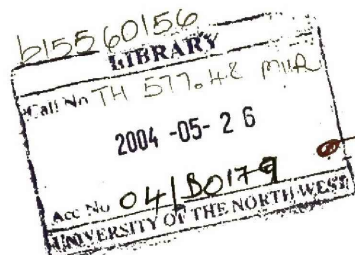


Concentration of soil nutrients beneath canopies of *Acacia erioloba* trees in a semi-arid savanna environment of the North-West province, South Africa

by



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Dissertation submitted in fulfilment of the requirements for the degree of Master of Science in Agriculture (Soil Science) in the Department of Crop Science in the Faculty of Agriculture, Science and Technology at the University of North West

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DEDICATION

The work is dedicated to all the people who have participated in making this research work possible and as good as it is. These people include lecturers, technicians, students, and my family. May the love and grace of GOD be with them.

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ABSTRACT

Acacia erioloba (synonym: *Acacia giraffae*) commonly known as Mpatsaka (Sotho), Mokala (Tswana), Kameeldoring (Afrikaans) and camel Thorn (English) is an indigenous leguminous tree that is adapted and commonly found in semi-arid savanna environments of South Africa. Being a leguminous plant, *Acacia erioloba* can fix atmospheric nitrogen into the soil. The objective of this study was to quantify the concentration of plant nutrients in soils beneath the canopies of *Acacia erioloba* trees in three land-use practices viz: fallow, grazing and bare land. Three trees were randomly selected in each land-use practice and soil samples were collected from beneath and beyond the tree canopies at depths of 0-10 and 10-20 cm.

Consistently, soil analysis revealed that the concentration of nutrients (N, P, Ca, Mg, Zn and Mn) and soil biological properties (organic carbon, particulate organic matter, microbial biomass nitrogen and microbial biomass carbon) among the land-use practices were in the order: fallow > grazing > bare. Differences in the concentration of soil nutrients between the land-use practices seemed to be influenced by management within the land-use practices. Nitrogen, phosphorus, potassium and zinc were significantly higher ($p < 0.05$) in land under grazing while calcium and magnesium, were significantly higher ($p < 0.05$) under fallow land. As expected, bare land had the lowest concentration of all the nutrients studied. The presence of animals around *Acacia erioloba* trees contributed to higher concentration of nutrients in land under grazing. The differences in the values of biological properties were considered to be likely due to higher plant biomass on the topsoil compared to the subsoil that increased the microbial activity. The improved biological properties are thought to have improved the nutrient concentration through processes such as mineralisation of nutrients from organic matter.

With the exception of phosphorus (P), potassium (K) and zinc (Zn), concentration of all other nutrients (N, Ca, Mg and Mn) was not significantly different ($p < 0.05$) in soil from beneath the tree canopy and those from beyond the tree canopies in all land-use practices. Topsoil (0-10 cm) had significantly higher ($p < 0.05$) concentration of all nutrients and biological properties that were measured compared to the sub soil (10-20 cm). This was attributed to the fact that much of the decomposition of soil organic matter takes place on the surface layer of the soil where most of the organic materials are added. Nutrient

uptake from deep soil layers by roots of the trees may be another important mechanism that could enrich surface soils beneath *Acacia erioloba* tree with nutrients.

The availability to a wheat crop of the nutrients found beneath the canopies of *Acacia erioloba* was evaluated using a "Neubauer" seedling technique in a glasshouse. Wheat seedlings were grown into PVC pots filled with soils collected from beneath and beyond the tree canopies. The wheat that was grown in soils collected beneath *Acacia erioloba* trees had significantly higher ($p < 0.05$) growth and nutrient uptake than that grown in soils from beyond tree canopies. Plant height, dry matter yields and nutrient uptake by the wheat seedlings were in the order fallow > grazing > bare land. The plant height were 20.9, 16.4 and 14.2 cm for fallow, grazing and bare, respectively. This was attributed to the high accumulation of organic matter from different sources such as leaf litter, grass residues and animal wastes under fallow and grazing land. Fallow and grazing promotes large organic matter inputs and therefore create conditions that favour rapid decomposition of organic matter and mineralisation of nutrients.

Correlation coefficients between soil nutrients and nutrients in the tissues of wheat show that there was a strong and significant relationship between the two. It was suggested from these results that *Acacia erioloba* trees has a potential to be used in agroforestry systems within the farming systems of the small-scale farmers in the semi-arid savanna ecosystem of the North-West Province. Such systems could include agrisilviculture and sylvopastoral. If *Acacia erioloba* trees are to be included in agroforestry systems, the densities need to be increased. This would imply increasing their propagation. More techniques of propagating the tree need to be researched. The nitrogen fixing potential of *Acacia erioloba* needs to be thoroughly investigated.

DECLARATION

I declare that this dissertation for the degree of Master of Science in Agriculture at the University of North-West hereby submitted, has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

Signed by : **Romeo Ndamuleleni Murovhi**

Signature : 

Date : 12 - 12 - 03

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INTRODUCTION AND STUDY OBJECTIVES

Nutrient cycling has been defined as the exchange of nutrient elements between the living and non-living parts of the ecosystem (Townsend, 1973; Frissel, 1978; Foth, 1984). Generally, nutrients that are essential for growth of plants and animals are passed from soil to plant and soil again; this sequence of transfers through a series of compartments constitutes one of the simplest representations of a nutrient cycle (Frissel, 1978). Growth of all vegetation depends on the circulation of nutrients, which reach the soil as organic matter. Organic matter undergoes an often-complex series of changes that restore them to forms in which plants can use them again (Jackson & Raw, 1966; Delorit *et al.*, 1984). All plants growing in soils absorb nutrients needed for their growth from the bulk of soil that they penetrated by roots and root hairs. When plant materials decomposed, nutrient elements that have been accumulated in the tissues are released back to the ecosystem. Liberated nutrients again become available for absorption by plants (Ewusie, 1980).

Decomposition and mineralisation are the primary means for transforming and recycling nutrients into available forms for plant uptake (Meentmyer, 1978; Wood & Raison, 1982; Lynch, 1984; Tracy & Frank, 1998). Mineralisation is the conversion of organic nitrogen such as protein into ammonium nitrogen. For example, nitrogen becomes available for plant use if it is converted into NH_4^+ or NH_3 forms. It is through the process of nutrient cycling where nitrogen can be converted into these forms. Similar transformations occur in all other nutrient elements.

Soil microbes play a significant role in transforming organic matter into ionic forms that can be used by plants. Various microbes tend to decomposes organic matter (Bridges & Davidson, 1982). The most important three groups of these microbes are bacteria, fungi, and actinomycetes (Thompson & Troeh, 1978). There is however a number of other factors that determines organic matter decomposition, namely: temperature, soil pH, land-use system, and moisture availability (Paul & Clark, 1989).

The rates at which nutrients are mineralised and cycled depend on land-use system and its associated management practices. Many theories and practical implications have been cited and questions have been posed on how land-use system influences and enhances the nutrient cycling processes. Agroforestry system is one of the land-use systems that have been shown to play a significant role in nutrient cycling processes (Weil & Mughogho, 1993). Agroforestry is referred to as the land-use system in which trees or shrubs are grown in association with agricultural crops, veld, or livestock, and in which there are both ecological and economical interactions between trees and other components (Lundgren, 1982; Esterhuysen, 1989). Agroforestry plays a vital role in controlling and modifying the nutrient cycling processes.

Nutrient cycling processes play a tremendous role in sustainable agriculture. In the absence of commercial fertilizers, nutrient cycling is the only practical means in which nutrient elements can be made available for plant use. As it has been mentioned earlier, plants absorb nutrients in specific forms. Nutrient cycling helps in bringing or cycling back nutrient elements that were used by plants, animals and microorganisms back into the ecosystem. It is through this process that nutrients that were lost due to leaching, denitrification, and volatilisation can be retrieved again. For example, nitrogen can be brought back into the ecosystem by using leguminous plants that are capable of fixing atmospheric nitrogen. Leached nutrients can be cycled back to surface layers where they can be used again by other growing plants.

Acacia erioloba is a common leguminous tree found widely in semi-arid savanna of the North-West province and it can be used in agroforestry system for the benefit of all small-scale farmers (Carr, 1976; Dakora & Keya, 1996; Materechera, 1999; Smit, 1999). *Acacia erioloba* forms a valuable component of grazing land in most arid and semi-arid areas. Domestic ruminants obtain significant quantities of food from them. The dense canopies protect soil from erosion by wind and raindrop impact and their deep roots act as soil stabilisers and nutrient pumps. In addition, the root nodules of *Acacia erioloba* can fix atmospheric nitrogen in soil. Pods of the tree provide food for livestock and fuel in large areas of the semi-arid zones of Africa (Turnbull, 1987). Bush and grasses that grow beneath the canopies of *Acacia erioloba* tree create microclimate that can enhance nutrient cycling processes.

Although the ecological importance of *Acacia* species has been emphasised (Carr, 1976; Turnbull, 1987; Materechera, 1998), very little work has been done to quantify nutrient cycling potential by *Acacia erioloba* trees in the semi-arid savanna environment of South Africa. The primary objective of this study was to quantify the concentration of nutrients beneath the canopies of *Acacia erioloba* trees and to determine how the nutrients are influenced by different land-use practices. A secondary objective was to quantify the availability of nutrients in soils beneath *Acacia erioloba* canopies to a wheat crop. The specific questions to be answered by this study were:

- a) How does the concentration of soil nutrients beneath the canopies of *Acacia erioloba* differ from those beyond the canopies? Do these concentrations change markedly with depth?
- b) How does different land-use practices influence the concentration and distribution of soil nutrients beneath the canopy of *Acacia erioloba*?
- c) How bio available are the nutrients beneath and beyond the canopies of *Acacia erioloba*?
- d) Do trees (*Acacia erioloba*) influence the biological properties of soil beneath their canopies?

