, and increasing degradation of harmful pesticides.

There is a limit on the amount of organic carbon that can be stored in soils and the actual amount of soil carbon that can be stored is dependent on the farming system (management practices), soil type and climatic conditions, as well as the initial soil carbon level of the site (Anonymous, 2007; Chan, 2008). Anonymous (2007) singled out soil type among the other factors and stressed that in many situations, the levels of soil organic carbon did not appear to be strongly related to soil type . It is usually higher in forest and pasture areas (Anonymous, 2007). It generally follows continental rainfall and temperature patterns (carbon accumulation increases with increasing rainfall; carbon decomposition increases with increasing temperature – these factors are then influenced by the annual input of carbon to the soil system). Monitoring levels of soil organic provides a good measure of the impact of land management on soil health. Exploitative, environmentally damaging land management practices tend to reduce soil carbon levels (Anonymous, 2007). Humus or stable fraction of soil organic matter contributes mainly to nutrient holding capacity (cation exchange capacity) and soil color (Anonymous, 2007).

Measurement of soil organic carbon gives an estimate of the amount of organic matter in a soil as a percentage by weight although soil carbon density (t/ha) can also be estimated and is useful for carbon accounting purposes (Anonymous, 2007). The level of organic matter in the soil is a broad indicator of soil condition and many management practices that are effective in increasing SOC are also effective in improving crop and pasture yields (Anonymous, 2007; Chan, 2008). Soil organic matter gradually decrease with depth from relatively high concentrations in the A horizon, even though the particular pattern of distribution differs among soils (Garcia-Moya & Mackell, 1970; Archer, 1985). Soil carbon levels are determined by factors such as rainfall, temperature, vegetation and soil type and reach equilibrium values associated with individual systems and locations (Chan, 2008). These equilibria are disturbed however when areas are cleared and used for agricultural production (Chan, 2008).

Carbon is essential for plant growth, due to its effects on other soil properties. Organic matter is important since it binds soil particles together into stable aggregates, which are necessary for soil structural stability. It is also involved in adsorption of cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}), which are important in plant nutrition, and can significantly influence soil water holding capacity, especially in more sandy soils (Anonymous, 2007; Van Noordwijk *et al.*, 1999) suggest that even moderate differences in soil texture and/or pH, can lead to changes in soil organic carbon similar in magnitude to those of the land use change. That is why Van Noordwijk *et al.* (1999)

proposed to use a ratio of the measured organic carbon and a reference organic carbon value for soils of the same texture and pH as a "sustainability indicator".

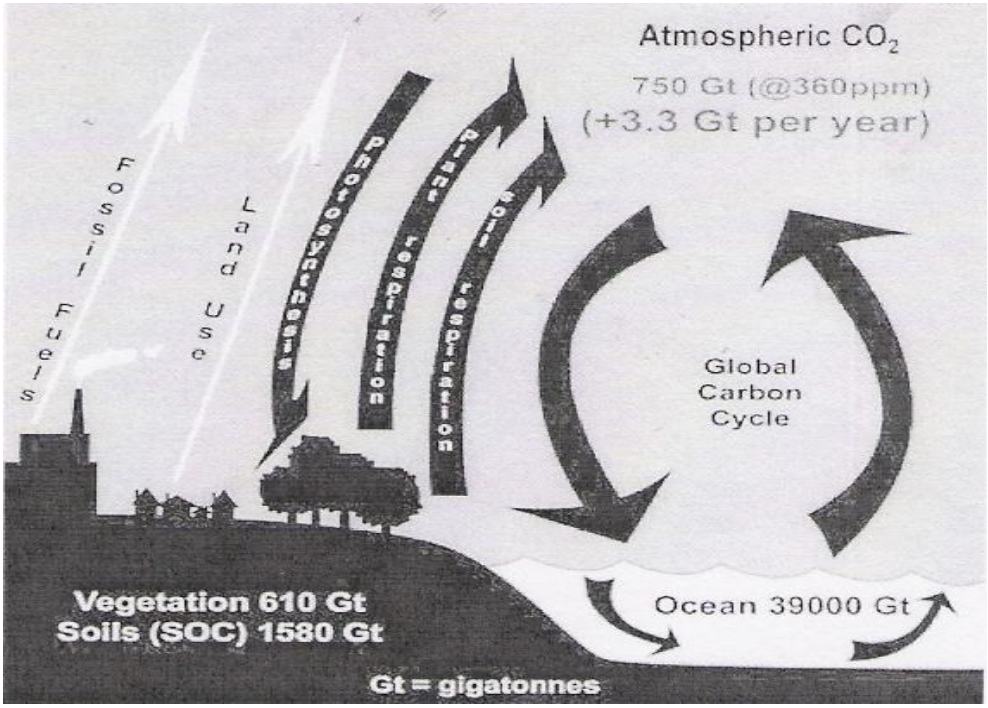

Figure 4.6 Soil organic carbon (SOC) is part of the natural carbon cycle (Chan, 2008)

Microorganisms (microbes), using the plant raw material as a source of energy, decompose the plant residues in the soil. Some of the organic material is completely decomposed and plant nutrients are available during the process of decomposition when they are being used as food for the microbes. This so-called "negative period" is especially noticeable in the case of nitrogen plant food. The organic material that is not completely decomposed forms intermediate products resistant to breakdown like humus. If conditions are favourable, these stable products will remain in the soil and become part of it, darkening and changing the colour of the soil to shades of brown. Humus is colloidal and together with clay colloids, takes part in Base Exchange reactions, which are important for plant nutrition (Buys, 1974). This is noticeable mostly in the topsoil where most of the organic matter is found.

The net result, when land is subjected to overgrazing, is a decline in the quantity of organic matter (Archer, 1994). Soil temperature, aeration and availability of water influence the rate of loss of soil organic matter. If organic matter losses from cultivated soils lead to critically low organic matter contents varying from 1-3 %, serious management problems can occur in all texture groups (Archer, 1994).

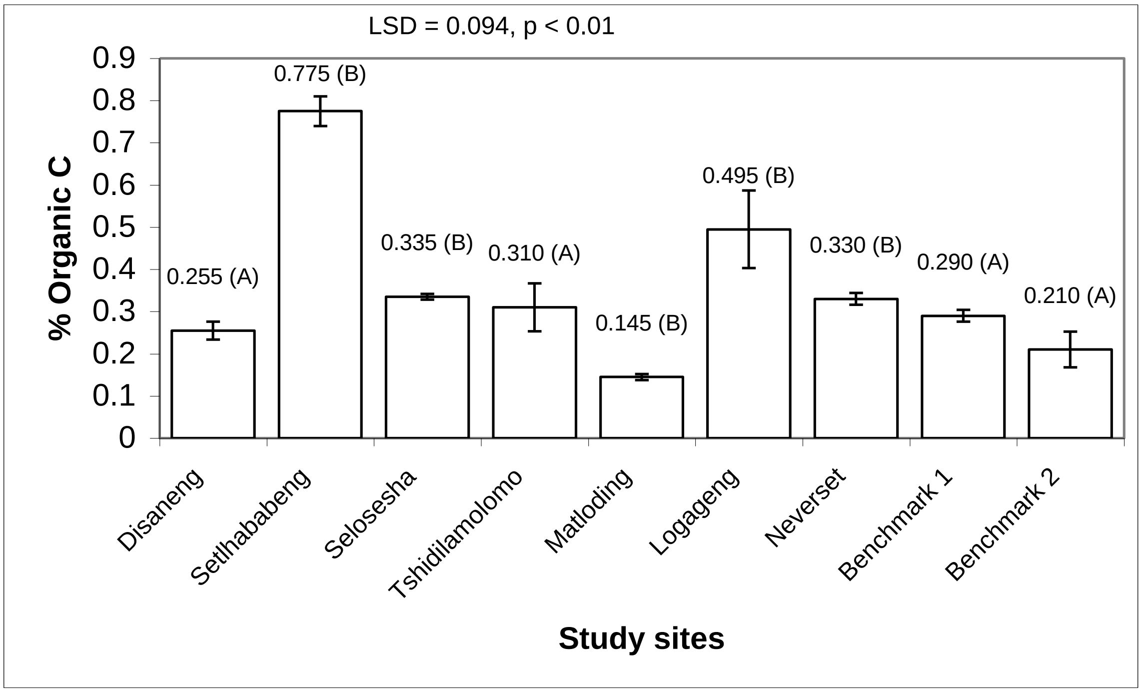

Figure 4.7 Mean percentage organic carbon from the soils in the study and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

4.3.5 Soil nitrogen (N) from the study sites

No significant ($P < 0.05$) differences were recorded in the soil N of all the study sites and benchmark sites except that of Setlhabaneng (Figure 4.8). Overhead shade in N- limited environments may increase available soil N (Wilson *et al.*, 1986; Wilson & Wild, 1995) of which the encroached sites have a higher % of trees canopies cover (See Chapter 3) and hence more shade. The results are consistent with expectations because there is normally higher soil N in soils that are encroached compared to the open spaces (Belsky *et al*., 1989; Hagos & Smit, 2005).

Soil nitrogen is the nutrient required in the greatest quantity by most crops (Archer, 1995). Nitrogen, after water is generally considered as the most limiting factor for plant growth in semi-arid regions (Eskew & Ting, 1978). As an element, Nitrogen is one of the most complex substances in behavior, occurring in soil, air and water in organic and inorganic forms, thus provides the difficult problems in making fertiliser recommendations (Archer, 1985). The basic functions of nitrogen in plants are stated in Table (4.2).

Microbial nitrogen fixing biomass has been found to be higher in the soils from the leguminous canopies than from the root and grassland zones (Belsky *et al*., 1989). However, leguminous shrubs appear to serve the same function as the non-leguminous shrubs in the nitrogen economy of the community studied since the differences in nitrogen content of roots, stems, and leaves were not associated with the legume characteristic (Garcia-Moya & Mckell, 1970). Garcia-Moya & Mckell (1970) concluded that the importance of shrubs lied more in the way they served as a reservoir for soil fertility in desert regions rather than in any significant participation in symbiotic nitrogen fixation. Soil nitrogen gradually decreases with depth from relatively high concentrations in the A horizon, even though the particular pattern of distribution differs among soils (Garcia-Moya & Mckell, 1970). Garcia-Moya & Mckell (1970) found no significant differences in nitrogen content of legume shrubs and non-legume shrubs. This suggested that the nitrogen fixing ability of leguminous plants had no effect on the plant nitrogen content. Nitrogen fixation in non-leguminous plants similar to the symbiotic relationship with legumes has been found to exist in several genera of angiosperms (Garcia-Moya & Mckell, 1970). This implies that the non-leguminous species identified in the study sites (See Chaprter 3) could have a potential to fix nitrogen similar to the leguminous species.

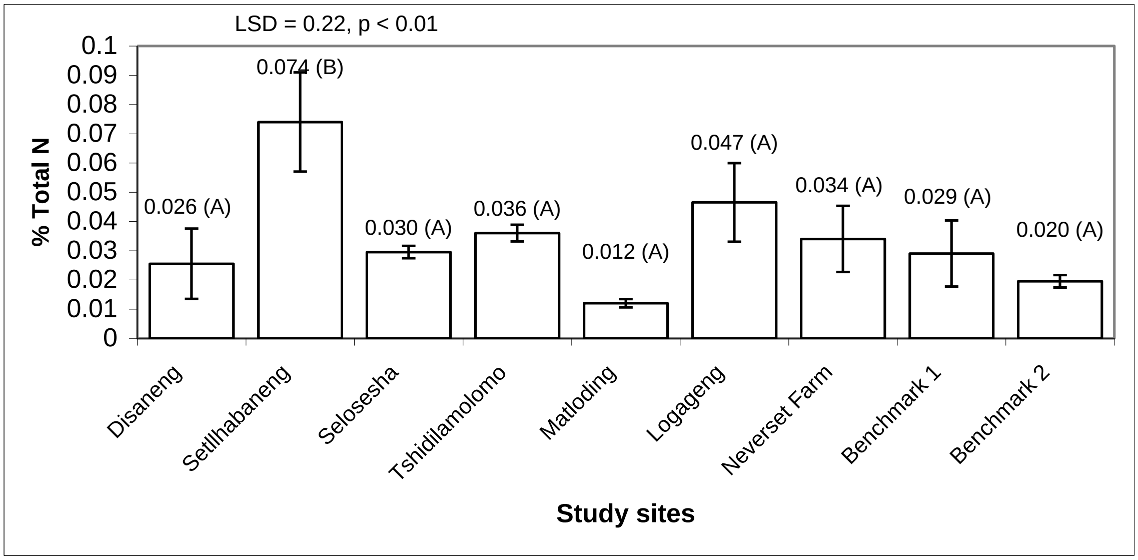

Figure 4.8 Mean soil nitrogen (N) from Disaneng and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

Leguminous species, such as those present in the study sites (Chapter, 3), have the potential for establishing a symbiotic relationship with nitrogen fixing *Rhizobium*, bacteria (Virginia & Jarell, 1983; Hogberg, 1986; Smith *et al.*, 1987; Vetaas, 1992). The utilization of atmospheric nitrogen by this bacterium increases the amount of bio-chemically available nitrogen in the nutrient cycle of the sub-canopy zone (Vetaas, 1992).

Nitrogen comes entirely from the atmosphere, where it occurs as gas that plants cannot use. Soil organisms change the gaseous nitrogen to forms that plants can use. Some nitrogen recycles as living creatures die and return nitrogen to the soil, while some is carried deep into the ground by water and some is changed back to its original form by microbes (Plaster, 1992). This is why the relationship of leguminous plants and nitrogen fixing bacteria is important.