LITERATURE REVIEW

2.1 Introduction

Plants need nutrients for growth, development and yield production. Yield of crops is partly determined by nutrient availability. In other words, nutrients are referred to as plant food. Nutrient elements are divided into two categories, namely: essential and non-essential elements. Essential elements are those that are needed by plants for both growth and development. Non-essential elements are those that are used by plants with little or no effect in both growth and yield production. Nutrient elements are further divided into macro and micronutrients (Table 2.1). Macronutrients are those that are needed by plants in large amount, for example, nitrogen, phosphorus, calcium, magnesium, potassium and sulphur. Micronutrients are those that plants need them in small amount, for example, zinc, copper, manganese, iron and many more (Russell, 1973; Delorit *et al.*, 1984).

Plants require carbon, hydrogen, and oxygen that are derived from CO₂ and H₂O in photosynthetic tissues of plants. In addition to these three elements, plants require at least thirteen other elements for tissue construction or biochemical processes (Table 2.1). These elements originated from different sources such as soil, water and air. Beside these sixteen essential elements, some plants also accumulate elements that are not essential but have beneficial effects. For example, Celery has found to have an accumulation of sodium (Na), which resulted in the improvement of flavor (Foth, 1984).

Nutrient elements are not readily available for plant use. They become available through mineral weathering and organic matter decomposition. After weathering or decomposition, plants absorb nutrients as cations or anions (Table 2.1). If one or more of these nutrients are lacking, deficiency symptoms will then appear. The degrees in which these symptoms develop depend on the nature of a lacking nutrients, type of plant and amount of nutrients required by plants. Unbalances of these nutrients in soils affect the crop performance and yield production.

Table 2.1. Elements required for plant growth

Element	Symbol	Forms in which element is taken up
Carbon	C	CO_2
Oxygen	O	O_2
Hydrogen	H	H^+
Macronutrients		
Nitrogen	N	NO_3^- , NH_4^+
Potassium	K	K^+
Calcium	Ca	Ca^{++}
Phosphorus	P	H_2PO_4^- , $\text{HPO}_4^{=}$
Magnesium	Mg	Mg^{++}
Sulfur	S	$\text{SO}_4^{=}$
Micronutrients		
Iron	Fe	Fe^{++}
Chlorine	Cl	Cl^-
Manganese	Mn	Mn^{++}
Zinc	Zn	Zn^{++}
Boron	B	$\text{BO}_3^{=}$
Copper	Cu	Cu^{++}
Molybdenum	Mo	$\text{MoO}_4^{=}$

Source: Delorit *et al.* (1984); Kuun *et al.* (1987)

Availability of nutrients in soils does not necessarily guarantees the survival of plants. The most important factor that regulates growth and development of plants is the manner in which available nutrients are taken up (absorbed) by plants from the bulk of soil. The amount of nutrients to be absorbed by plants is governed by the size of the plant roots. As the roots system enlarges and ramifies the roots occupy a great volume of soil, and there is an increase in the ability of plant to absorb nutrients from the soil. Nutrients are absorbed by plant in an ionic form as indicated in Table 2.1. Nutrient movement (mobility) is largely depending on the type of nutrient element; for example, phosphorus is considered immobile while nitrogen is highly mobile. There are at least three ways in which plants obtain nutrients, namely: Mass- flow, this occurs when nutrients move in solution towards

the roots. The uptake of water by plant reduces soil moisture in the vicinity of the roots. The result is a regular replacement of moisture supply in the direction of the plant roots. The dissolved nutrients that move in this stream are called mass-flow. The amount of nutrients moved to roots by mass-flow depends on the amount of water moved to the root and the concentration of nutrients in the water (Foth, 1984).

The other way in which plant takes up nutrients is termed diffusion (Movement of water from a region of high concentration to a region of low concentration). Diffusion includes the movement of nutrient ions through the soil water and from exchange site along the surface of soil particles. When there is insufficient movement of nutrients to the root surface by mass-flow, diffusion plays an important role. The up take of ion reduces the concentration of that ion at the root surfaces, establishing a diffusion gradient outwards from the root surface and causing the diffusion of ions towards the root. Plant roots through the contact process absorb some of the nutrients. Contact exchange refers to when the roots are in direct and close contact with soil particles (Kuun *et al.*, 1987).

Nutrient up take is affected by various factors. For example, soil compaction tends to reduce the availability of oxygen for root respiration. It was also established that soil compaction reduces the up take of potassium more than did phosphorus or nitrogen. Moisture content influences the rate of movement of ions from soil surface to the root systems. It has been observed that drying the soil also reduces phosphorus uptake. The density and distribution of roots in the soil also plays an important role. The importance of root density observed when the mobility of the nutrient in the soil decreases. Crops with deeply penetrating root systems require less fertilization than those with shallow root systems.

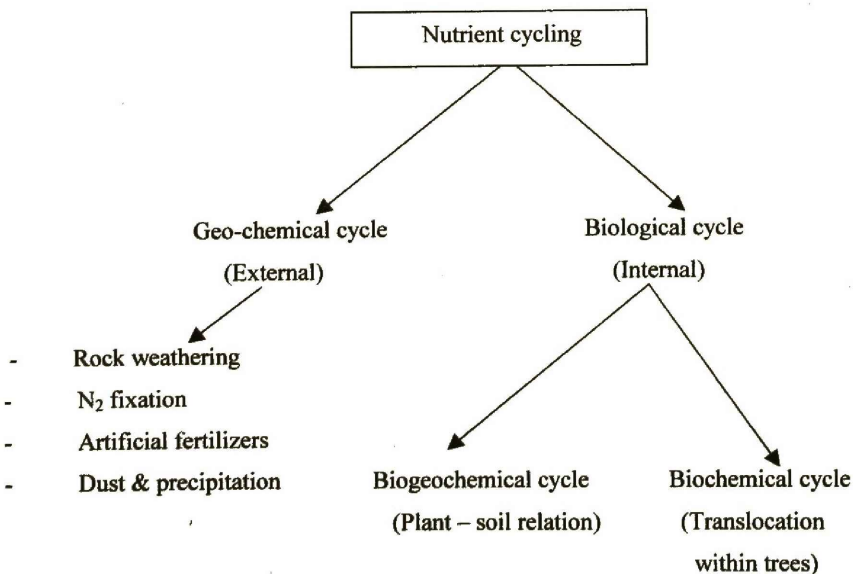
2.2 Nutrient cycling processes

The flow of nutrients in the biosphere is continuous between three main compartments, namely, organic store (soil); biomass store (living organisms above and below ground); and inanimate organic excreta of living organisms. Cycling represents the movement of elements between reservoirs (e.g. rocks, oceans, atmosphere, and biota). All the elements on which life depends are involved in cycles during which they may pass through the soil, water, air, and rock, as well as through living organisms. Remezov (1959) stated that the

nutrient cycles are divided into two categories, namely, an external geochemical system and an internal biological cycle (Figure 2.1). The geochemical cycle involves transfer of minerals into or out the ecosystem. This cycle imports from such sources as dust and precipitation, weathering of parent rock (volcanic), fixation of nitrogen, and fertilization. While outputs include leaching and erosional losses in drainage water, volatile losses from fire and denitrification, and removal in harvest.

Biological nutrient cycling (Figure 2.1) involves the transfer of nutrient between the forest floor, soil and the associated plant and animals communities. Switzer and Nelson (1972) proposed that Remezov's biological cycle can be split into two parts: one cycle dealing with translocation of nutrients within trees, and the other cycling involving the soil – plant relationship. They called the internal transfer of nutrients within the standing tree biochemical cycle and the transfer between the soil and tree biomass the biogeochemical cycle. Figure 2.1 represent the integration of Remezov's, Switzer and Nelson's model of nutrient cycling processes in nature.

Figure 2.1 The nutrient cycling structure



Source: Remezov (1959); Switzer & Nelson (1972)

2.3 Sources and sinks of plant nutrients in the soil

Soil nutrients are believed to originate from different sources such as weathering of parent rocks (volcanic), atmosphere and artificial fertilizers. The major inputs of nutrients in the semi-arid savanna are from weathering of minerals in soils and rocks and from the atmosphere (Trudgill, 1977). The atmosphere is an important long-term source of nutrients particularly nitrogen through electrical charge and fixation by leguminous trees. The amount of nutrients supplied through fixation and electrical charge differs from one climate to the other. For example, the average input (kg ha^{-1}) of elements into ecosystems by precipitation in temperate regions is as follows: nitrogen (0.2 - 0.6); potassium (1 - 10); calcium (3 - 19); magnesium (4 - 11). It was also reported that the annual content of nitrogen in rainfall at Samaru as being 4 - 5 kg N ha^{-1} . Fixation of nitrogen by nodules and bacterial root associations is the primary pathway by which atmospheric nitrogen is converted to forms usable by higher plants (Stevenson, 1986). Under natural vegetation, many leguminous wood and herbaceous plants have root nodules that enable plants to fix atmospheric nitrogen.

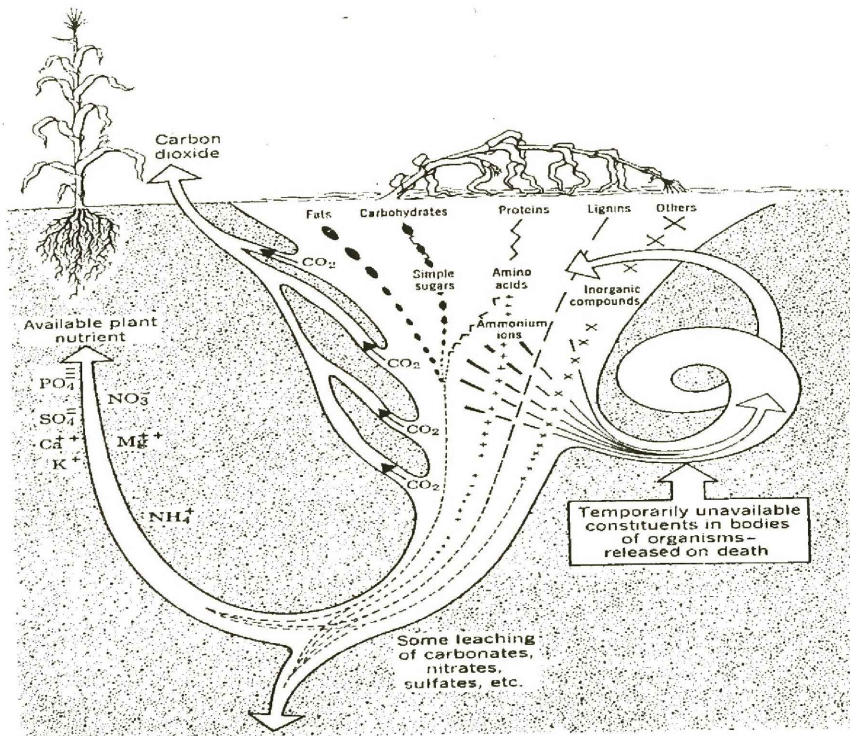
The application of commercial fertilizers is considered to be a means of increasing rates of nutrient cycling and tree growth in nutrient deficient soils. The addition of phosphates and nitrogen fertilizers counteract the deficiency and alter the functioning of the nutrient concentration in the soil (Thompson & Troeh, 1978). The use of commercial fertilizer is seen as the rapid means of enhancing nutrient cycling; however, most of the people who live and farm in the rural semi-arid savanna areas of North-West province are very poor and cannot afford to buy commercial fertilizers.

2.4 Contribution of organic matter to nutrient cycling processes

When plant, animal or microorganisms dies, they form part of organic matter. Soil organic matter consists of an accumulation of undecomposed or partly decomposed plant and animal residues (Aduayi & Ekong, 1981; Knapp, 1979; Bridges & Davidson, 1982). Organic matter in soil is derived from the above ground as well as the below ground parts of a plant. Generally, leaves and needles constitute up to 80% of the plant litter, while roots make up the remaining 20% although this could be as much as 50% in grasslands.

The quantity and quality of plant litter determines the amount and the rate in which nutrients can be cycled. There is a strong relationship between the organic matter and the manner in which nutrients are transformed as indicated in Figure 2.2.

Figure 2.2 Contribution of organic matter to nutrient cycling



Source: Foth (1984)

2.5 Decomposition of organic matter

Before nutrients are released from organic matter, decomposition process should take place. Decomposition occurs (sooner or latter) by microbes. This is the process whereby organic residues are physically broken down and the component nutrients are released (Swift *et al.*, 1979). Lynch (1984) consider decomposition as an integral part of nutrient cycle, as it is the break down of soil organic matter into components that can be used by plants, and the rate of decomposition determines the rate of release and recycling of nutrients in available forms for plant use (Wood & Raison, 1982; Tracy & Frank, 1998)

In the savanna ecosystem, litter decomposition follows three pathways: via microbial oxidation; via the gut of a detritivore; and via combustion in fire. In low rainfall areas such as the North-West province, the main macro fauna groups involved in litter decomposition are termites, millipedes, dung beetles, ants, and cockroaches. Among all other factors, climatic conditions play a tremendous role in decomposition and nutrient cycling processes. In the semi-arid savanna, where temperature is very high, decomposition tends to be very high. Some of the important soil microbes are affected by high temperature and thus also affect the cycling of soil nutrient (Alexander, 1961; Paul & Clark, 1989).

The nature of plant species also determines the rate of decomposition. Plant litter contains lignin, polyphenols, cellulose, hemicelluloses, sugars, proteins and nucleic acids (Table 2.2). The concentrations of these chemicals depend on the plant species. Some plants contain more concentration of these chemicals while others have less concentration. Lignin is the third most common plant polymer and is strikingly different in structure from all of carbohydrate-based polymers. It helps make plants more resistant to pathogens. Lignin degrades slowly because it is constructed as a highly heterogeneous polymer. Lignin is degraded by a variety of microbes including fungi, actinomycetes, and bacteria. The best-studied organism with respect to lignin degradation is the rot fungus *Phanerochaete chrysosporium* (Maier *et al.*, 2000). Plant species that have low lignin and polyphenols are thought to decay or decompose very easily and release nutrients rapidly unlike those plants that are high in lignin and polyphenols (Taylor *et al.*, 1989). The latter are thought to be more resistant to decomposition and tend to release nutrients very slowly (Swift *et al.*, 1979). All these factors tend to affect nutrient cycling process in one-way or the other.

Table 2.2 Organic components of a plant material that affects its decomposition

Plant component	% Dry mass of plant
Cellulose	15 – 60
Hemicellulose	10 – 30
Lignin	5– 30
Protein & Nucleic acid	2 - 15

Source: Maier *et al.* (2000)

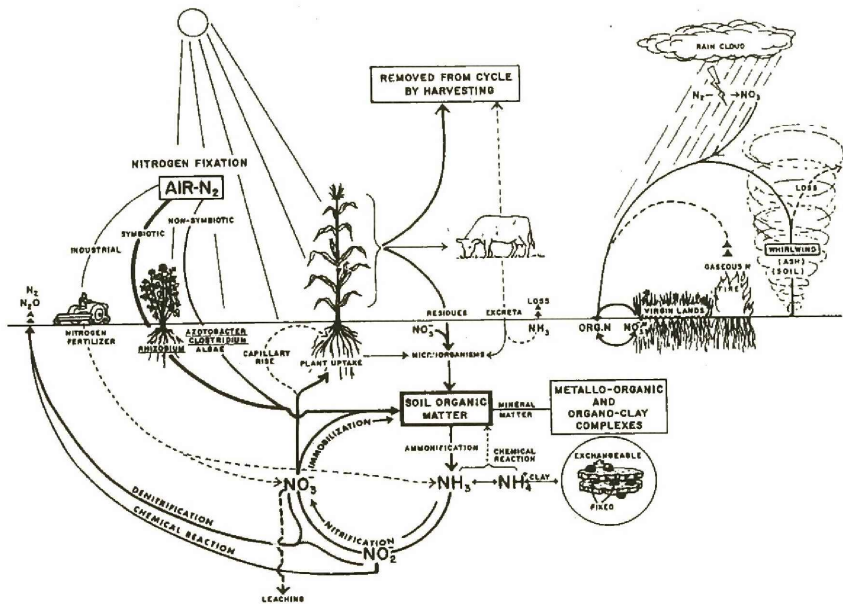
2.6 The cycles of major nutrient elements in semi-arid savannas

Although the majority of nutrient elements are released from organic matter, their process of mineralization and fixation are not the same. Carbon, unlike nitrogen and phosphorus, follow its own trend to complete its cycle. It is therefore recommended to consider the cycling of these elements separately. Nitrogen and phosphorus will be considered because they play an important role in determining the success or failure of agricultural production in the semi-arid savanna.

2.6.1 The nitrogen cycle

Nitrogen plays a vital role as far as crop production is concern and a thorough understanding of its cycle and management can be a valuable tool for farmers. The largest nitrogen pool in the semi-arid savanna is in the soil (Stevenson, 1994a). The amount of nitrogen available in soils also differs from one horizon to the other and with depth. Jones (1973) found that total nitrogen in savanna soils ranges from 0.008 - 2.90 % with an average of 0.051 % in the upper layers (0-15 cm) of cropped soils or soils under grass fallow. The smallest amounts of soil nitrogen were found in the northern part of the Sahel region where annual rainfall is less than 400 mm. The nitrogen cycle (Figure 2.3) as suggested by Stevenson (1986) shows that legumes can fix nitrogen from the atmosphere and convert it into forms that are available to plant use (i.e. NH_4^+ , NH_3).

Figure 2.3 The nitrogen cycle



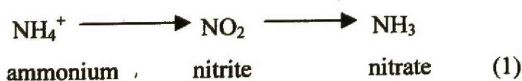
Source: Stevenson (1986)

Nitrogen is essential for the production of proteins, which are in turn important constituents of the cytoplasm of cells. Nitrogen is also important in nucleic acids, many hormones and co-enzymes. Nitrogen forms part of the chlorophyll molecule and dark green colour of the leaves. Deficiency symptoms of nitrogen include stunted plants with small leaves and yellowing of the lower older leaves while the upper younger leaves remain green. Severe cases lead to the leaves becoming brown and drying. Nitrogen is believed to originate from different sources such as weathering of parent rocks (volcanic), atmosphere and artificial fertilizers. The major inputs of nitrogen in the semi-arid savanna are from weathering of minerals in soils and rocks and from the atmosphere (Trudgill, 1977). The atmosphere is an important long-term source of nitrogen particularly nitrogen through electrical charge and fixation by leguminous trees.