Table 4.4 Acceptable limit of soil quality indicators (Bornman *et al.*, 1989)

Soil indicator	Acceptable range
SOM (%)	1.5 – 2.0
C : N	1:10 – 1:14
EPP (Exchangeable potassium %)	(3-7)

Most of the total nitrogen content of desert soils is found in the shallow surface layer where it is tied up in the organic matter of litter and living plants (Garcia-Moya & Mckell, 1970). That is where shrubs make their greatest contribution. Leaching through the sandy soil during infrequent thunderstorms in arid areas results in rapid loss of any nitrogen liberated in the mineralization of organic matter (Garcia-Moya & Mckell, 1970).

4.3.5.1 Carbon : Nitrogen ratios of soils in study sites

The soil in Tshidilamolomo (Table 4.5) is the only site whose soil Carbon/Nitrogen ratio is outside the range of soil quality indicators (Table 4.4). Belsky *et al*. (1993) found C/N ratios and bulk soil densities to be lower under tree canopies than in the open. According to Table 4.4, values outside the ranges indicate "problems" with the soil quality (Bornman *et al*., 1989). Differences in soil C/N ratio have been attributed to the nitrogen content of the litter itself, local variations in soil conditions according to topography as well as parent material (Yamakura & Sahunalu, 1990).

The carbon – nitrogen (C/N) ratio of soil organic matter is a measure of the quality, rather than the quantity of the organic matter (Swift *et al*., 1979; Yamakura & Sahunalu, 1990). It is related to the patterns of nitrogen immobilization and mineralization during organic matter decomposition by microorganisms (Swift *et al*. 1979; Yamakura & Sahunalu, 1990). The C:N decreases as decomposition proceeds and is negatively correlated with the rate of nitrogen mineralization (Yamakura & Sahunalu, 1990). Some studies have indicated an increase of the soil C/N ratio with a decrease in temperature and an increase in moisture (Yamakura & Sahunalu, 1990). Yamakura & Sahunalu (1990) used soil C/N ratio as an indicator of site quality because it is unidirectional and works irrespective of climatic, fire and species regime. It is also related to the speed of decomposition and the rate at which organic nutrients are mineralized and become available for readsorption into the vegetation (Yamakura & Sahunalu, 1990).

Table 4.5 Carbon Nitrogen ratios of soil from study sites

Site Name	**Carbon : Nitrogen ratio**
Disaneng	**10 : 1**
Setlhabaneng	**10 : 1**
Selosesha	**11 : 1**
Matloding	**12 : 1**
Tshidilamolomo	**9 : 1**
Logaganeng	**11 : 1**
Neverset	**10 : 1**
Benchmark 1	**11 : 1**
Benchmark 2	**11 : 1**

4.3.6 Exchangeable cations content of soils from study sites

4.3.6.1 Potassium (K) of soils

Only the soil in Disaneng and Matloding had significantly ($p < 0.05$) lower soil K than the other study sites (including benchmark sites) (Figure 4.9). Soil K was generally higher (but not significantly ($p < 0.05$) in the study sites than benchmark sites (Figure 4.9). The higher soil K of the study sites is expected since geostatistical analyses in past studies have shown a higher cation content that is associated with the presence of trees and shrubs (Refer to Chapter 3) in arid habitats (Hagos & Smit, 2005; Liao *et al*., 2006). The significantly lower ($p < 0.05$) differences in K contents in the soils of Disaneng and Matloding were not expected.

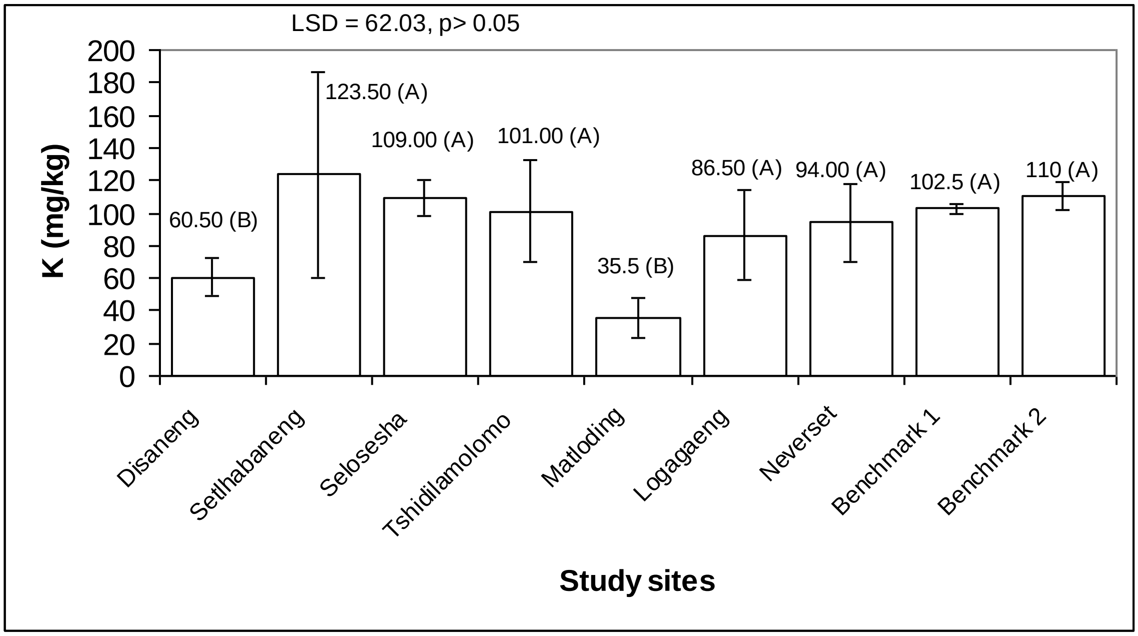

Figure 4.9 Mean K content of soil from study and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

Potassium in soil does not exist in organic form and is second to nitrogen in terms of quantity needed by crops (Archer, 1985). The main role of ionic potassium in the plant is to regulate the cell water content (Table 4.2). Also maintaining cell turgor and maximum rates of cell expansion depends on cell potassium levels (Archer, 1985).

Potassium is unique from the other major soil cations in being preferentially held by some clay minerals (Archer, 1985). This way which potassium chemically reacts is in contrast to sodium, which is weakly adsorbed and is readily leached (Archer, 1985). The chemical reactivity of potassium of being preferentially held by some clay minerals in the soil is strongly influenced by soil texture, specifically clay content and mineralogy (Archer, 1985). The soil texture of the study sites soils were similar (Table 4.3). This implies the overall insignificant ($p > 0.05$) differences in soil K was expected (Figure 4.9).

4.3.6.2 Calcium (Ca) of soils from study sites

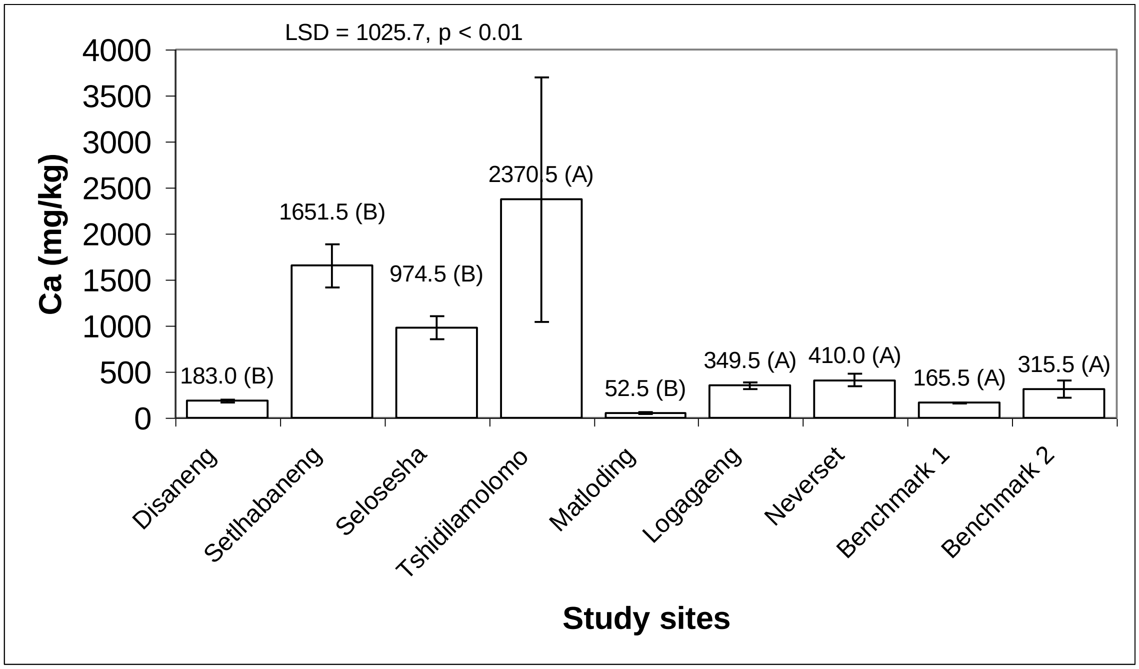

Figure 4.10 Mean Ca content of soil from study and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

High ($p < 0.01$) differences in soil Ca were recorded among some sites, and compared to the benchmark sites (Figure, 4.10). Selosesha and Setlhabaneng recorded significantly ($p < 0.05$) higher exchangeable soil Ca (974.5 mg/kg and 1651.5 mg/kg respectively, Figure 4.10) than the benchmark sites 165.5 mg/kg and 315.5 mg/kg (Figure 4.10), while Matloding scored a significantly ($p < 0.05$) lower soil Ca (52.5 mg/kg) than the benchmark sites (Figure 4.10). Logageng, Tshidilamolomo, Logageng and Neverset farm soil Ca had no significant ($p > 0.05$) differences with the benchmark sites (Figure, 4.10). It was expected that the exchangeable Ca in the study sites soils would be higher than the benchmark sites because of the presence of woody plants at high densities (See chapter 3) at these sites (Bernhard-Reversat, 1982; Vetaas, 1992; Isichei & Muoghalu, 1992; Belsky *et al*., 1993; Young, 1989; Belsky, 1992, Hagos & Smit, 2005). The Ca contents in soil in

Disaneng and Matloding contrasted the expectations with significantly lower soil than Benchmark 2 and Disaneng having a slightly higher soil Ca than that of Benchmark 1.

Calcium is a major nutrient required by all crops and is required mainly for cell elongation and cell division. Calcium deficiency shows in the youngest plant tissue resulting in stunting of stems and a lack of leaf expansion. In practice, the lack of mobility of calcium in the plant produces far more crop problems than absolute deficiency (Archer, 1985).

4.3.6.3 Magnesium (Mg) of soils from study sites

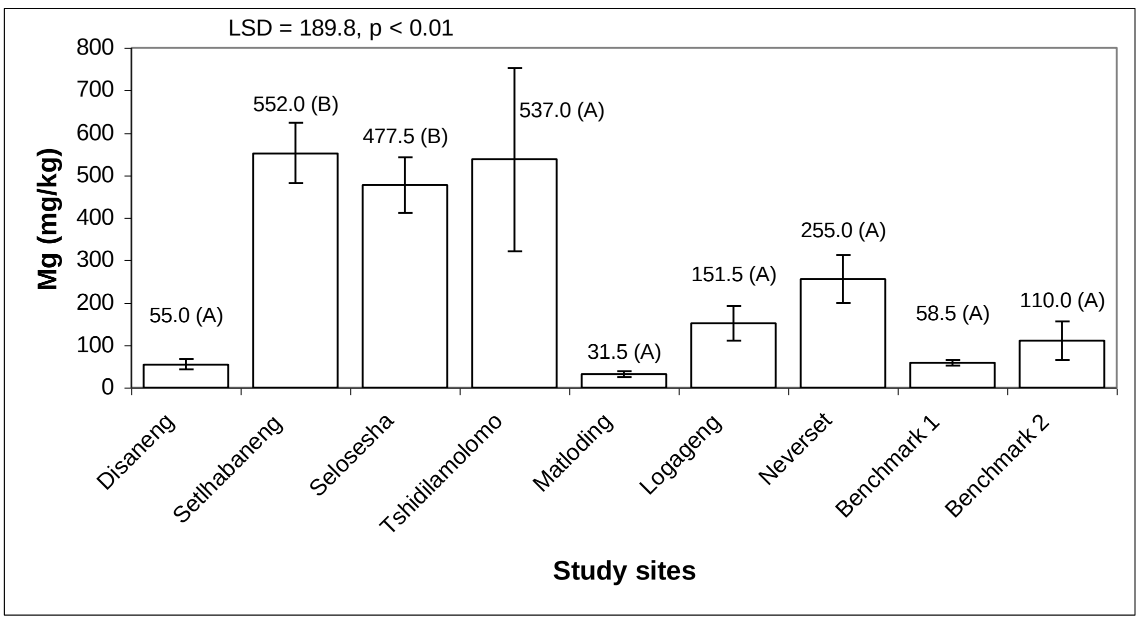

Figure 4.11 Mean Mg content of soil from study and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

Only soils from Setlhabaneng and Selosesha had significantly higher Mg than those of the benchmark sites (Figure 4.11). The soils from all the other sites had higher or lower Mg than the benchmark sites but not statistically significant (Figure 4.11). Hagos & Smit

(2005) found higher soil Mg although statistically not significant, under tree canopies compared to non-encroached areas.

Magnesium is important as a constituent for chlorophyll and enzyme activator (Table 4.2), and therefore in the process of photosynthesis.

4.3.6.4 Sodium (Na) of soils from study sites

The differences in soil Na at the study sites and benchmark sites were not significant ($p > 0.05$) (Figure, 4.12). The soil Na was higher in Disaneng, Setlhabaneng, Logageng and Neverset Farm, while it was lower in Selosesha and Tshidilamolomo compared to the benchmark sites (Figure 4.12). Na, although not essential for plants (Archer, 1995), is normally higher in the vicinity of woody plants (Isichei & Muoghalu, 1992; Belsky *et al*., 1993; Young, 1989; Belsky, 1992, Hagos & Smit, 2005).