The amount of nutrients supplied through fixation and electrical charge differs from one climate to the other. Fixation of nitrogen by nodules and bacterial root associations is the primary pathway by which atmospheric nitrogen is converted to forms usable by higher plants. Under natural vegetation, many leguminous wood and herbaceous plants have root nodules that enable plants to fix atmospheric nitrogen. For example, in parts of northern Sudan and Sahel zones, *Acacia albida* is a well-respected and protected tree because of its nitrogen fixing ability (Kowal & Kassam, 1978; Weil & Mughogho, 1993).

There are some non-leguminous trees that are capable of fixing nitrogen, for example, *Casuarina* Spp. Free-living organisms that include blue – green algae also fix nitrogen in soils. The most numerous bacterium species found in the Savanna is *clostridium* followed by *Azotobacter* and *Beijerinckia*. It was also reported that the amount of nitrogen fixed by these free-living bacteria is about 6 kg N ha⁻¹yr⁻¹. The abundance of woody leguminous trees in the savanna zone enhances the fixation of nitrogen from the atmosphere and this process plays a tremendous role in the cycling of nutrient. Such woody leguminous include *Acacia erioloba*, *Acacia albida*, *Acacia karoo* and *Acacia tortilis*.

Mineralisation (as defined in the introduction) is regarded as the starting point of the nitrogen cycle. It is the conversion of organic nitrogen such as protein into ammonium (NH₄⁺) and nitrate (NH₃) forms. Under mineralisation, two important processes do occur. These include ammonification and nitrification. These processes are very important in the cycling of nitrogen and are controlled by many factors including temperature, microbial activity, pH, and moisture content of the soil. Ammonification is the process whereby organic nitrogen is hydrolysed to NH₄⁺. The reaction catalysed by enzymes from many heterotrophic microorganisms. Nitrification is the conversion of ammonium to nitrite and nitrite to nitrate (equation 1). Nitrification occurs rapidly in well aerated, moist, warm, fertile soils containing abundant ammonium nitrogen and is negatively affected by soil temperature.



According to Kowal and Kassam (1978), microbial activity in the savanna zones ceases during the dry season due to severe desiccation of the soil surface. The level of mineral nitrogen reaches its peak at the beginning of the rainy season, and is lowest at the height of the rains and at a low-medium level during the dry season (Wild, 1972a). In Senegal it was reported that a high level of biological activity occurred at temperatures as high as 55 - 65 °C with maximum mineralization occurring at about 50 °C. In Nigeria, Wild (1972b) found that ammonification continued at soil moisture tensions below wilting point, but that nitrification was arrested at lower soil moisture tensions. Due to the generally high temperatures that exist in semi-arid areas, the rate of ammonification would be expected to be high.

Loss of nitrogen from soils results in a serious soil fertility problem for crop production. Nitrogen losses include: leaching, burning or volatilisation and denitrification. From lysimeter studies conducted in Senegal, it was estimated that nitrogen leaching in a savanna environment might account for between 5 and 30 kg N ha⁻¹ yr⁻¹ from a 1 m - soil depth. Measurements of leaching rates in a ferruginous sandy soil (Wild, 1972a) indicated that 1.0 cm of rainfall moved nitrate down the profile by 7.0 cm, 0.2 - 1.6 cm in a leached ferruginous soil, and 1.7 cm in the ferrallitic soil. In central Senegal, under conditions that favoured volatilisation, losses of NH₃ were only 5 - 10 kg N ha⁻¹ yr⁻¹ (Kowal & Kassam, 1978).

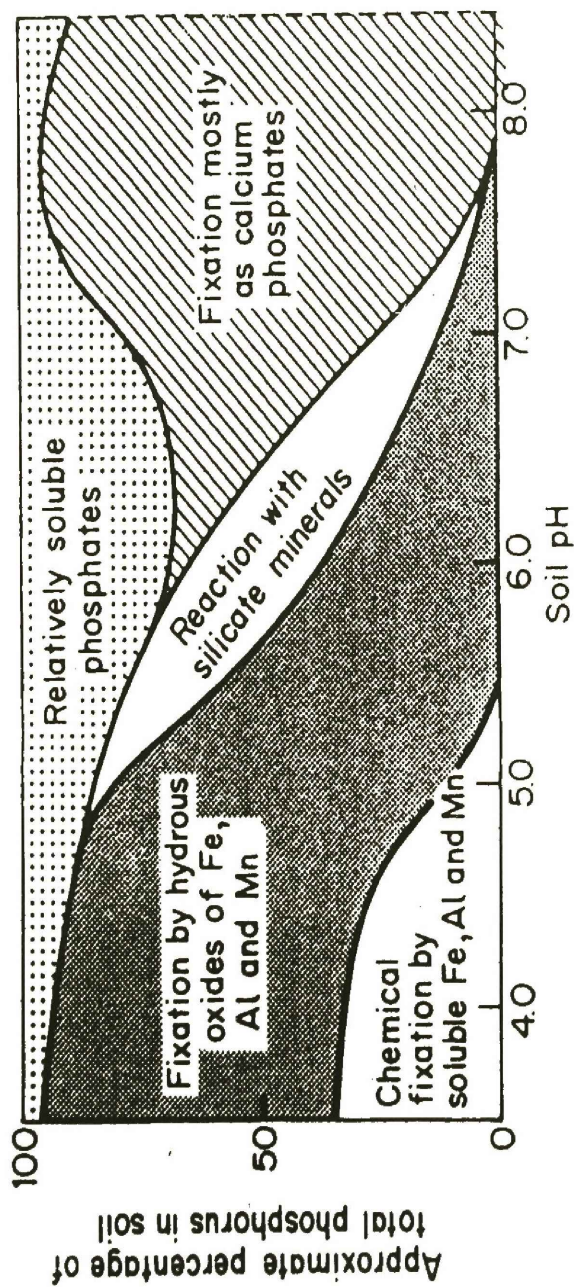
Burning of residues from crops and fallow land creates a problem in nutrient cycling process in the savanna. Loss of nitrogen due to burning are estimated to range from 20 - 40 kg N ha⁻¹ yr⁻¹ (Nye & Greenland, 1960). Loss of nitrogen due to erosion and surface run off tend to occur once the surface vegetative cover has been removed for agriculture or forestry. The soil is no longer protected by the canopy of litter, aerial biomass and by the usually dense mat of root hairs. Depending on the slope of land and degree of exposure to wind and rain, significant amounts of soil can be wasted or blown away together with nitrogen and other plant nutrients. In Nigeria, losses by run off from bare fallow were estimated to be 10 kg N ha⁻¹ yr⁻¹ while for a crop covered soil was only within the range 0.3-3 kg N ha⁻¹ yr⁻¹.

2.6.2 The phosphorus cycle

The phosphorus cycle in the soil is a dynamic process involving soils, plants and microorganisms. Major processes include uptake of soil phosphorus by plants, recycling through return of plant and animal residues, biological turnover through mineralisation and immobilization, fixation reactions at clay and oxide surfaces and solubilisation of mineral phosphates through the activities of microorganisms. In nature, all phosphorus consumed by plants is returned to the soil in plant and animal residues. Phosphorus (P) is one of the main limiting nutrients for crop production. Phosphorus is taken up by plants in the form of $\text{H}_2\text{PO}_4^{2-}$. Plants take up phosphorus from the soil solution. However, soil solution phosphorus constitutes only a small fraction of total soil phosphorus (Tiessen *et al*, 1984). Savanna soils have small quantities of phosphorus and the main source of phosphorus is appetite rocks. Studies in West Africa showed that the value of total phosphorus in the upper horizons ranges from about 61 - 229 ppm. There is a tendency of phosphorus to react with soil components to form compounds relatively insoluble and therefore unavailable to crops. Once phosphorus is fixed in this manner, the whole process of phosphorus cycling is also disturbed or reduced drastically. The average content of total phosphorus in the surface of savanna soils ranges from about 80 to 150 ppm (Enwerzor & Moore, 1966).

Phosphorus immobilization is a major problem that affects the cycling of phosphorus. React with other soil components (e.g. occlusion in ferric oxides, or sequestrate in the microbial biomass) and become unavailable to plants (Scholes & Walker, 1993). Soil with a high potential for phosphorus immobilisation are said to be phosphorus fixing. The PO_4^{3-} fixing capacity of a soil increases with increasing clay content, especially kaolinite. Organic matter has a great influence on availability of phosphorus because during decomposition CO_2 is formed which dissolves in soil water to form H_2CO_3 . Soil pH plays a major role in the availability of phosphorus. Phosphorus availability is best in the pH (H_2O) range between 5.3-7.5. Consequently, most severe problems of phosphorus fixation are experienced in strong acid soils. At pH 7.0 calcium and aluminium phosphate predominate, in the pH range 5.6 – 6.8, aluminium phosphate prevails, at pH values lower than 5.5 iron phosphate and phosphorus linked with organic matter predominate (Jordan, 1985). Only calcium and aluminium phosphate are thought to be directly available to plants (Figure 2.4)

Figure 2.4 Inorganic fixations of phosphates at various soil pH



Source: Jordan (1985)

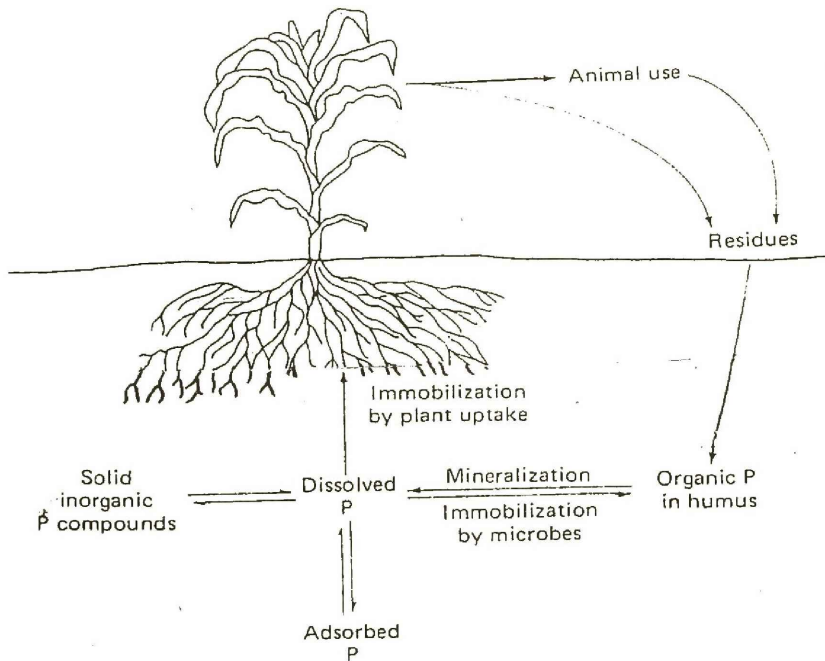
Another problem that affects phosphorus cycling is the ways in which phosphorus is lost from the soil. These ways include: leaching, erosion and crop removal. They reduce the amount of phosphorus that was supposed to be used by plants and recycled (Table 2.3). Stoeckler and Arneman (1960) found that 12 kg P ha⁻¹ was taken from the soil. Of this amount, 10 kg P ha⁻¹ was returned to the soil through plant litter and 2 kg P ha⁻¹ was lost due to crop removal, soil erosion and immobilization. In savanna ecosystems where the amount of phosphorus is generally very low and when poor soil management is practiced, the amount of phosphorus loss can exceed those reported by Stoeckler and Arneman (1960). Loss of phosphorus from the soil due to crop removal and soil erosion are common in the semi-arid and arid savanna zones (Enwezor & Moore, 1966). Leaching is not a serious problem in such ecosystems due to the low annual rainfall. The cycling of phosphorus in nature is presented in Figure 2.5.

Table 2.3 Annual uptake, retention and return of nutrients to the soil

Cycling processes	Nutrients (kg ha ⁻¹)			
	N	P	Ca	K
Uptake from soil	50	12	14	96
Stored in wood or lost from soil	10	2	4	13
Returned to soil in litter	40	10	10	83
Percent recycled (%)	80	82	70	86

Source: Stoeckler & Arneman (1960)

Figure 2.5 The phosphorus cycle



Source: Thompson & Troeh (1978)

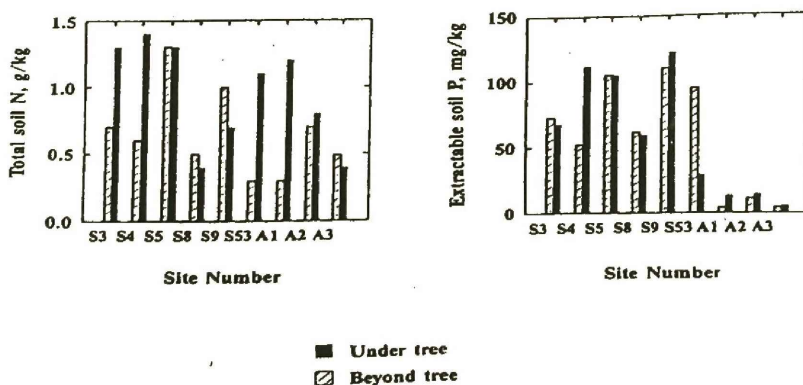
2.7 Nutrient cycling beneath tree canopies

Different experiments have been conducted in different parts of the world in order to observe whether there is a significant differences in the manner in which nutrients are transformed from one form to the other beneath and beyond tree canopies. Theories and practical implications have been advanced about nutrient transformation under tree canopies (Palgrave, 1993). Depending on the climatic conditions and the nature of trees, many researchers have found that nutrients are transformed much better and faster under tree canopies than in adjacent soil (beyond the tree canopies). In some of the observations, it has been found that temperate regions experience high rate of nutrients cycling due to high rainfall and more abundant organic matter. The opposite is true for semi-arid areas and dry-arid savanna that receives low annual rainfall. In West African countries such as Sahel, Nigeria, Sudan, and in other parts of Africa, many experiments on

the cycling of nutrients have been conducted. Different views, thoughts and conclusion have been drawn from the outcomes of the research. Some of the results were proved the hypothesis that high concentrations of nutrients are expected under the tree canopies (Weil & Mughogho, 1993), while others disapproved the hypothesis (Virginia, 1986; Gliessman, 1989).

In Malawi, Weil and Mughogho (1993) found differences in the concentration of both total nitrogen and phosphorus in soil under the canopies of *Acacia albida* and beyond the tree canopies (Figure 2.6). For example, treatments S3, S4, A1, and A2 showed a high concentration of total nitrogen under tree canopies than outside tree canopies, while treatments S5 showed no significant difference between the two canopy locations. Treatments S8, S9, and A3 showed a low concentration of nitrogen under tree canopies while high concentration of nitrogen was observed beyond tree canopies in both canopy locations. In case of phosphorus, treatments S3, S8, and S53 showed a high concentration of phosphorus beyond tree canopies while treatments S4, S9, A1, and A2 showed a high concentration of phosphorus beneath the tree canopies. These results suggest that annual crops can grow better beneath *Acacia albida* trees due to an increased concentration of nitrogen and phosphorus.

Figure 2.6 Concentration of nitrogen and phosphorus in soils beneath and beyond the canopy of *Acacia albida* in Malawi

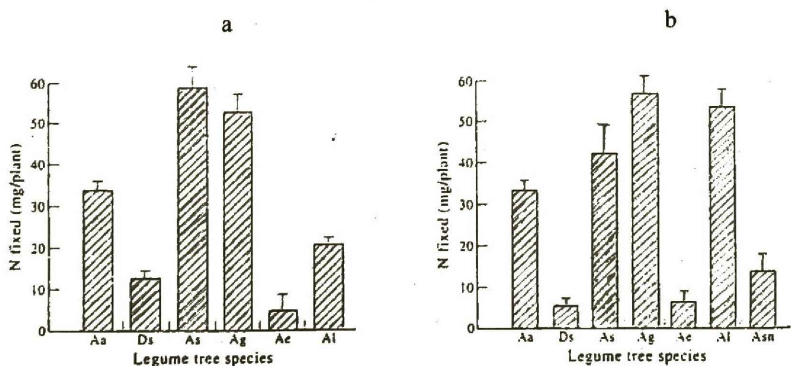


Source: Weil & Mughogho (1993)

Both legumes and non-leguminous tree species have been used as sources of soil nitrogen. Leguminous trees such as *Acacia albida*, *Acacia Karroo*, *Acacia erioloba*, *Acacia senegal*, *Prosopis glandulosa*, *Cajanus cajan* and *Leucaena leucocephala* have commonly been used (Carr, 1976; Turnbull, 1987). One of the reasons that these species have been used is that they fix a reasonable amount of nitrogen. Symbiotic fixation by these woody leguminous tree species is believed to increase the concentration of nitrogen in soils under trees (Bernhard-Reversat, 1982). Roots of many trees can also access nitrogen that may have leached into deeper soil layers and concentrate it to the surface of the tree (Tiedemann & Klemmenson, 1977; Belsky *et al.*, 1989).

Masutha *et al.* (1997), studied the nitrogen fixing ability of seven (7) woody leguminous species under two different soils. In Venda soils (Figure 2.7a), *Acacia sayel* and *Acacia galpinii* showed highest rate of N₂ fixation, followed by *Acacia auriculiformis* and *Acacia lebbeck*. *Acacia erioloba* showed the lowest rate of N₂ fixation due to poor nodulation. In the Klipspruit soil (Figure 2.7b), *Acacia galpinii* and *Acacia lebbeck* were the highest in N₂ fixation, and were closely followed by *Acacia sayel* and *Acacia auriculiformis*. These results imply that some leguminous trees can be included in agroforestry systems because they have the ability to fix atmospheric nitrogen.

Figure 2.7 Amounts of nitrogen fixed by selected tree legume species after inoculation in Venda (a) and Klipspruit (b) soils



Aa = *Acacia auriculiformis*, Ae = *Acacia erioloba*, Ag = *Acacia galpinii*, Al = *Albizia lebbeck*, As = *Acacia sayel*, Ds = *Dalbergia sissoo*

Source: Masutha *et al.* (1997)

The fertility status of soils under tree canopies gives a good indication of the amounts of nutrients being added by the tree. Other plants can use nutrients that are added to the soil through leaf litter. High concentrations of nutrient under the tree canopy are related to the organic matter content of the soil under the trees (Kadeba & Benjaminsen, 1976; Dangerfield, 1990; Hassink *et al.*, 1993). The litter inputs from trees is mixed with inputs from grasses, birds, insects and other animals which rest, live and eat under the trees (Belsky *et al.*, 1989; Georgiades, 1989).