Sodium cation (Na^+) does not exist in organic form and is not an essential element for plants, but is a major nutrient in animal nutrition (Archer, 1985). Sodium is not essential for forage crops but crops such as beetroot show yield responses to the application of sodium fertiliser (Archer, 1985).

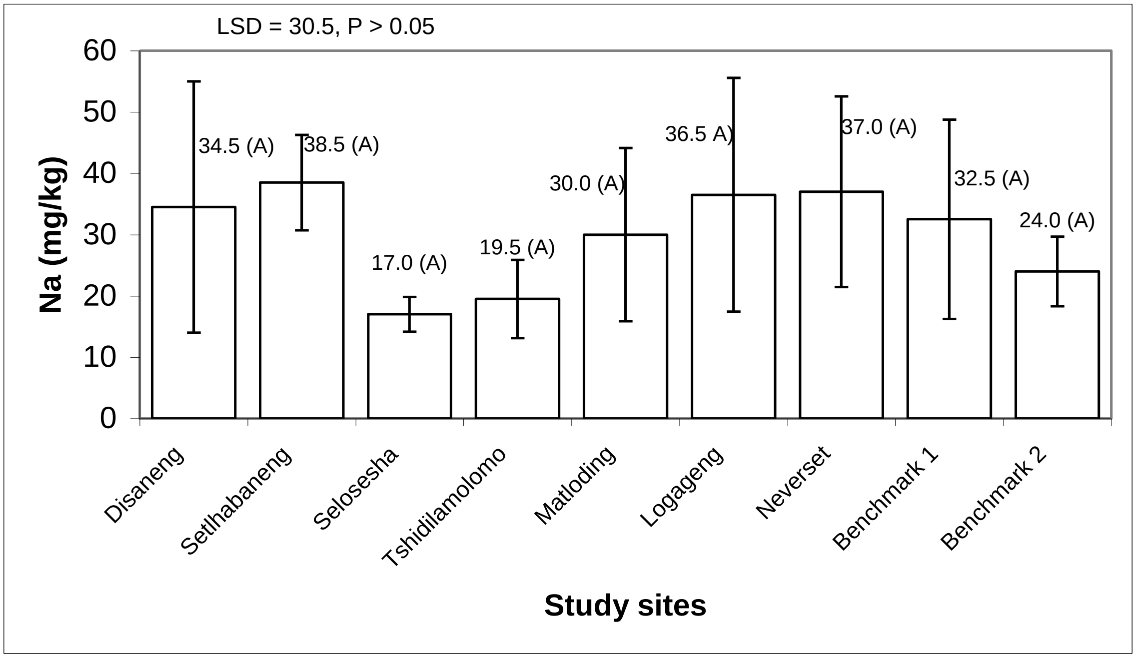

Figure 4.12 Mean Na content of soil from study and benchmark sites (A indicates statistically not significant ($p > 0.05$) differences and B indicates statistically significant ($p < 0.05$) differences).

4.3.7 Electrical conductivity of soils from the study sites

There were no significant ($p > 0.05$) differences in soil electrical conductivity in all the study sites besides in Tshidilamolomo which recorded significant ($p < 0.05$) differences with the benchmark sites. Soil EC in Tshidilamolomo is significantly higher than the benchmark sites (Figure 4.13).

Soil EC with field verification has been related to specific properties that affect crop yield, such as topsoil depth, pH, salt concentrations (salinity), water holding capacity and cation exchange capacity (Doerge *et al*., 2004). This does not necessarily imply that there is higher soil cation exchange, salinity and temperature in Tshidilamolomo than benchmark sites (Figures, 4.13 & 4.14). Soil EC has been correlated with the CEC where a higher EC has been found to demonstrate a higher CEC (Moore & Walcott, 2001). This was not clearly demonstrated in the study where only Tshidilamolomo had a significantly higher soil EC (Figure 4.13). Soil EC has also been closely correlated with soil texture (Hartsock *et al*., 2002). Clay impacts EC because of the exchange cations and water films associated with it. Soils with high clay content have numerous, small water-filled pores that are continuous and usually conduct electricity better than sandier (Table 4.3) soils (Doerge *et al.*, 2002). Conduction of electricity in soils takes place through the moisture-filled pores that occur between individual soils particles. Therefore, the EC of the soil is affected by the following soil properties (Doerge *et al.*, 2004):

- **Pore continuity**- Soils with water-filled pore spaces that are connected directly with neighbouring soil pores tends to conduct electricity more readily (Doerge *et al.*, 2004). Soils with high clay content have numerous, small water filled pores that are quite continuous and usually conduct electricity better than sandier soils similar to the study sites (Table 4.3). This sandy texture of the soil in study sites (Table 4.2) could account for the generally low soil EC pattern of the study sites. It is not significantly different from one another except for Tshidilamolomo (Figure 4.11). Compaction will normally increase soil EC (Doerge *et al.*, 2004) which implies that the soils from Setlhabaneng, Selosesha and Neverset farm were highly compacted (Figure 4.12).
- **Water content** – Dry soils have a lower EC than moist soils (Doerge *et al.*, 2004). This could explain the significantly high soil EC (Figure 4.10) of Tshidilamolomo site which is located in a reparian region.
- **Salinity Level** - Increasing concentration of electrolyte (salts) in soil water will dramatically increase soil EC (Doerge *et al.*, 2004).
- **Cation exchange capacity**- Mineral soils containing high levels of O.M. (humus) and/ or 2: I clay minerals such as montmorillonite , Illite or vermiculite have a much higher ability to retain positively charged ions e.g Calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), or hydrogen (H^+), than soils that lack these constituents. The presence of these ions in the moisture filled pores will enhance soil EC the same way salinity does (Doerge *et al.*, 2004). It was expected that soils from Setlhabaneng, Selosesha and Neverset would have a higher EC (Figure 4.13) since they had significantly

higher CEC (Figure 4.12) than the benchmark sites. Instead, only soil from Tshidilamolomo had a significantly higher soil EC (Figure 4.13).

- **Depth**- the signal strength of EC measurements decreases with soil depth (Doerge *et al.*, 2004). Therefore, subsurface features will not be expressed as intensely by EC mapping as if it were located nearer to the soil surface.
- **Temperature**- As temperature decreases toward the freezing point of water, soil EC decreases slightly. Below freezing, soil pores become increasingly insulated from each other and overall soil EC declines rapidly (Doerge *et al.*, 2004). The soils in the study area experience similar climate (Figure 2.2) so it was expected that these effects of temperature on soil EC would be evident.

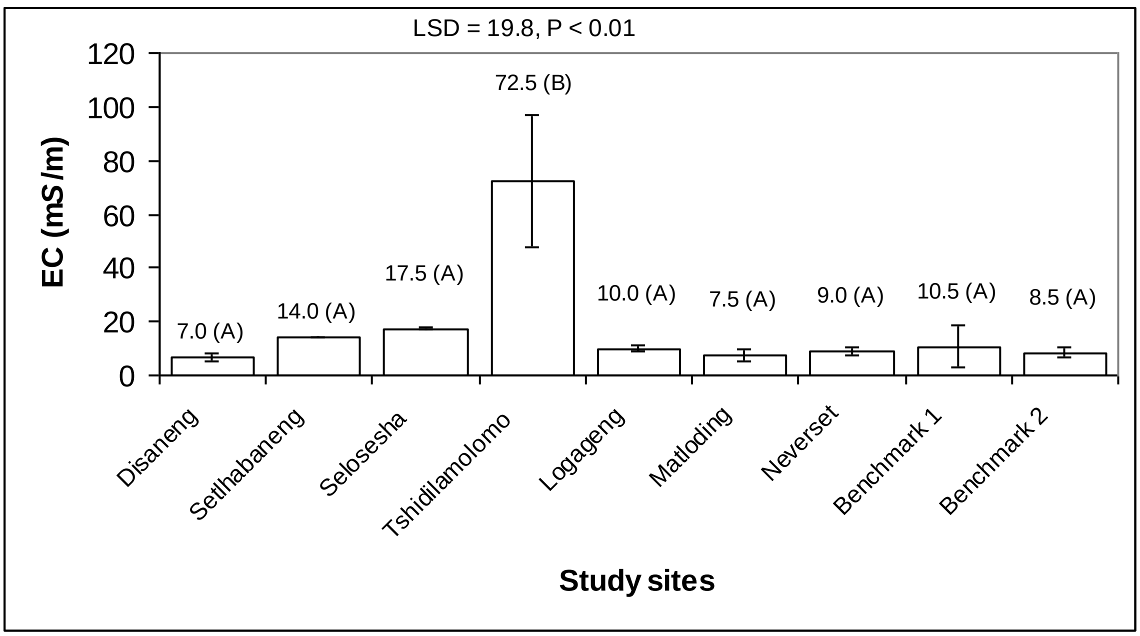

Figure 4.13 Mean electrical conductivity of soil in the study and benchmark sites

Soil conducts an electrical current, with some soils having good electrical conductivity while the majority has poor electrical conductivity (Anonymous, 2005). Moisture retention of soils was investigated in terms of soil electrical resistance in this study. Electrical conductivity is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of millisiemens per meter (mS/m) (Doerge *et al*., 2004). Soil electrical conductivity (EC) is a measurement that correlates to soil properties affecting crop productivity including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter (O.M.) level, salinity, subsoil characteristics depth to clay pans and exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Doerge *et al*., 2004).

Increased moisture retention capacity in soils around trees has also been documented (Kellman, 1979). Soil moisture varies with rainfall interception, soil infiltration, soil temperature, evaporative surface area, and relative humidity (Vetaas, 1992; Belsky & Canham, 1994), which is why differences in soil moisture between patches and their surrounding communities are less predictable than differences in light and temperature (Belsky & Canham, 1994). It is expected that surface soils below forest gaps are to be moister than soils of closed forests because less precipitation is intercepted by overhead canopies and less soil water is lost to evapotranspiration (Belsky & Canham, 1994). Instead, soils of tree-dominated patches in savannas have generally been reported to be moister than soils of adjacent communities (Joffre & Rambal, 1988).

4.3.8 Cation exchange capacity (CEC) and adsorption in study sites

The cation exchange capacities of Setlhabaneng, Selosesha and Neverset soils were significantly ($p < 0.05$) higher than those of benchmark sites (Figure 4.14). This implies that there was a high absorption of macronutrients (Ca, Mg, K & Na) that are not easily leached in this soils. There were no significant ($p > 0.05$) differences at other sites relative to the benchmark sites (Figure 4.14). Therefore, cation exchange activities of the soil at these sites should be similar. Campbell *et al*. (1994) found that the influence of trees on cation levels is greater in sandy soils than fine-textured soils. This is because the exchange capacity of fine-textured soils (e.g. clay) is determined mostly by soil texture whereas organic matter is the prime determinant of exchange capacity in sandy soil (Campbell *et al*., 1994). This applies in the study area which is sandy soils with little clay fraction (Table 4.3). The significantly high soil CEC of Setlhabaneng, Selosesha, and Neverset can thus be related to the high organic litter from the high woody plant densities at these sites (Chapter 3).

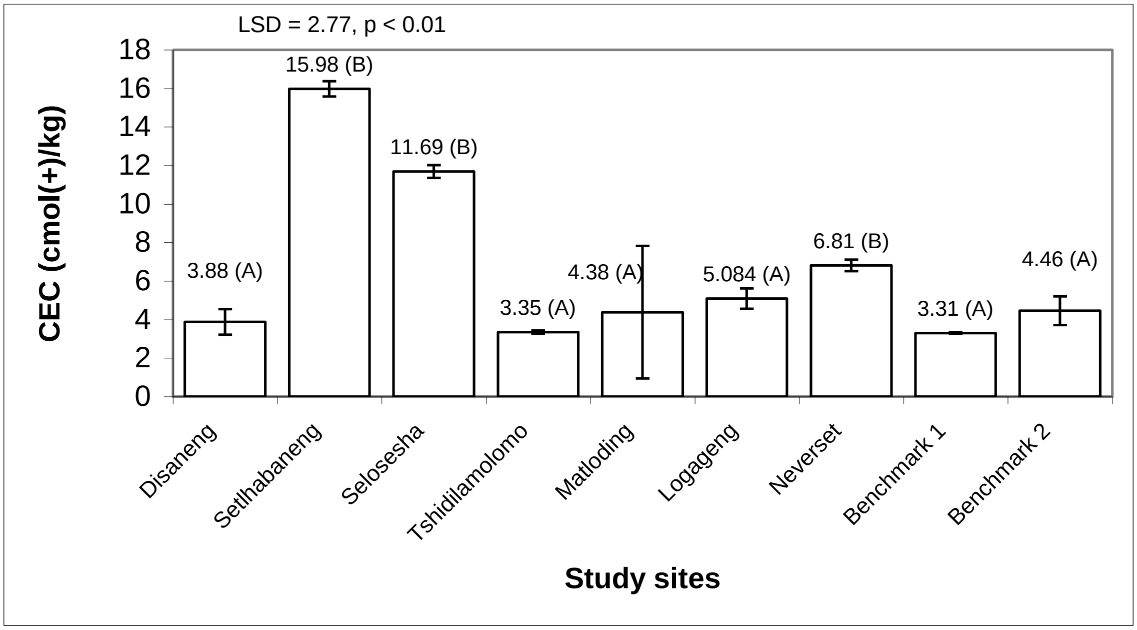

Figure 4.14 Mean cation exchange capacity of study and benchmark soils.

The cation exchange capacity (CEC) of soil is a measure of the total negative charge of a soil and gives a measure of its cation-retaining properties (Archer, 1985). Cation exchange capacity is the ability of the soil to hold onto nutrients and prevent them from leaching beyond the roots (Cooper & Regents, 2006). The higher the cation exchange capacity a soil has, the more likely the soil will have a higher fertility level and when combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity (Cooper & Regents, 2006).