Leaching of nutrients from the topsoil is regarded as a serious problem that reduces the concentration of nutrients in this layer. In agroforestry systems, plants with deep root systems play a vital role in retrieving nutrients that had leached down to the lower soil horizons. High concentration of nutrients beneath tree canopies could also be due to the presence of grazing animals (both wild and domesticated). Animals prefer to rest under trees when not engaged in other activities (Figure 2.8). They therefore, through urine and dung, concentrate nutrients collected from other areas of the grazing paddock on the soil under the tree canopy (Smit, 1999).

Birds also build their nests on the canopies of trees, for example, *Acacia* species (Figure 2.9). These trees have a dense canopy, which protect the birds against wind, sun and other predators. During their stay, birds deposited their droppings all over under the tree canopies. Bird's litter is a good source of nutrients (nitrogen, phosphorus, and potassium) (Smit, 1999).

Figure 2.8 Dairy cattle resting beneath the canopy of *Acacia erioloba* tree at Molelwane farm in the North-West Province, South Africa

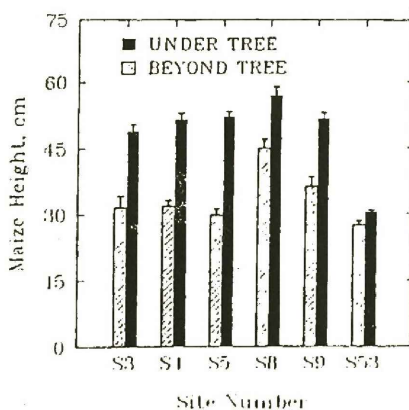


Figure 2.9 Bird's nests (A) in *Acacia erioloba* tree



Weil and Mughogho (1993) planted maize under and beyond the canopies of *Acacia albida* at two locations in Malawi. The results showed high stem height in maize that was planted under tree canopies than that planted beyond the tree canopy (Figure 2.10). There are a number of factors that could contribute to higher height of maize grown under the canopies of *Acacia albida*. These include: reduced temperature, reduced evaporation, increased organic matter, increased moisture retention, increased cation exchange capacity and increased nutrient concentration (Gliessmann, 1989). All these factors favor nutrients concentration, therefore making this site (sub canopy) an ideal place for crops to grow.

Figure 2.10 Height of maize grown beneath and beyond the canopy of *Acacia albida* in Malawi



Source: Weil & Mughogho (1993)

Some scientists have focused their attention on the changes in soil properties under tree canopies that would contribute to nutrient cycles and concentration. Radwanski and Wickens (1981) conducted a study to observe differences in soil properties between soil found under *Azadirachta indica* and Bare fallow. The results (Table 2.4) showed that nutrient concentration in soils under trees were higher than the adjacent bare soil. Except for soil phosphorus, soils under the canopy of *Azadirachta indica* showed a high concentration of pH, organic carbon, nitrogen, total exchangeable base, cation exchange capacity and base saturation than adjacent soils. This finding suggests that *Azadirachta*

indica trees are capable of enhancing nutrient concentration under their canopies compared to a bare area. The implication of the results is that crop farmers can include the trees in agroforestry systems in order to reduce the use of commercial fertilizers and to improve the fertility status of their soils.

Table 2.4 Comparison of soil properties in soil under *Azadirachta indica* and bare fallow

Soil properties	Fallow under <i>Azadirachta indica</i>	Bare fallow
pH	6.8	5.4
Organic C (%)	0.57	0.12
Total N (%)	0.047	0.013
Phosphorus (ppm)	68	195
TEB (me/100g)	2.40	0.39
CEC (me/100g)	2.25	1.70
Base saturation (%)	98	20

TEB = Total exchangeable base
 CEC = Cation exchange capacity
 BS = Base saturation

Source: Radwanski & Wickens (1981)

Some researchers have realized that the concentration of nutrients under tree canopies differs from one tree to another. However, Young (1989) went far beyond this point. He also observed that the distance, as measured from the tree trunk towards the canopy margin, also played a role in determining the amount of nutrient concentration under the tree canopies. Table 2.5 shows that the concentration of nutrients tended to decrease from tree trunk towards the canopy margin. The results were however not consistent for all the parameters that were measured. For example, nitrogen concentration was higher next to the tree trunk and decreased towards the canopy margin (i.e. from 0.0 – 2.0). For organic

matter on the other hand, the concentrations were lower next to the tree trunk, but the concentration increased drastically in the third spot (1.0) but decreased again towards the canopy margin. In such experiments, one need to understand that it is not always possible to find that the concentration of nutrients would always be higher next to tree trunk and decrease gradually towards the canopy margin. These differences in concentration can be due to canopy size, age of tree, tree species and land-use system.

Table 2.5 Changes in soil properties due to distance from a tree crown

Soil properties	Distance from tree stem (in crown radii)				
	0.0	0.5	1.0	1.5	2.0
Total N (%)	0.088	0.067	0.06	0.045	0.043
Organic matter (%)	1.77	1.87	2.09	1.52	1.19
Exch. K me/100g	1.64	1.29	1.29	1.33	1.49
Exch. Na me/100g	0.73	1.23	0.93	1.09	0.78
pH	6.7	6.7	6.4	6.4	6.3

Source: Young (1989)

Virginia (1986) made a comparison of the concentration of nitrogen and phosphorus between two tree sites (i.e. under tree canopies and beyond tree canopies). He conducted his experiment under the canopy of *Prosopis glandulosa*. His results (Table 2.6) showed that both nitrogen and phosphorus concentration were higher under the tree canopies. The results showed significant differences between nutrient concentration under the tree canopy and away from the tree canopy. The concentration of nitrogen was 195 mg kg⁻¹ under the tree canopy and 62 mg kg⁻¹ beyond the tree canopy. Phosphorus concentration was 7.7 mg kg⁻¹ under the tree canopy and 0.8 mg kg⁻¹ beyond the tree canopy. These results indicate that *Prosopis glandulosa* tree is capable of cycling both nitrogen and phosphorus and can be thus effectively used in an agroforestry system.

Table 2.6 Concentration of nitrogen and phosphorus under *Prosopis glandulosa*

Nutrient	Concentration (mg kg ⁻¹)	
	Under canopy	Beyond canopy
N (NO ₃)	195	62
P (PO ₄)	7.7	0.8

Source: Virginia (1986)

Some researchers have used crop growth as an indicator of the higher concentration of nutrients under tree canopies. The influence of nutrients under the canopies of *Acacia albida* on growth of crops has been well documented in several parts of Africa (Poschen, 1986; Weil & Mughogho, 1993). However, yield increases beneath the tree canopies have not occurred in all cases. Poschen (1986), found 50% or greater yield increase in 20 out of 40 paired samples, but in 10 of the pairs, sorghum or maize yielded about the same or even less under *Acacia albida*. Considering the outcomes of this experiment, it is quite possible to find results that do not support the hypothesis that nutrients are always higher under tree canopies.

2.8 Role of agroforestry and other land-use systems on nutrient cycling

Agroforestry is defined as a system combining agriculture and trees of varying longevity (ranging from annual through biannual and perennial plants), arranged either temporally (crop rotation) or spatially (intercropping), to maximize and sustain agricultural yield (Lundgren, 1982). Livestock can be an important component of agroforestry systems. All of the components of agroforestry (trees, crops and animals) play an important role in the cycling and concentration of nutrients beneath the tree canopies.

The integration of trees with other agricultural activities is believed to enhance long-term sustainability and productivity of many agroecosystems. This is attributed to the role these trees playing in controlling erosion, maintaining soil organic matter, improving nutrient cycling and ameliorating microclimates (Steppeler & Nair, 1987). The degree to which

trees influence surface soil properties depends on the species of tree and the property measured.

Trees are capable of translocating nutrients from deep soil layers inaccessible to roots of most annual crops (Gliessman, 1989). Litter fall and decaying roots also tend to accumulate nutrients in the surface soil layers around the trees. Dancette and Paulain (1969) found that on a per hectare basis, *Acacia* trees contributed 5.3 tons of dry organic matter and 300 kg of nitrogen to the soil beneath their canopies. Large canopies intercept wind, precipitation, and solar radiation, as well as contribute to the organic matter and nutrients to the soil surface.

In the semi-arid savanna ecosystem, where there is a deficiency of nutrient elements (especially nitrogen & phosphorus), agroforestry is seen as a way of enhancing the cycling of these nutrients so that they can be made readily available for crops (Young, 1989; Kerkhof, 1990). Leguminous trees are considered as the best trees in agroforestry because they are capable of fixing atmospheric nitrogen. Non-leguminous crops that do not fix nitrogen can also benefit from this combination. In South Africa, agroforestry has involved the planting of various shrubs and legume trees such as *Acacia galpini*, *Acacia senegal*, *Acacia erioloba*, *Albizia lebbbeck*, *Cajanus cajan*, *Leucaena leucocephala*, *Virgilia divaricata* and *Dalbergia sisoa* together with food crops mostly in poor rural and peri-urban areas. The strategy of using trees was seen as a simple, better and cheapest means of maintaining soil fertility (Masutha *et al.*, 1997).

Another reason for advancing agroforestry system was to minimize the cost of commercial fertilizers and provide low cost energy timber for poor communities. *Acacia* trees are also regarded as multipurpose because they provide many opportunities to the communities and are thus ideal for agroforestry in the poor rural and peri-urban regions. The main reason of planting these trees in rural and peri-urban areas was that many of these areas fall under the semi-arid zones where the soil fertility status is poor and agricultural production is also low. Furthermore, there was a lack of knowledge to farmers on how to manage and conserve the soil for maximize yield production. (Burlley & Van Carlowitz, 1984).

In an agroforestry system, the contribution of roots in the nutrient concentration can also play an important role in nutrient cycling (Pritchett, 1979). Roots tend to increase the amount of soil organic matter. Combination of deep-rooted plants with shallow root crops enhances the cycling of nutrients in the ecosystem. Deep roots intercept and absorb nutrients into soil surface layers of the soil where the shallow roots can access them, so making nutrient cycle more closed (Atkinson *et al.*, 1983; ILCA, 1986; Young, 1988; Ong *et al.*, 1991). Another advantage of practicing agroforestry is that some tree species have the ability to change soil properties and increase fertility, especially in the wooded savanna regions (Dancette & Paulain, 1969).

Other land-use systems that have an impact on nutrient cycling include cultivation, fallowing and the introduction of pasture for grazing. Studies have shown that continuous cultivation tends to reduce the amount of organic matter and this in turn affect nutrient transformation and availability. The concentration of nutrients from cultivated field is thought to be much lower than the concentration of nutrients under some leguminous trees. For example, in the Goz sands of eastern Kordafan in Sudan, a comparison between soils of adjacent plots, one that had been continuously cultivated with agricultural crops for 30 years and the other that was under *Acacia senegal* for the same period, showed the significant differences (Table 2.7). A soil that was under continuous cultivation showed a lower concentration of organic nitrogen compared to that under *Acacia senegal* (65.0 ppm vs 110.0 ppm). Similar results were found for soil pH where soil pH was also low in cultivated soil (5.2) compared with soils under *Acacia senegal* (6.3).

Table 2.7 Comparison between continuously cultivated soil and soils under *Acacia senegal* tree

Soil properties	Continuous cultivation	<i>Acacia senegal</i>
pH	5.2	6.3
Organic nitrogen (ppm)	65.0	110.0

Source: FAO (1974)

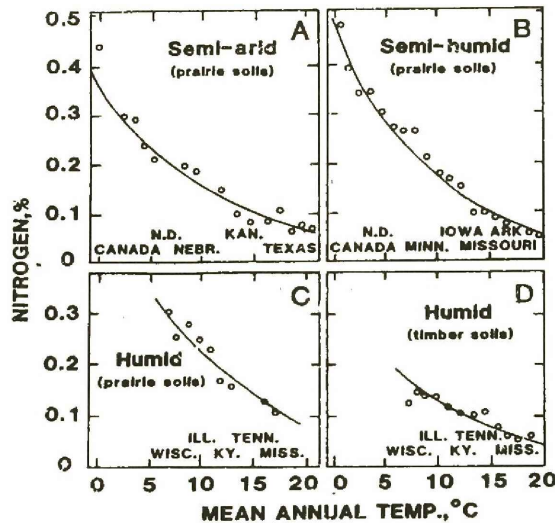
Fallowing is a practice where cultivated land is rested for a period in order to restore its fertility after a long period of cultivation. During the rest period, different kinds of plants and grasses grow on the soil. The plant species die and add organic matter to the soil. Plant materials can be incorporated into the soils so that they release nutrient elements that were locked in them during the growing period. Furthermore, as the plants grow, they cover the soil surface with their leaves thereby creating a microclimate around that area that is conducive to nutrient cycling. The microclimates that are formed include: reduced temperature and evapotranspiration, increased moisture content and increased organic matter. Most of these microclimates favour microbial activities that are the main agents of decomposition and mineralisation

The majority of plant species that tend to grow during fallow period are short season plants (annual plants) that grow very fast and die within a short period. Most of these plants have a low C: N ratio and are easily decomposed. The amount of nutrients that accumulated within the plants during the fallow is released during organic matter decomposition resulting in a reasonable increase in nutrient concentration in the soil. Growing leguminous plants in a fallow land helps to increase the amount of nitrogen through nitrogen fixation. Nye and Greenland (1960) estimated annual increase of nitrogen per hectare to be in the amount of 39 kg nitrogen in bare soil and 67 kg nitrogen in the vegetation under fallow forest.

2.9 The effect of climate on nutrient cycling in a savanna ecosystem

Climate is the most important single factor that determines the adaptation of plant species at any location. It also controls the quantity of plant material produced, and the intensity of microbial activity in the soil. Consequently, climate plays a prominent role in determining organic matter levels. Nutrient transformation and turnover in soils is largely affected by climatic changes and type of land-use. Climatic factors that control nutrient cycling include temperature and precipitation. Jenny and Raychaudhuri (1960) made extensive studies on the effect of climate on nitrogen (N) levels in the soil. The result from a North and South transect in semi-arid, semi-humid and humid regions of the USA are shown in Figure 2.11. In each case the N content of the soil was two to three times lower for each 10 °C rise in mean annual temperature.

Figure 2.11 Average Nitrogen content of the soils as related to mean annual temperature



Source: Jenny & Raychaudhuri (1960)

Several explanations have been given for the decrease in soil nitrogen and carbon levels with an increase in mean annual temperature (Jenny & Raychaudhuri, 1960; Scholes & Sanchez, 1990). In cold climates, for example, the soil is frozen for a good portion of the year and biological activities of microorganisms and higher plants are reduced. In semi-arid areas (Prairie soils) soil nitrogen was in the range 0.2 - 0.45 % at mean annual temperature between 0 - 5 °C. However, as the mean annual temperature increased from 5 - 15 °C, nitrogen dropped from 0.2 - 0.1 %. The nitrogen concentration dropped drastically as the mean annual temperature increased from 18 - 20 °C. This experiment gives an explanation on why semi-arid savanna areas have lower amounts of nitrogen and other nutrients.

2.10 The influence of fire on nutrient cycling in a savanna ecosystem

The role of fire in the maintenance of structure and function in African savannas is probably the oldest issue in savanna ecology, although certain aspects remain contentious (Phillips, 1965, 1968; Scholes & Walker, 1993). Fire is used as a means of clearing vegetations for cultivation in most forest and savanna zones. Burning has its advantages and disadvantages. Cass *et al.*, (1984), have reviewed literature on the effects of fire regime in soil properties of Southern African ecosystems, including the savannas. Since the inorganic nutrients are mostly returned to the soil in the form of ash, there is seldom a significant change in the total amount of available basic cations, but sometimes an upward shift in their distribution in the profile. Carbon, nitrogen, phosphorus, and sulphur, are partially or completely lost to the atmosphere in wild fires. The nitrogen, phosphorus, and sulphur returned to the soil in the ash are in available inorganic form.

Materechera *et al.*, (1998) reported that if the grazing land is properly burned, the following amount of nutrients could be returned into the soil through ash: N (31 kg ha^{-1}), P (5.1 kg ha^{-1}), K (58.7 kg ha^{-1}), Ca (64.3 kg ha^{-1}), Mg (13.2 kg ha^{-1}). Aduayi and Ekong (1981) reported that burning increased the supply of nutrients in the soil solution. Burning also raised the pH and the concentration of nutrients (Ca, Mg, K, Na and P) in the surface layers likely due to the abundance of these nutrients in the ash (Aduayi & Ekong, 1981).

Repeated burning on the other hand has been suggested as the cause of lower than average organic matter content of savanna soils (Materechera *et al.*, 1998). According to Rasmussen and Collins (1991), 50-70 % of the carbon residues are lost as CO_2 during burning. Organic nitrogen is volatilised as N_2 or oxides of nitrogen (Raison *et al.*, 1985). Burning can damage quantity and quality of organic matter returned to the soil. Biederbeck *et al.*, (1994), for example, reported an accumulated loss of organic carbon and total nitrogen where cereal straw had been burned for over 20 years. Allen (1964) reported losses of 80 %, 53 % and 61 % for nitrogen, sulphur and carbon respectively during the burning of Canadian cullar vegetation. Nutrient cycling processes can thus be destroyed if burning is not properly timed. This happen through loss of organic matter content which is the storehouse of soil nutrients. It was also reported that fire decreased the root mass from 1755 kg ha^{-1} to 450 kg ha^{-1} (Snyman, 2002). Fire destroys most of the nutrient sources

such as plant residues, organic matter and root residues and therefore reduces the nutrient cycling processes.

One of the effects of burning is that the above ground parts of savanna vegetation are not returned to the soil, but merely provide ash (Jones *et al.*, 1990). Some of the nutrients in the vegetation are lost in burning (particularly nitrogen and sulphur) while some are lost through leaching and in run-off before plants can take them up the following wet season (Daubenmire, 1968). Burning therefore decreases the organic matter input into savanna soils resulting in the generally low organic matter contents of these soils (Kowal & Kassam, 1978). Christensen (1973) and Ruess and McNaughton (1987) have reported greater quantities of available nitrogen in burned and grazed soils.

2.11 General description of *Acacia erioloba* tree

2.11.1 Introduction

Acacia species belong to the family *mimosaceae*, which is the third largest woody plant family in Southern Africa (Carr, 1976; Smit, 1999). The genus *Acacia* is one of the most widespread and important in Africa. Its species are dominant over extensive tracts of land, especially in tropical and subtropical areas and in Southern Africa. *Acacia erioloba* is commonly known as Camel thorn (English), Kameel boom (Afrikaans), Mokala (Tswana), Mpatsaka (Sotho). It is found in the dry savanna environment of Southern Africa, including Namibia, Zimbabwe, Botswana and South Africa (Carr, 1976). In South Africa, the tree is found in parts of Northern Cape, Western Free-State, Mpumalanga, and North-West province (Smit, 1999). A typical *Acacia erioloba* tree is presented in Figure 2.12.