Cations are positively charged ions that are bound electrically to colloids (negatively charged clay and humus). This bonding is called adsorption. Ca^{2+}, Mg^{2+} and K^{+} cations are plant foods and are alkaline. H^{+} ion is what causes the soil to be acid (Buys, 1974). This implies that Selosesha soils have a high nutrient source because it has these cations in abundance. The adsorbed cations are held to the colloids and this prevents them from being lost by leaching. They are however, not held so tightly that they cannot be removed. Adsorbed cations may be exchanged with cations in the soil solution (Buys, 1974).

Table 4.6 Typical cation exchange capacities of soil constituents and soil CEC (Buys, 1974; Archer, 1985).

Colloid	**Remarks**	**Cation exchange capacity (CEC) (cmol(+)/kg)**
(i) Clay minerals:		
Kaolinite	Does not swell when wet	Virtually none
Montmorillonite	Swells when wet; water between layers	80- 150
Illite	Does not swell when wet; K between layers	10- 40
(ii) Organic:		
Humus		50- 400
(iii) Sand		5
(iv) Light loam		10
(v) Medium loam		20
(vi) Clay		30

There are different types of colloids in the soils that have different cation exchange capacities (Buys, 1974) (Table 4.6). Clay colloids consist of differently grouped layers of aluminium hydroxide and silica together with elements like potassium, magnesium and iron. The cation exchange capacities of soils in the study area are consistent with expectations according to Table 4.6 since the soil types of this study are designated sand to loamy sand (Table 4.3).

Cation exchange takes place when plants feed through their roots by absorbing nutrients from the solution that is continually being replaced by exchange from the colloids. Excessive rain and irrigation may cause cations to leach out. A soil gradually becomes acid when the cations are leached and they are not replaced by dissolution of the rocks, fertilisation or manuring. H^+ cations from the water displace other cations and similarly become alkaline or saline when Na^+ replaces H^+ and the other cations. Cation adsorption and exchange is therefore closely associated with the storage and availability of plant nutrients, plant nutrition and with the soil conditions of acidity and salinity. In this way, cations and colloids play an important role in soil fertility (Buys, 1974).

4.3.9 Soil resistance

Selosesha, Setlhabaneng, Tshidilamolomo, Logageng and Neverset Farm have higher soil moisture values than the benchmark sites in terms of their soil resistances (Figure, 4.15). It could be attributed to lower temperatures and evapotranspiration rates in the shade (Joffre & Ramball, 1988; Belsky *et al.*, 1989, 1993). Electrical resistance increases with soil dryness or simply that high resistance indicates low water holding capacity (Miles, 1998). This implies that the soils at Setlhabaneng and Tshidilamolomo were moister than soils in the other study sites and benchmark sites (Figure 4.15).

Soil moisture values have been found to be higher and lower in some cases below tree and shrub crowns than in the open (Belsky & Amundson, 1992). Soil moisture values are often lower below crowns, due to the increased rainfall interceptions and higher total evapotranspiration by the increased surface area of below- crown plants (Belsky *et al.*, 1993). The Soil moisture patterns below tree crowns are normally heterogeneous, because of fluctuating light and shade regimes and because rainfall is funneled by stem flow to the ground, where it recharges soil water, primarily near stem (Mauchamp & Janeau, 1993).

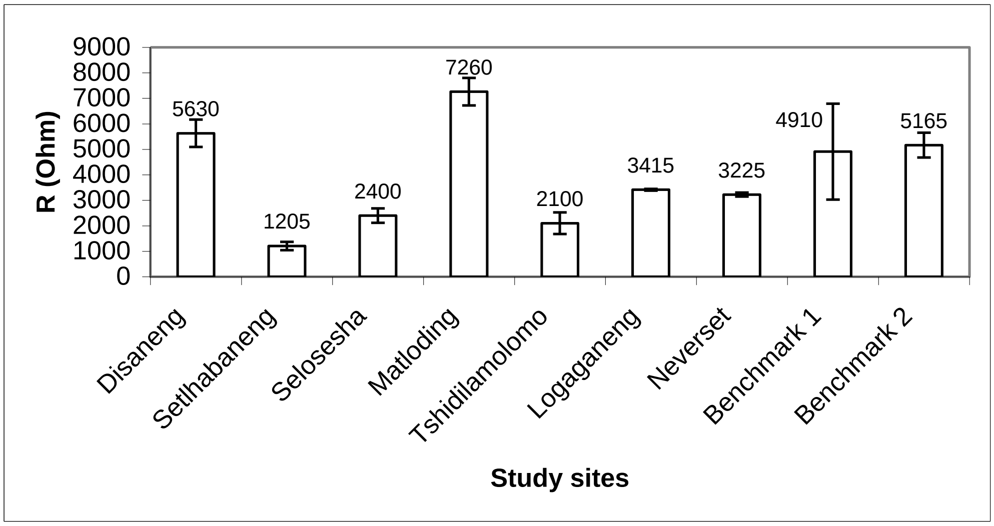

Figure 4.15 Soil resistances of study sites

Soil resistance varies widely throughout the world and changes dramatically within small areas (Anonymous, 2005) Soil resistivity is mainly influenced by the type of soil (clay, shale, etc.), moisture content, the amount of electrolytes (minerals and dissolved salts) and temperature (Anonymous, 2005). Measurement of electrical resistance is a good indication of the moisture content of the soil (Miles, 1998). It is essential for plants to have water for normal growth and it makes up a large percentage of the weight of the plant (Paxson, 2008).

4.4 Discussion & Conclusion

4.4.1 Discussion

Trees and shrubs in arid and semi-arid regions affect the spatial distribution cycling of nutrients by altering soil structure, microbial biomass, soil moisture, and microclimate by concentrating organic matter beneath their canopies (Kellman, 1979; Belsky *et al*., 1989, 1993; Hibbard *et al* 1999; Wiegand *et al.*, 2005). Soils under tree and shrub crowns commonly have higher contents of Ca, Mg, Na and K than soils in open spaces (interspaces) between individual crowns (Kellman, 1979, Bernhard-Reversat, 1982; Belsky *et al.*, 1989, 1993; Young, 1989; Isichei & Muoghalu, 1992; Belsky, 1992, 1994; Vetaas, 1992, Schlesinger; & Pilmanis, 1998; Liao *et al.*, 2006). Nutrient enrichment of the soils holds true for grasses as well as for shrubs and trees (Schlesinger *et al.*, 1996) but varies with species (Barth & Klemmedson, 1982, Smit *et al.*, 1999, Belsky *et al.*, 1989).

Nutrient retention of exchangeable cations (Ca, Mg, Na and K) has been found to differ in different types of savannas due to contrasts in soil properties which determine adsorption by cation exchange complexes (Kellman, 1985).

Higher plants need in addition to carbon, hydrogen and oxygen taken up from air and water, an adequate supply of the nutrients listed in Table 4.2 to grow and reproduce (Archer, 1985; Foth, 1984). Some plants take up non-essential nutrients such as sodium (Foth, 1984; Archer, 1985) which was measured in this study (Figure 4.12). A wide range of nutrients will be taken up by plants if found in the soil in which the plant is growing (Archer, 1985). Where crop is used for animal feed, particularly grass, the uptake of additional nutrients as indicated by Table 4.2 may be very important for animal production (Archer, 1985). Soil exchangeable Ca, Mg, Na and K were measured at the study sites.

Campbell *et al*. (1994) found that the influence of trees on cation levels is greater in sandy soils than fine-textured soils. This is because the exchange capacity of fine-textured soils (e.g. clay) is determined mostly by soil texture whereas organic matter is the prime determinant of exchange capacity in sandy soil (Campbell *et al.*, 1994).

4.4.2 Conclusion

No scientifically substantiated norms exist for the fertilization of all species of pasture grasses and species are therefore grouped according to expected or observed reactions (FSSA, 1989).

Soils of the study area have a high sand fraction and hence high infiltration rates, nutrient leaching and low soil water retention capacity.

It is clear from the data that the nutrient status of soils of encroached areas was higher than the benchmark sites although some of the differences were statistically insignificant. Soil Ca and Mg, was particularly enriched in Selosesha and Setlhabaneng (Figure 4.10 & 4.11). There were no statistically significant K and Na enrichment in the soils of the study sites although it was higher than at the benchmark sites (Figure 4.9 & 4.12). Soil phosphorus was generally highest at the encroached sites but only Tshidilamolomo soil had the significantly highest soil P (Figure 4.5). Organic carbon was higher at most of the encroached sites (71 % of the sites) where 80 % of the enriched sites had significantly higher organic carbon than that of the benchmark sites (Figure 4.7). % Total N did not demonstrate significant differences except Setlhabaneng which was significantly much higher than all the sites (Figure 4.8). It has been proven that woody plants enrich nutrients in soils under their canopies. It was then concluded that the higher nutrient content of the soils in the study area was facilitated by woody plants similar to other studies.

There were not many significant differences in the soil chemical properties except for the EC of Tshidilamolomo and the CEC of Setlhabaneng, Selosesha and Neverset farm which were significantly higher (Figure 4.13 & 4.14). The high soil CEC Tshidilamolomo and Setlhabaneng (Figure 4.14) could explain the high macronutrients content of the soils at those sites.

Soil moisture, texture and nutrients have been cited as the key environmental factors that regulate the productivity and structure of savanna vegetation (Scholes & Walker, 1993). Woody plant invasion affects soil moisture because in a natural system that is not overgrazed (Chapter 3), grass is able to extract water from the upper layers of the soil before it reaches the deeper penetrating tree roots. Woody plant encroachment thus reduces the soil's water moisture and inhibits grass growth.

Overgrazing results in soil erosion and loss of basal and canopy cover of the grassland community which is important in the dissipation of much of the energy of the falling raindrop. This energy would pulverize the soil with direct raindrop impact and results in splash erosion. The rate of soil loss increase as the veld's vegetation cover declines.

It is essential to manage this natural resource sustainably. Soil conservation programmes should be implemented particularly in the communal areas which have been affected by past political and socioeconomic factors. It is important that vegetation should be restored through selective thinning (Smit, 2004) in the affected areas to reduce soil erosion, and prevent the depletion of soil nutrients.

Chapter 5: Social surveys

5.1 Introduction

Pastoralists or communal farmers are people who derive most of their income or sustenance from keeping domestic livestock in conditions where most of the feed that their livestock eat is natural forage rather than cultivated fodder and pastures (Sanford, 1983). Nomads are normally included in the definition of pastoralists. In most cases pastoralists devote the bulk of their own and their families working time and energy to looking after their livestock than to other economic activities. Arid areas environments of Africa (including South Africa) are important economically as supporting the livelihoods of many people although often marginalized from mainstream economic and political life (Scoones, 1995). Pastoralists and the way in which they are forced to overgraze the rangelands is a distinct and separate component in Africa's growing environmental bankruptcy (Timberlake, 1985).

Communal farmers keep livestock for many reasons (e.g. milk, draught, meat, insurance, social standing, etc.) apart from income generation (Coetzee, 1986; Katjiua & Ward, 2007). Farming enterprises range from livestock owners with few stocks for subsistence and cultural purposes to commercially orientated farmers with cattle, sheep and goat holdings (Bembridge & Tapson, 1993).

South Africa has large areas of rangeland (veld) that are not privately owned but used communally by farmers for grazing domestic livestock and harvesting natural products such as fuelwood. Most of these communal areas are located in the former black homelands (e.g. Ciskei, KwaZulu, Transkei, Bophuthatswana and Venda). The Molopo District is located within the former Bophuthatswana (Figure 2.1, Chapter 2**).** The creation of these black homelands has had significant implications on land degradation in South Africa (Hoffman & Ashwell, 2001). These communal areas support approximately a quarter of South Africa's population and half of the national of the national livestock herd (De Bruyn & Scogings, 1998). Between 1950 and 1980, an estimated 1.4 million people were forced to leave white –owned farms and a further 90 000 were removed from urban areas (Hoffman & Ashwell, 2001). 94 % of these displaced people were resettled in black homelands. Homeland population growth increased from 4 million to 11 million between 1960 and 1980 (Hoffman & Ashwell, 2001). According to Hoffman & Ashwell (2001), these movements of people significantly affected the degree and rate of land degradation in these areas. The government intervened in very different ways in communal and commercial districts to combat land degradation. The government encouraged commercial farmers to participate in soil conservation by organising awareness programmes, providing extension services and subsidies and recommending self-organisation through the establishment of soil conservation committees. The law made provision for coercion but this was seldom resorted to (Hoffman & Ashwell, 2001).

34.9 % of people in the North West Province are urban dwellers, while most of the population (65.1 %) lives in the rural areas (North West Province Government, State of The Environment Report, 2002), where communal farming is practiced. This is in contrast to the national trend of 46.3 % and 53.7 % for rural and urban figures respectively. The rate of urbanization is increasing, largely due to the lack of employment opportunities in rural areas (North West Province Government, 2002). This implies that what happens in the communal areas of the province has a bearing on the majority of the population.

According to Hardin's (1968) "Tragedy of commons", the "commons" can only be justifiable if at all, under conditions of low-population density. This implies that privatization of land and natural resources is a way of ensuring that resources are not over-exploited. Overgrazing of communally managed rangelands in South Africa is an example of the results of land supporting large population densities in small areas (Hoffman & Ashwell, 2001). Communally managed areas, both in South Africa and globally, are generally perceived to be degraded and unproductive, contributing little to national economy, but such views are contested and the degradation debate continues unabated (Sanford, 1983; Belsky *et al*. 1989; Dahlberg, 1994; Critchley & Netshikovhela, 1998; Ward *et al*. 1998; Bezuidenhout, 2000; Ward, 2005).

The reduction or loss of the biological or economic productivity in arid, semi-arid and dry sub humid areas, resulting from land users or from a process or a combination of processes is termed land degradation (UNCCD, 1994). This loss of biological and economic productivity has a bearing on rural communities quality of life who depend mostly on the land for subsistence. Political and economic conditions, demographic patterns and land–use practices differ markedly in commercial and communal areas (Hoffman & Ashwell, 2001). The highly inequitable access to land in South Africa resulted in low population densities in white farming areas but very high population densities in communal areas. Official statistics suggested that between 1960 and 1980, the population of the rural reserves in South Africa increased from about 4,5 million to 11 million people. Many of these communal areas were situated in parts of the country where soil erosion and topography of the land resulted in land degradation (Hoffman & Ashwell, 2001). Small-scale resource-poor communal farmers are often obliged to pursue land-use practices that best meet their family's immediate needs for food, fuel, shelter and cash as well as to their social and cultural obligations to the community in which they live (Douglas, 1990).

According to Section 24 of the Bill of Rights in South Africa (White Paper on Environmental Management Policy for South Africa, 1998), everyone is guaranteed the right:

(a) to an environment that is not harmful to their health or well-being; and
(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –

- Prevent pollution and ecological degradation;
- Promote conservation; and
- Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Section 8 of the Bill of Rights (White Paper on Environmental Management Policy for South Africa, 1998) binds government to give effect to the environmental rights in section 24. In terms of section 24 people can take legal action to protect their environmental and other rights, even where government has no obligation in terms of any other statute to give effect to these rights. Section 24 also compels government to pass reasonable legislation to protect the environment, prevent pollution and ecological degradation (such as woody plant encroachment), promote conservation, secure sustainable development and to ensure compliance with this legislation. Section 7 (2) places government under a constitutional duty to respect, promote and fulfil this right. The government must, therefore formulate a clear policy on how it will give effect to this right in the exercise of environmental governance and ensure compliance with environmental legislation. The constitution furthermore places government under a legal duty to act as a responsible custodian of the nation's environment. The Government has formulated the principles, vision, strategic goals and governance approach set out in the White Paper on Environmental Management Policy for South Africa (1998) with this constitutional imperative uppermost in mind.

According to the White Paper on Environmental Management (1998), the government views sustainable development as a national priority and its goal is to lay the foundations for sustainable development based on integrated and holistic environmental management practices and processes over the five years since its inception. The government then committed itself to:

- ✓ Use government resources in the most effective way to implement policy, integrate and coordinate its approach to environmental management across departments and all state organs in all spheres of government;
- ✓ Introduces an integrated and coordinated management regime that addresses the total environment and all human activities impacting on it;
- ✓ Ensure that all aspects of environmental governance including norms, standards, legislation, administration and enforcement are dealt with uniformly across departments and in all spheres of government.

Central to these approaches by government is the recognition of its role as legal custodian of the environment within the borders of South Africa. As legal custodian, it is expected to ensure that the environment is not harmful to human health or well-being for the benefit of present and future generations. The government has a duty to manage the environment, and particularly human impacts upon it, in a sustainable way for the public good and benefit, while protecting the nation's environmental heritage. With the fragmentation of environmental functions throughout government institutions, government is obliged to take reasonable measures to guide, supervise, arbitrate intergovernmental conflicts, and monitor all organs of state in all spheres to achieve integrated and holistic environmental management.

Government appointed the national Department of Environmental Affairs and Tourism as the leading agent responsible for ensuring the integrated and coordinated implementation of its policy on environmental management to overcome this fragmentation. The Department of Environmental Affairs and Tourism accepted the responsibility of ensuring that appropriate and necessary measures are taken to:

- Ensure that people's environmental rights are enforced;
- Ensure that government fulfils its obligation to act as the custodian of the environment;
- Promote, coordinate and enhance sustainable development within all government agencies at national, provincial and local levels;
- Develop, and coordinate the implementation of, an integrated and holistic environmental management system.

According to Section 2 of National Environmental Management Act 107 of 1998 (NEMA) (White Paper on Environmental Management Policy for South Africa, 1998), it should be accepted that with the right to own, manage, and use natural resources comes the duty to prevent environmental harm and to protect the rights of people. Which in this case are activities that lead to land degradation such as overgrazing. Earth's ecological systems integrity must be protected and restored with special concern for biological diversity and the natural processes that sustain life.

Poverty affects 62 % of the North West Province's population which is the second highest provincial figure for South Africa (Department of Agriculture, Conservation, Environment & Tourism, DACET, 2002). The Province’s unemployment rate of 37.7 % is the fourth highest in South Africa. The (commercial) farming sector provides opportunities for employment for the rural communities, but the income derived from this sector is very low. There is also little upward mobility in this sector due to the education levels attracted to the employment. Linkages are found in relation to food security and unemployment. The higher the level of unemployment, the more food insecure the population becomes. That has a spiraling effect on other social elements such as health and crime (DACET, 2002).

The status of many settlements is currently not in harmony with the concept of sustainable development. Sustainable development was then defined as development which meets the needs of the present, without compromising the ability of future generations to meet their own needs (the Brundtland Report, UN General Assembly document A/42/427, 1987). The definition contained two key concepts which are:

- The concept of needs, in particular the essential needs of the world’s poor, to which overriding priority should be given; and
- Idea of limitations imposed by the state of technology and social organization on the environment’s abiIity to meet present and future needs.

In South Africa’s macro-economic and fiscal policy, the term “sustainable development” however is used in relation to the growth potential of the economy and to keep within the carrying capacity of the environment. Sustainable development in South Africa requires that special attention be given to addressing the needs of previously disadvantaged communities. The focus is on ensuring that environmental sustainability**,** health and safety are not compromised, and that natural and cultural resources are not endangered.

Sustainable development must ensure that the direction of investments, the orientation of technological developments and institutional mechanisms work together towards the goal of the sustainable use of environmental resources in a way and at a rate that will meet present and future needs (White Paper on Environmental Management, 1998). Negative impacts of sustainable development include:

- Degradation of natural resources such as soils, vegetation and water resources; large amounts of accumulated and unprocessed domestic waste;
- Crime and unemployment;
- Stress on the health and social welfare system; and
- Poor roads and infrastructure (Department of Agriculture, Conservation, Environment & Tourism, DACET, 2002).

Social survey studies were conducted at the villages in the study sites by interviewing community members using a questionnaire (Appendix 2). The aim of the survey was to understand and link the communal management practices and perceptions with bush encroachment. This questionnaire (Appendix 2) was constructed to gather as much information as possible about the community in terms of five categories/ sections of organization or issues. 33 Questionnaires were distributed in the communities of Disaneng (11), Setlhabaneng (10), Selosesha (5) and Tshidilamolomo (7) (Figure 2.1, Chapter 2). The questionnaire (Appendix 2) was also translated into Setswana to enable those people who do not understand English to participate.

5.2 Materials and methods

Materials

A structured questionnaire (Appendix, 2) with mostly open ended questions was used to interview members from the communities. The five categories of questions (Appendix 2) in the survey were used at the study sites which were:

(i) Personal information;
(ii) Infrastructural information;
(iii) Financial information;
(iv) Agricultural information; and
(v) Environment.

Demographics, social factors such as health, education, employment and welfare aspects were analysed. MS Powerpoint presentations were also used at Disaneng to inform the community about "bush encroachment" and its effects on the environment. This presentation was also done to investigate the communities' perceptions regarding the issue. The people were allowed to ask questions after the meeting.

5.2.1 Personal information

Respondents were asked different questions including their sex, age, education level, marital status, age of spouse, age and number of children as well as the contribution of each member to the household income (Appendix 2).

84 % of the respondents interviewed were above the age of 50 and had been living in the area all of their lives. A few of the migrant workers said that they came back to retire. The most prominent age group in all the villages was the youth that were in the 0-18 years age group (Figure 5.1). There were more women than men in all the age groups at all the villages in the study area except those within the 0-18 age group at Logageng (Figure 5.1). This was consistent with national and provincial figures (Department of Agriculture, Conservation, Environment & Tourism, DACET, (2002). There was a larger proportion of females (average of 51.9 %) compared to males and 50.8 % of the people in the North West Province (DACET, 2002). This is similar to the situation in the study area where the women made up 49.8 % of the population and the males made up 50.2 % (Figure 5.1).

In ‘typical’ African culture, males do most field and farm work, while the females have to perform the domestic chores. These social responsibility roles are sometimes reversed when the men are sick, disabled or unable to perform these chores. An elderly woman stated that her husband is too old and sickly to work in the fields. Fields of people in such situations are sometimes abandoned, neglected and left uncultivated.

The literacy rate of approximately 70 % of the people in the North West Province according to the Development Bank of South Africa (1998) is well below the national average of 82.8 % (DACET, 2002). This is ascribed to the elderly and women living in the rural areas of the North West Province.

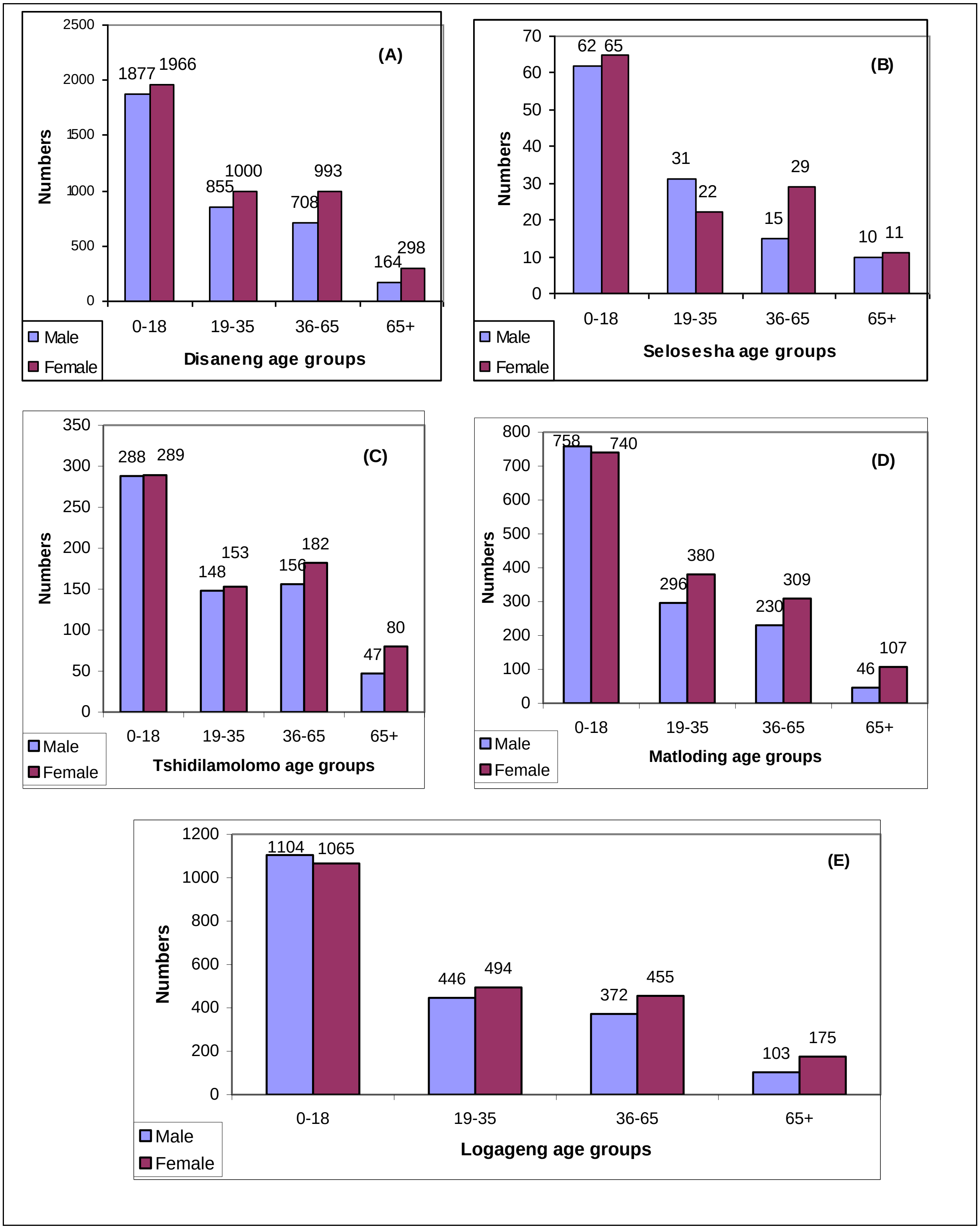

Figure 5.1 Age group distributions at study sites.

The population in the different villages are disadvantaged as far as far as schools are concerned (Table 5.1). Figures 5.1 to 5.6 highlight the high illiteracy levels in all the villages. 30 % of the population in the communities has no form of education whereas those with incomplete primary education contributed from 28 % to 41 % of the communities (Figures 5.2 to 5.6). Disaneng Village had the highest number of matriculants at 7 % (Figure 5.2). People with a tertiary education contribute to only 1 % in all the communities (Figures 5.2-5.6). This implies that less than 2 % of the people in these communities had professional qualifications. It also indicates that it is ‘unlikely’ that the community members are able to make informed decisions about environmental management, farming practices or write viable business plans.

It was established that most dependents in the households did not contribute any form of income to their families.

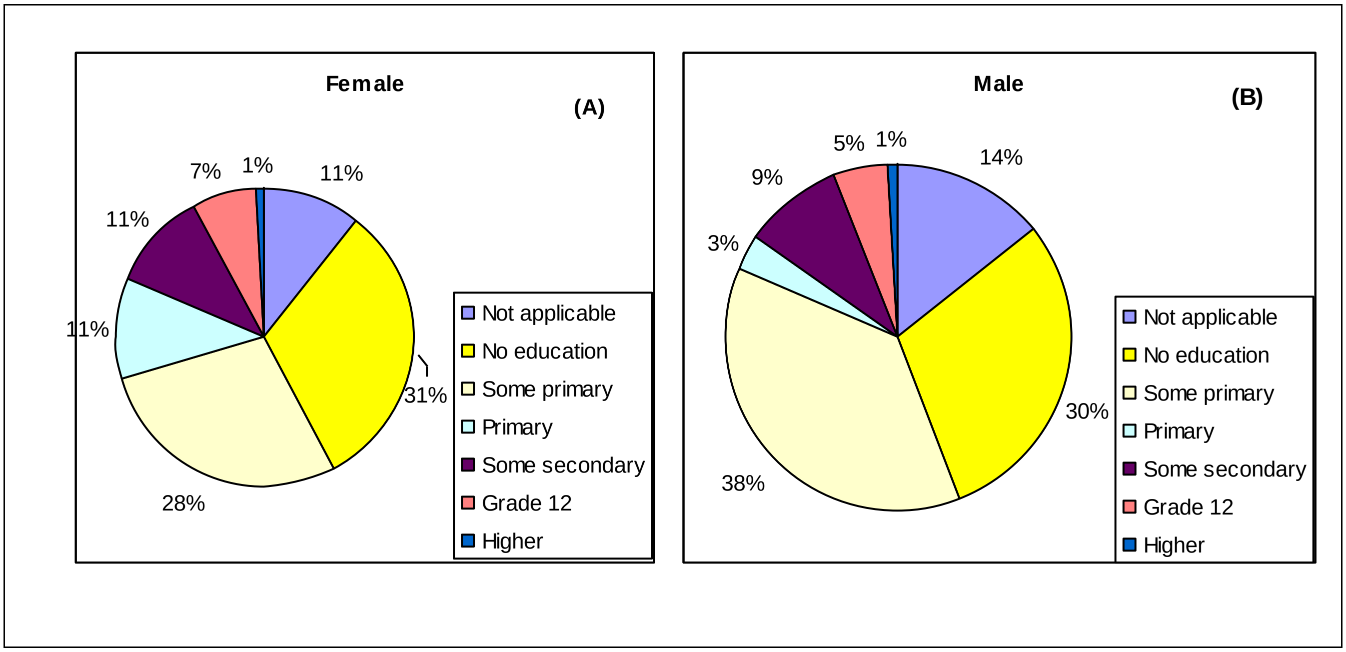

Figure 5.2 Education levels of Disaneng Village residents (Statistics South Africa, 2001).

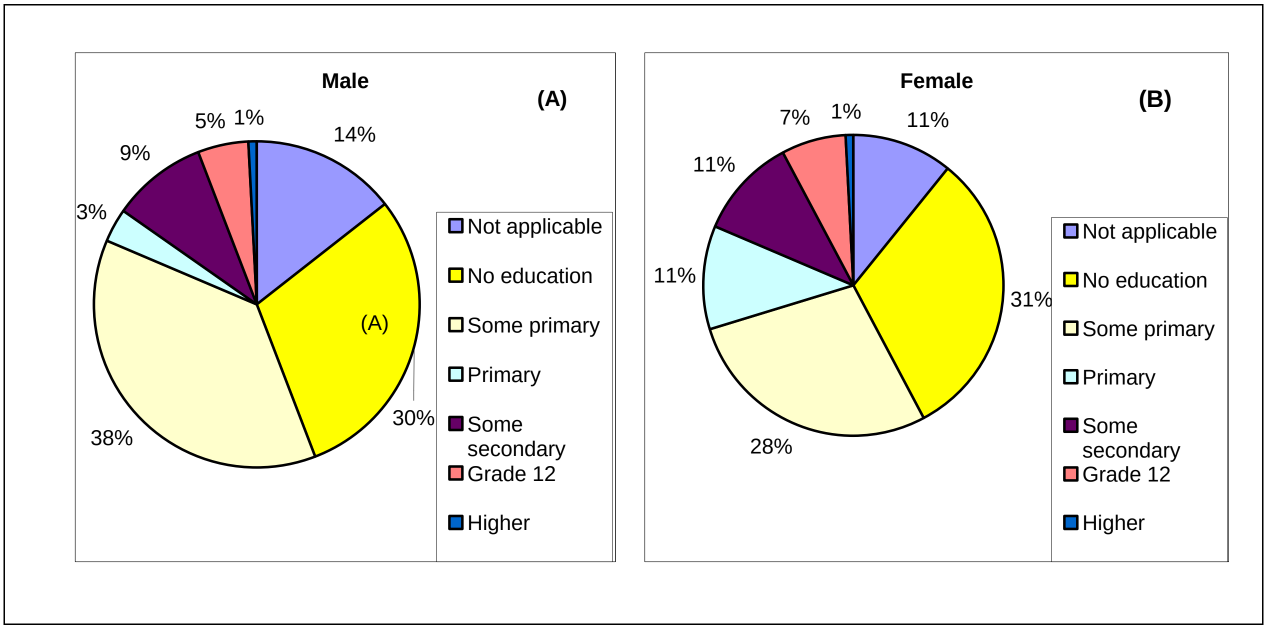

Figure 5.3 Education levels of Selosesha Village residents (Statistics South Africa, 2001).

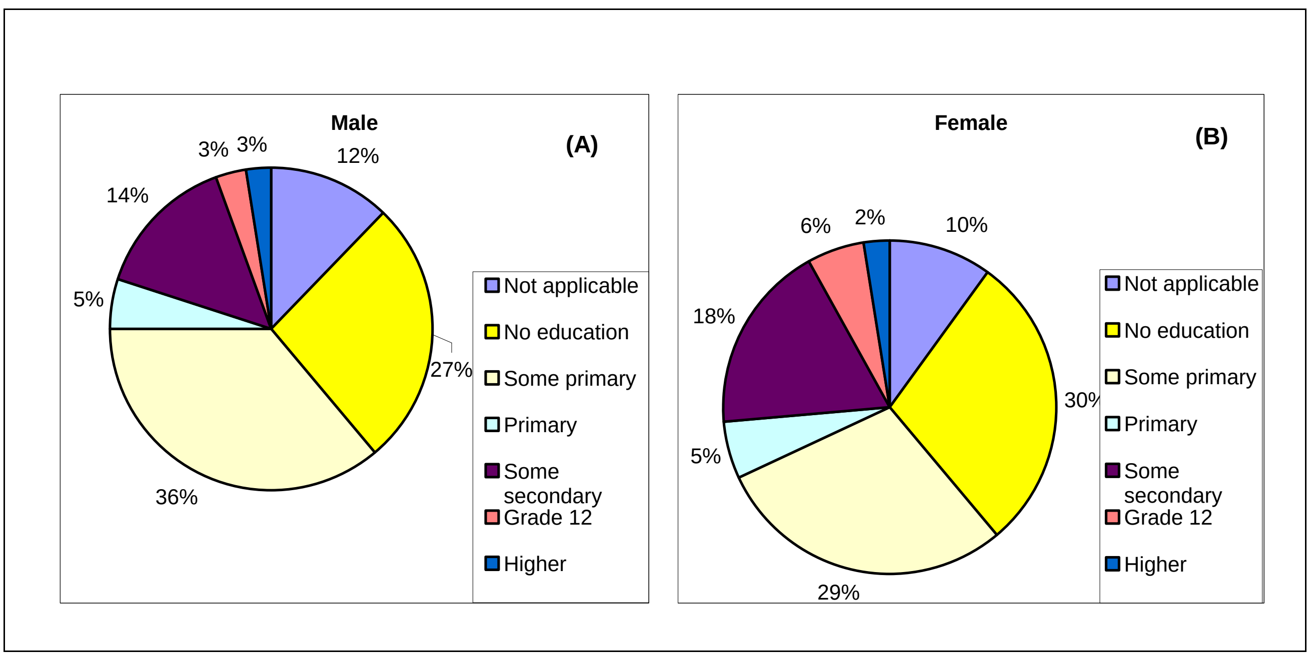

Figure 5.4 Education levels of Tshidilamolomo Village residents (Statistics South Africa, 2001).

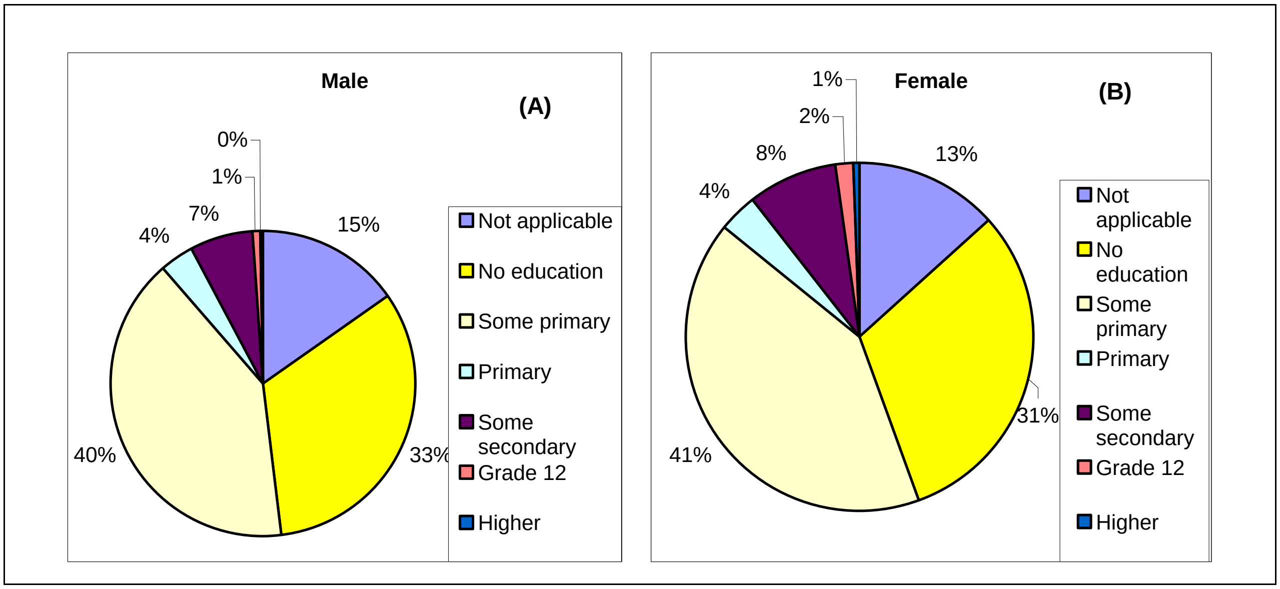

Figure 5.5 Education levels of Matloding Village residents (Statistics South Africa, 2001).

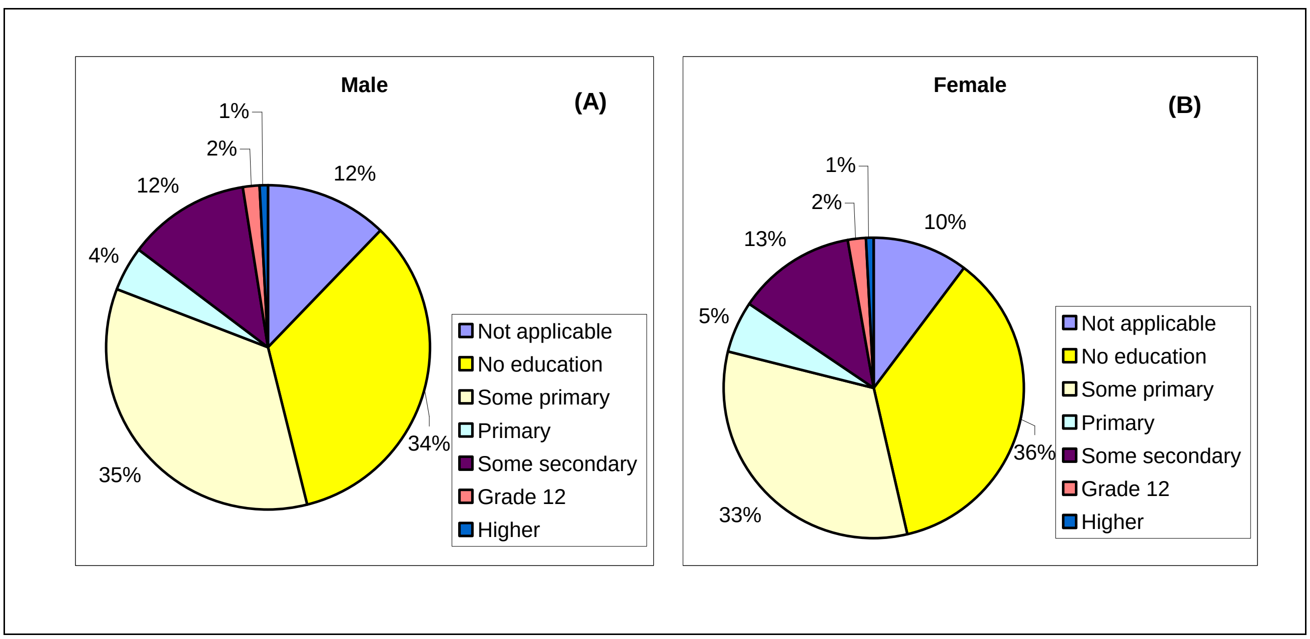

Figure 5.6 Education levels of Logageng Village residents (Statistics South Africa, 2001).

5.2.2 (Section 2) Infrastructural information

This section (Appendix 2) was designed to investigate matters relating to the communities social infrastructure that includes, transport, water, education and health issues.

5.2.2.1 Transport in the study area

Transport facilities included private and public transport in the form of busses, cars and use of donkeys. Donkeys were the most common form of transportation locally used by more than 65 % of the respondents in all the villages. There seems to be adequate transport to meet the needs of the communities in all the villages. Public transport services like busses to Mafikeng, can only be accessed at certain regular times known by the community. Taxis have an irregular random time schedule and normally move only when all the seats are occupied. This can be often frustrating for the commuters that sometimes arrive late at their destination because of this.

5.2.2.2 Water and store access in the study area

Water at all the different villages was available for free at public taps or from public boreholes. It was expected that more taps would be placed at certain villages in the future by the government but the proposed payment methods were uncertain. Water use included domestic and agricultural uses.

Some respondents in the villages indicated that they had vegetable gardens, but most were not in use because of various reasons that varied from old age, lack of manpower, fences, equipments and non-sustainability**.** They mostly bought their vegetables from Mafikeng if they were not available at the local cafes or tuck-shops.

5.2.2.3 Schools in the study area

Access to educational facilities or opportunities varied across all provinces in South Africa according to the DACET (2002). Data from DACET (2002) suggest that the North West Province compares favorably to the rest of South Africa. Although the proportion of the population 20 years and older that attended school in the lower or primary education levels are higher than the national average it, lagged behind the national average at the secondary and tertiary levels. Availability of schools in the study area is shown in Table 5.1.

There was a local primary school serving up to grade 8 in Selosesha where the community has access to water. The respondents in Selosesha acknowledged that there were good teachers at their school. They complained about the old school building which was built in 1976 and 'falling apart' due to lack of maintenance. There is one primary school in all the villages except for Disaneng which has 3 primary schools (Table 5.1). It is because Disaneng was the most populated community in the study area with a total population of 7 861 (Figure 5.1). Logageng is the second most populated village with 4 213 (Figure 5.1) residents and has two primary schools (Table 5.1). Middle and high school students from the villages who lacked these facilities (Table 5.1) and often had to walk long distances daily to go to the nearest village with such facilities.

Table 5.1 Schools in the study area

Villages	**Primary schools**	**Middle schools**	**High schools**
Disaneng/ Setlhabaneng	3	1	2
Selosesha	1	0	0
Tshidilamolomo	1	0	1
Matloding	1	0	0
Logageng	2	1	1

5.2.2.4 Health facilities in the study area

Access to health facilities available for people in Selosesha is at a clinic at a nearby village that is 2 to 3 hours walk away. All the other villages have a clinic within their boundaries.

5.2.3 Financial information

It was established that most families in all the villages were depended on pension grants and child support grants from the elderly who were in the minority (Figure 5.1). They have to support residents from the other age intervals financially (Figures 5.5 & 5.6). Social security grants for the North West Province have increased from R 158 million in 1994 to R 203 million in 1999, representing a 25.5 % increase over the 5-year period (DACET, 2002). Approximately 75 % of the total expenditure of the South African National Government is dedicated to old age grants (DACET (2002). Welfare facilities are inequitably distributed in the North West Province. Based on the United Nations Human Development Index (DACET, 2002), the North West Province is the third lowest of South Africa's provinces in terms of quality of life. Rural women and youth are the main vulnerable social groups that require economic support (DACET, 2002).

According to DACET (2002), the North West Province is characterised by high unemployment rates and inequality in terms of access to resources and poverty. When this study was conducted, 60.7 % of the population of the North West Province is regarded as economically active. However, it only has a potential labor force of 1.2 million people, of which 62.3 % are employed. The mining industry is the largest sector of the economy, which employs 39 % of the employed in the North West Province (DACET, 2002). Most people in the North West Province follow an "elementary" occupation, employing 27.7 %, which are jobs characterised by "low skills" compared to "scarce skills" (DACET, 2002).

More than 80 % of the respondents were unemployed at all the villages (Figures 5.7-5.11). The majority of the respondents earned between R 400 and R 800 monthly (Figures 5.6-5.11) which clearly indicates the level of poverty. The third largest majority (9 %) was people who were earning less than R 400 (Figures 5.7 to 5.11). Unemployed mothers who receive government child support grants contributed mostly to this group. The child support grant in South Africa replaced the state maintenance grant in 1998 and was implemented to reduce the burden on women who are responsible for taking care of children up to the age of seven (DACET, 2002).

It was established that the majority of the farmers were not full-time subsistence farmers. The alternative source of income was from the spouses or housewives who were not old enough to receive a government old age pension grant.

Saving money was not possible in a community where there was hardly enough funds to meet the monthly household demands. Money is used for household needs such as food and "running" of the home. Members of the Selsesha community were sometimes allowed to buy goods on credit where permissible at the local tuck shops and pay at month end.

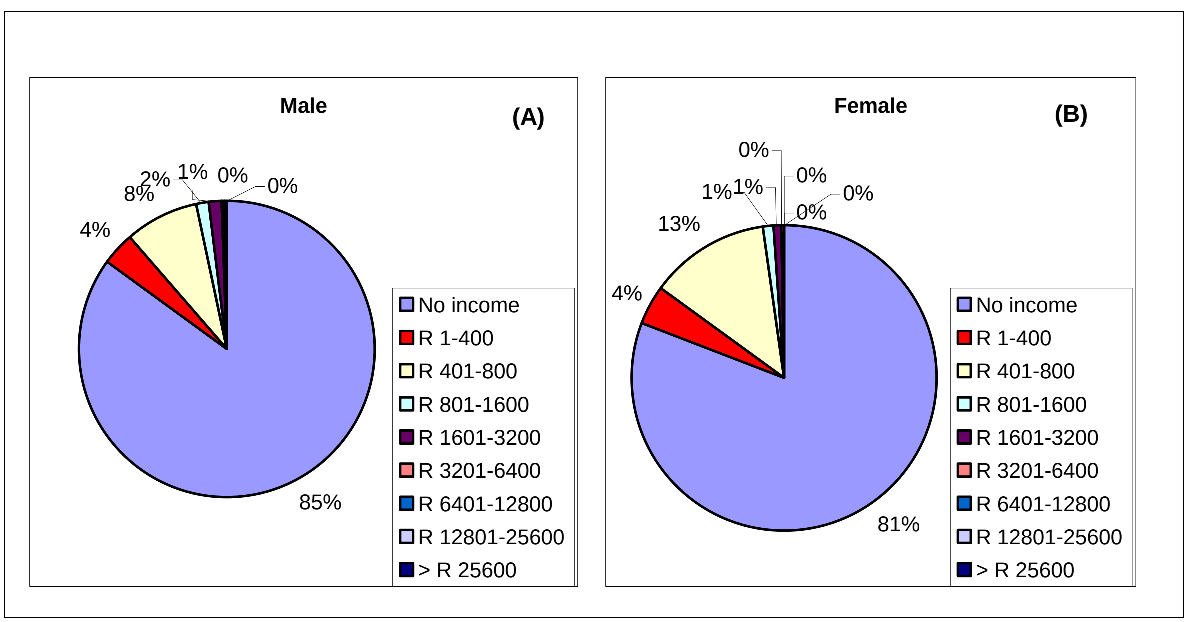

Figure 5.7 Income levels in Disaneng.

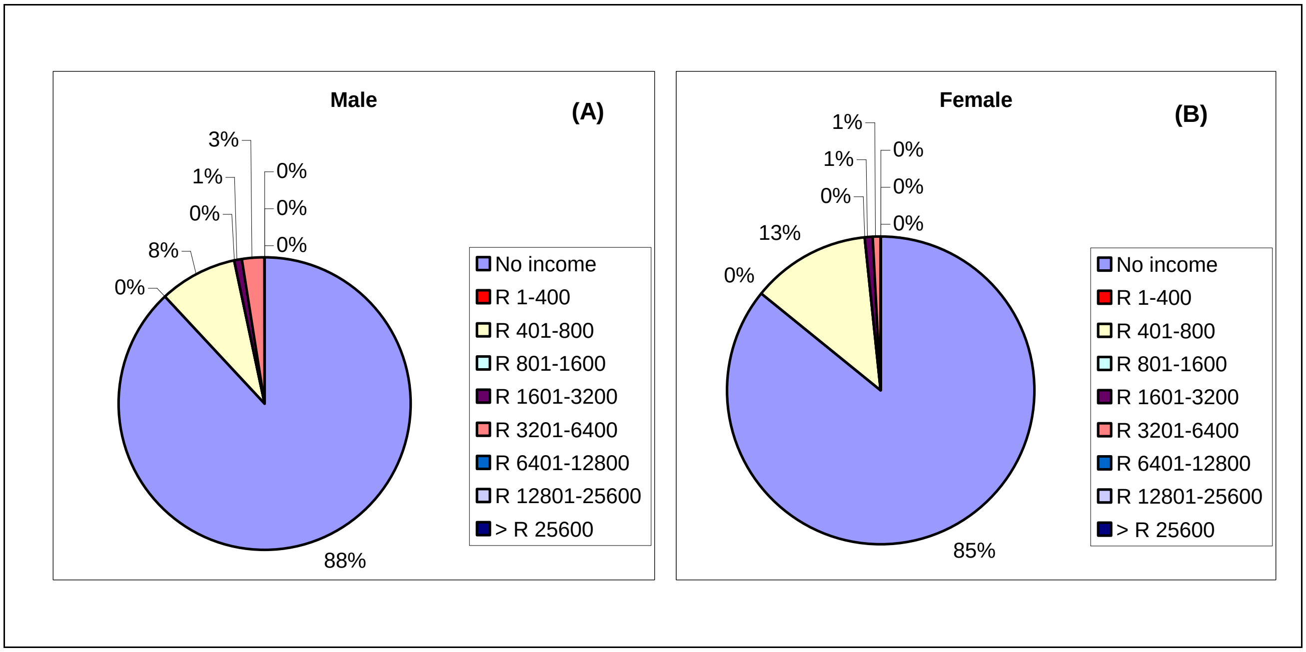

Figure 5.8 Income levels in Selosesha.

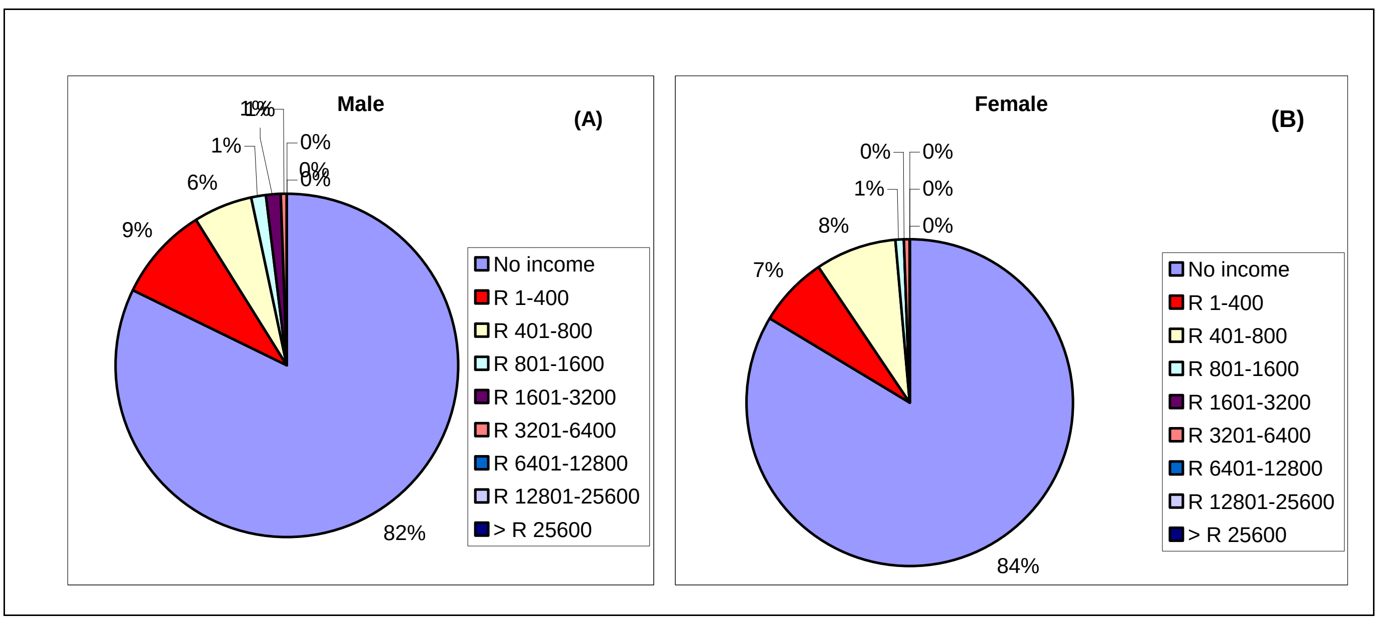

Figure 5.9 Income levels in Matloding.

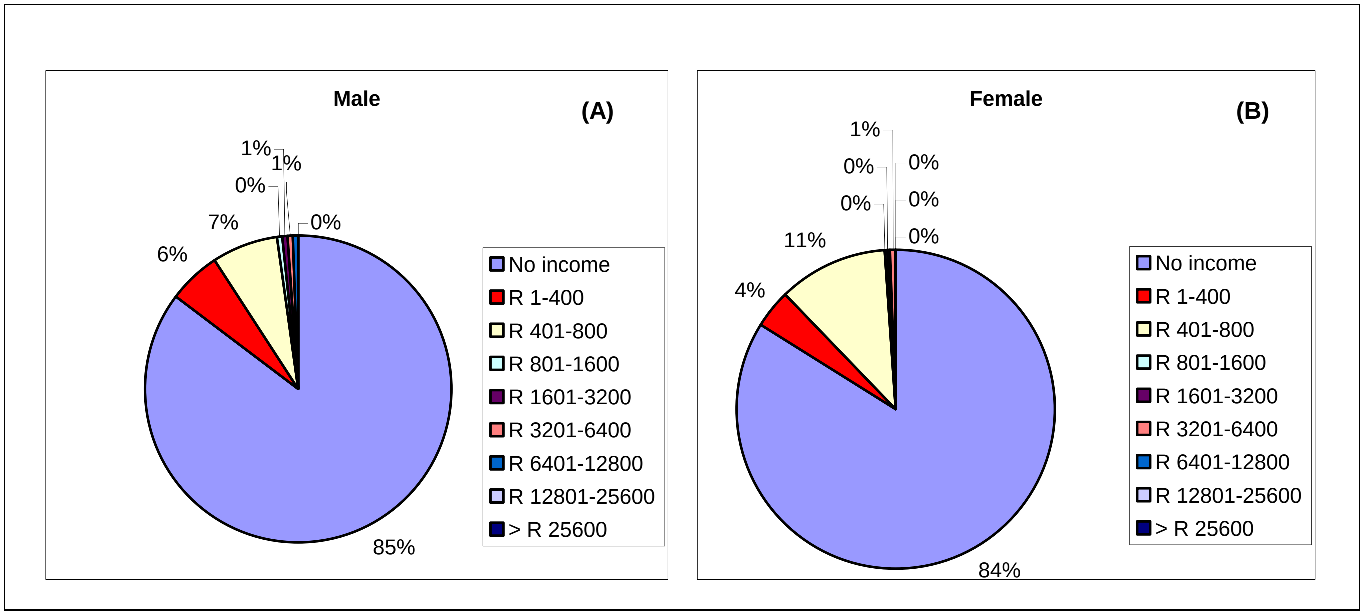

Figure 5.10 Income levels in Logageng.

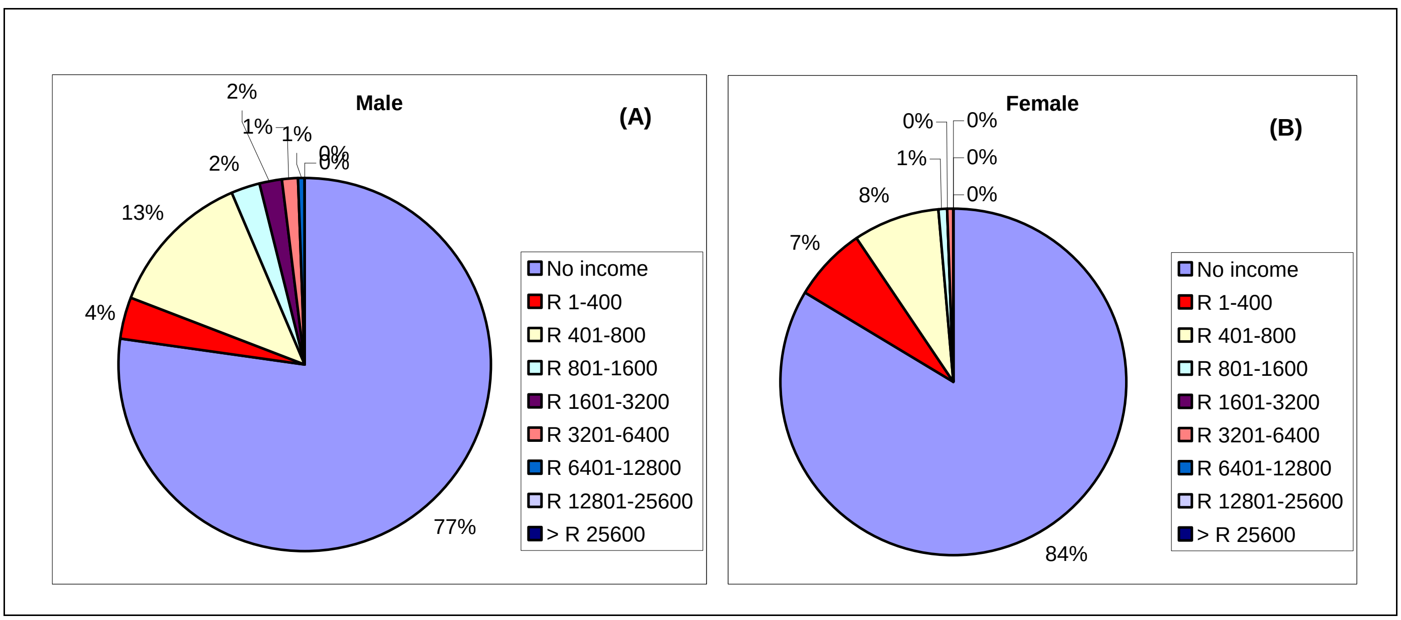

Figure 5.11 Income levels at Tshidilamolomo

A consequence of the predominantly poor social conditions is that the majority of the population live under is the so-called "poverty trap" (DACET, 2002). The "poverty trap" with its' severe spiral of ever increasing pressure on the environmental resource base results in environmental degradation (DACET, 2002) and it is evident in the study area.

5.2.4 Agricultural information

Most community members farmed with donkeys, cattle, maize, sunflower and beans. 80 % of the respondents had 4 cows, 9 goats and 10 chickens. The main reason for farming is subsistence. Approximately 3 goats and 1 calf die at birth at all the villages, with the main reason being diseases.

Meat, eggs and animal hide are used domestically by 88 % of the respondents at the villages. A mean average of 1 animal is auctioned by weight when there is a shortage in the home at nearby villages.

There were no fences or camps for controlling grazing patterns. This implies that continuous grazing is practiced with no rest periods for the veld. Overgrazing then becomes a "problem" and the community blames lack of fences for this 'problem of the commons'. The community farmers believe fences and good rain can solve, or at least minimize overgrazing. Legislation for fencing in South Africa is the Fencing Act No. 31 of 1963 (Fencing Act No. 31, 1963) for fencing of farms and other holdings. This legislation is not applicable to any plot, stand or lot situated within a municipal boundary, village or township, unless such land is at least one morgen in extent and one of a number of contiguous plots on which farming operations are carried on. It seems that it is not helping much in the study area where there are no fences except for around houses.

Some rangelands in communal areas are overstocked with livestock well beyond the carrying capacity of the area (DACET, 2002). There has been degradation of the natural resource base (land degradation) through insufficiently defined property rights that have resulted in some areas being over-populated, e.g. tribal or communal land. The use of pesticides, fertilizers and potentially harmful other chemicals should be effectively controlled land farming practices reviewed to determine optimal practices, best suited for the land (DACET, 2002).

The respondents claimed that there was little help if any, from the Department of Agriculture, but that there are veterinarians that come regularly and inform them to be prepared when they come to vaccinate livestock.

The rangelands are communally managed. This implies that nobody wants to take responsibility in rehabilitating and monitoring the general condition of the veld because it is not privately owned land. Other farmers believed that fencing would reduce overutilization of the veld.

5.2.5 Environment

Some community members were under the impression that the rangelands productivity would increase when it was fenced and there was adequate rain. Desertification is a threat to this area and affects the general farming potential in the study area.

There were some meaningful meetings that took place in the community, but they were mostly restricted to health issues and were not environmentally orientated. The lack of fences and camping system was blamed mostly on the deterioration of the land. It is hoped that government would intervene and assist the community in their plight for infrastructure and resources.

5.3 Conclusion

A consequence of the predominantly poor social conditions that the majority of the population live under, is the so-called “poverty trap” (DACET, 2002). This implies that poor people in the communal areas are directly dependent on what the environment offers. People consider their immediate environment as a natural resource that can be exploited indefinitely. This will eventually lead to a continuous and even more intensive pressure on the environment for natural limited resources such as available grazing for animals**.**

If sustainable agricultural and food systems are to be developed, even sustainable economies and societies at large, ecological literacy and new forms of social organisation need to be developed as advocated by Pretty (2002). Environmental awareness programmes should take into account the high level of illiteracy in the study area. A high priority should be given to actions that ameliorate the social and economic impacts of unemployment particularly those that lead to environmental degradation. The National Government as the 'legal custodian' of the environment should put more effort in ensuring sustainable development. The short term costs of the problem of land degradation could be far less than the long term costs that can be irreparable. Appropriate welfare support for unemployed and disadvantaged persons should remain a high priority. A strategy for the socio-economic upliftment of people living in rural areas needs to be developed and implemented. There is a need to address the social implications of illiteracy, urbanization, youth development and rural community's health services.

Few of these settlements populated by formerly disadvantaged communities have any significant economic base of their own. Rural development strategies that involve community participation need to be implemented more rigorously and efficiently to meet the needs of the communities.

Most of the community members were younger than 18 years old which could still be educated about environmental awareness. Environmental threats such as desertification could be more 'real' and better understood by the communities. Section 29 (1) (a) of the Bill of Rights of the The South African Constitution, provides everyone with the "right to basic education", while Section 29 (1) (b) adds that everyone also has the "right to further education". More schools as the lack thereof is evident in section (5.22) were required. Qualified teachers should be deployed in these communal areas which could improve the quality and literacy levels shown in the communities. Educated people are more likely to find employment or be self employed, make informed decisions and alleviate poverty and dependence from social grants.

Transport and basic infrastructure such as water access and stores for basic household needs were available to meet the basic needs of the community but improvements were required. Better equipped public health care facilities should be built in every village to relieve the stress of transport inadequacy especially during emergencies.

The average number of livestock per family seemed to pose no threat of overstocking. Lack of fencing was quoted as a crisis in all communities. It is recommended that the communities employ a 'neighborhood watch' and the tribal authorities impose fines and involve the police to anyone found tempering with the fences.

Chapter 6: Discussion and conclusion

Communal farming practices in the Molopo District were evident. The rangelands were over utilized and overgrazed. Woody plant invasion of grasslands was evident in this area, thus lowering the grazing capacity of the area. Local farmers consider invasion of *Acacia mellifera* to be the most serious problem in rangelands. Mismanagement and the incorrect grazing strategies by local farmers contributed to the problem.

It was clear from the results that all the study sites experienced woody plant invasion, where all the study sites except the benchmark sites, had woody plant densities of more than 2 000 TE/ha (Chapter 3). This evidence led to the conclusion that grass growth was almost totally suppressed when related to the findings of Moore & Odendaal (1987).

The semi-arid climate of the area (Chapter 2) has been a contributing factor according to the United Nations Convention to Combat Desertification (UNCCD, 1995) definition of land degradation. Climate determines the type of natural vegetation and also a contributing factor to the prevalent type of vegetation (Hoffman & Ashwell, 2001). This includes effects of the types of agriculture and disturbances from human activities (Chapter 5). The models that illustrate climate influence were discussed in Chapter 3.

Acacia mellifera, *A. tortilis*, *Dichrostachys cinerea* and *Prosopis velutina* were the most abundant encroachers in the study sites (Chapter 3). *Acacia mellifera* has a shallow root system and eventually competes directly with the herbaceous sward. This explains why a herbaceous sward was limited in these study sites. Smit (1999) stressed that the roots of *A. mellifera* can extend linearly up to seven times the extent of the canopy-spread and can thus extract nutrients from well outside its canopy radius. *Prosopis velutina* is an alien invader and was found to be abundant along the Molopo River. The pods of *Prosopis velutina* are palatable and are thus distributed by man and animals. Chemical control is advised to control the invasion of these species, especially with respect to *Acacia mellifera*, *A. tortilis* and *Dichrostachys cinerea*, but manual control is advised in the case of *Prosopis* control, because of the deep taproot system.

Rainfall in the study area is often patchily distributed and irregular. This further gives the encroaching woody component the advantage over the grass sward as the roots of woody plants normally extend far beyond their projected canopy radius.

Soil types vary in terms of fertility and texture as well as their ability to absorb, retain and redistribute water (Hoffman & Ashwell, 2001). Hoffman & Ashwell (2001) stated that factors of variation make certain soils more susceptible to degradation by waterlogging, salinisation and wind and water erosion. Variations, although slight when comparing other sites, were observed in the soils of the study area (Chapter 4). Nutrient enrichment, especially organic carbon and nitrogen were also observed from the soils of the study sites. The invading woody species supplement the soil with nutrients, necessary for grass growth. The texture of the soil in the study sites can be described as ‘sandy’ and this implies that there is a poor water holding capacity. In ‘good’ rainy seasons, the rain will thus infiltrate down to the deeper taproots of the woody species, thus denying the herbaceous sward the necessary moisture.

The poverty of the local communities results in their direct dependence on what the physical environment can provide (Chapter 5). Between 80% and 90% of the residents have no income and is thus totally dependent on the immediate resources in their area. It has lead more intensive pressure on the environment for natural limited resources such as available grazing for animals which is overgrazing**.** The social survey (Chapter 5) also revealed that besides poverty, the local inhabitants also have limited infrastructural mechanisms needed for their ‘day to day’ activities. Transport was found to be a ‘general’ problem. Most respondents indicated that transport is limited and that donkeys are often the only option in this regard. This implies that most households had a number of donkeys that they kept for transport purposes, not keeping in mind that they also have an negative impact on the already scarce grazing material.

The situation in the study sites is thus similar to the ‘tragedy of commons’ described by Hardin (1968), because everyone wanted to have the ‘best’ out of the resources. This will eventually lead to an overexploitation of these resources. Resources in communal areas, especially grazing land and water are limited and needs proper management. This can only be done if and when the local people get property rights and get the responsibility of taking care of 'their' land.

Literacy, particularly ecological literacy and sustainable development as well as new forms of social organisation need to be developed. The National Government as the 'legal custodian' of the environment, as well as the local authorities should work together with the communities to ensure sustainable development. This could encourage less dependence on social grants and appropriate natural resource use.

Under the current conditions, the implementing of a bush control strategy could make a far more worthwhile contribution to stabilize farming operations in the area. These areas need to be rehabilitated in order to improve the general grazing capacity of the grazing lands.

Hagos & Smit (2005) stated that *Acacia mellifera* is of important economic value, if it is not in high density and can be used as a valuable fodder tree on game farms in semi-arid areas. The favorable effects of *Acacia mellifera* and the other invading species discussed in Chapter 3 on the soil nutrient status should thus be considered when a bush control program is implemented in the area. It is thus recommended that the encroacher species be controlled by chemical arboricides (Hagos & Smit 2005). In order to reach this goal, it is important for the Department of Agriculture to intervene. The Department of Agriculture should aid communities by supplying chemical arboricides and assist them with the control process. This, however will only be successful if the local people gets property rights and own land 'of their own'. In this way they will accept responsibility of 'proper grazing management structures' and the eventual rehabilitation of degraded grazing land.

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