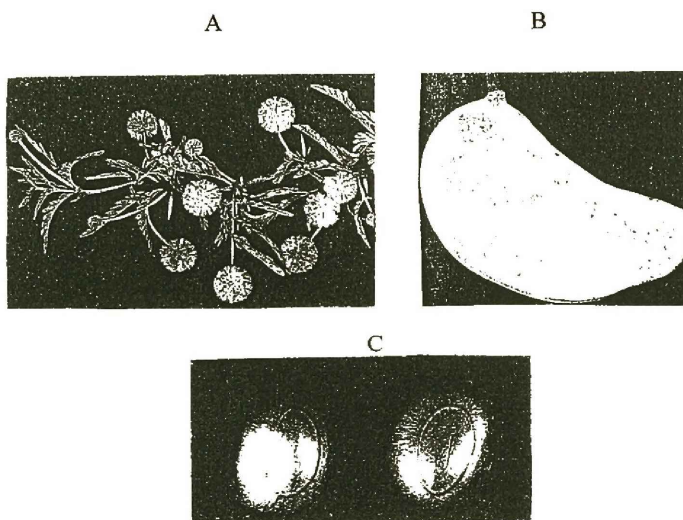
Figure 2.12 The Camel Thorn Tree (*Acacia erioloba*)



2.11.2 Seed availability and seedling establishment

Acacia erioloba produces large quantity of seeds. Seeds are contained inside the pods. Each pod can contain up to 24 seeds. The number of pods produced is determined by the age and size of the tree. Pods are usually sickle- shaped. Mature pods can attain a length, measured on the curve of 60 - 150 mm, a width of 15 - 50 mm and thickness of up to 15 mm. The pod is hard, woody and is indehiscent. The seeds are dark red-brown to purplish-black in colour with a mean size of 8 - 14 x 7 - 10 mm (Carr, 1976; Smit, 1999). Cattle eat the fallen mature pods of *Acacia erioloba* and subsequently the seeds are dropped throughout the veld in dung heaps (Viswanath *et al.*, 2000). Figure 2.13 indicates the flower, pod and seeds of *Acacia erioloba* tree.

Figure 2.13 Flower (A), pods (B) and seeds (C) of *Acacia erioloba* tree



2.11.3 Growth and development of *Acacia erioloba* tree

The height of a fully-grown *Acacia erioloba* tree can be up to 22 m and the trunk can have a diameter of up to 1.5 m. The tree is semi-deciduous with dark grey but sometimes blackish-brown bark. Thorns are in pairs at nodes that are spaced at intervals from 20 -50 mm. There may be from 1 - 7 leaves per node with a yellow stem. Flowering normally takes place from late august through mid-October, commencing before, or together with the appearance of new leaves. Flowers have been observed as late as December. Flowers are bright yellow and sweetly scented.

2.11.4 The significance of *Acacia erioloba* tree in a community

Acacia erioloba is a multipurpose tree (Burley & Van Carlowitz, 1984). The wood of *Acacia erioloba* is used as firewood and for charcoal. The tree grows very large and has been used locally for the construction of furniture. The wood may also be used as durable poles and fence-posts. Tourism as an industry for wooden carvings made from this tree is also expanding at a fast rate. The bark, leaves, fruits, roots, and flower have traditionally been used as food and medicines for people. For example, the bark of *Acacia erioloba* is burnt, crushed and used in treating headaches. In some countries, the tree gum is used as

glue. Binnate leaves allow inter (mixed) cropping with food crops. *Acacia erioloba* tree has a dense canopy that provides shade for homesteads and livestock.

The presence of *Acacia erioloba* in a grazing land provide for an additional feed source to a variety of game as well as domestic stock. *Acacia erioloba* act as a habitat for several creatures (both small and big). Flowers of *Acacia erioloba* form an important food supplement for many game species and livestock. Many insects also depend on this tree for food. The pods are highly palatable with a high crude protein content and play an important role in the nutrition of herbivores. Pastoralists who actively collect pods to feed their livestock have long realized the value of the pods and seeds as a feed supplement during the dry season. The pods of *Acacia erioloba* are favoured because they contain up to 6 % crude protein and the seeds up to 33 % crude protein and 3.5 % fat. The leaves may contain up to 17 % crude protein with a digestibility of 35 % (Smit, 1999). However, the pods and young leaves of *Acacia erioloba* contain prussic acid and may cause poisoning in livestock. It has been shown that milk yield increased in cattle that were fed with *Acacia erioloba* pods (Palgrave, 1991).

CONCENTRATION OF SOIL NUTRIENTS BENEATH CANOPIES OF *ACACIA ERIOLOBA* TREES UNDER DIFFERENT LAND-USE AND MANAGEMENT PRACTICES

3.1 Introduction

The concentration of plant nutrients is influenced among other factors by land-use and management practices. Higher nutrient concentrations beneath tree canopies have been related to greater organic matter input to the soil beneath the trees (Kadeba & Benjaminsen, 1976). Other mechanisms which have been associated with high nutrients beneath the tree canopies are the importation of organic matter by birds, insects and other animals which rest, live and eat in or beneath trees (Belsky *et al.*, 1989; Georgiades, 1989) and symbiotic nitrogen fixation by some savanna trees including *Acacia erioloba* (Bernhard-Reversat, 1982). Some studies have shown that the size of the canopy and age of tree also influences the concentration of nutrients beneath tree canopy (Jung, 1970; Roos & Allsopp, 1997).

The different land-use and management practices that are used in the villages of the semi-arid areas of North-West province can cause differences in the physical, chemical and biological properties of the soil. Changes in land-use and management practices can alter the patterns of organic matter accumulation within the soil. Any changes that affect organic matter also affects the concentration and cycling of nutrients. Long term studies have demonstrated that soil organic matter accumulation in agriculture are affected by land-use and management practices such as crop rotation, tillage, mulching, manipulation of soil fauna and the application of nutrients and organic amendments (Biederbeck, *et al.*, 1994; Campbell *et al.*, 1999).

The accumulation of organic matter is largely determined by land-use practice, climate as well as trees and grasses around the area. Land-use practices such as burning of the veld, uncontrolled grazing and continuous cultivation may reduce the amount of plant residues that would be transformed into organic matter. This in turn reduces the mineralisation and cycling of nutrients. Leaves of the tree together with grasses and other herbaceous plants

that grow beneath tree canopies can also add large amount of organic matter. Organic matter is a storehouse of plant nutrient and is closely related to soil fertility, soil structure and permeability (Thompson & Troeh, 1978). The objective of this study was to quantify the concentration of nutrients beneath the canopies of *Acacia erioloba* trees, and to see if land-use practices have an influence on this concentration. The hypothesis being tested was that the concentration of nutrients would be higher beneath tree canopies compared to areas beyond tree canopies. The specific questions to be answered by this study were:

- Does nutrient concentration in soil beneath the canopy of *Acacia erioloba* differ from that beyond the tree canopy?
- How do different land-use practices influence the concentration and distribution of nutrients beneath the canopy of *Acacia erioloba*?

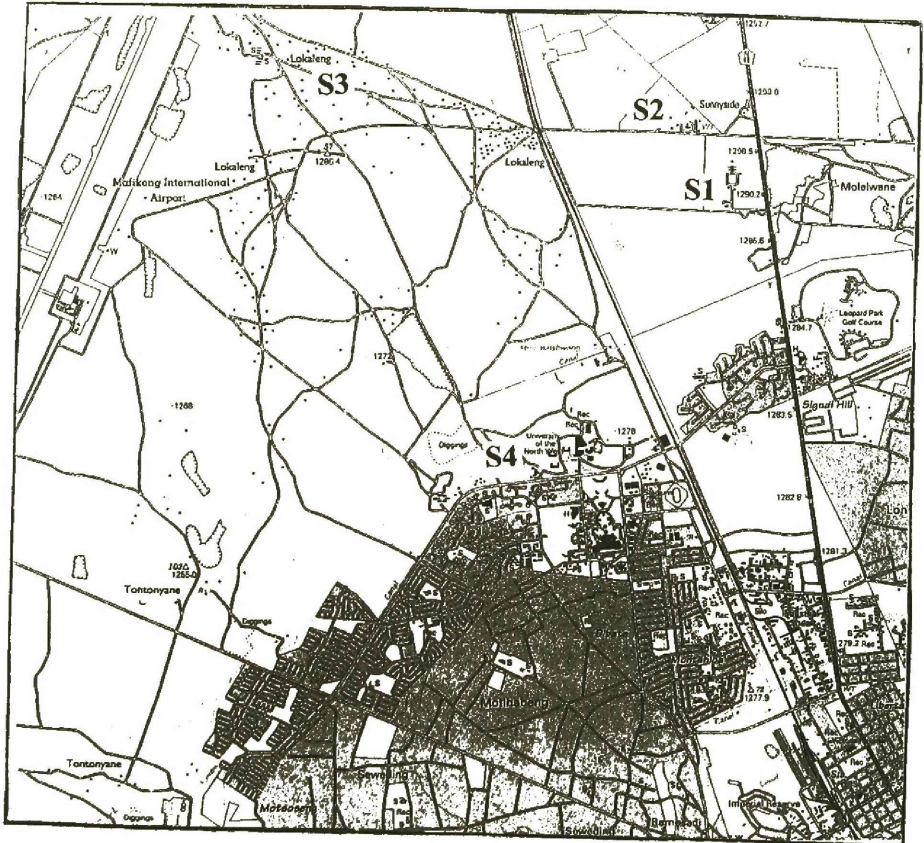
3.2 Methodology

3.2.1 Description of study area

3.2.1.1 Location and vegetation

The study was conducted in areas surrounding the city of Mafikeng in the North-West province of South Africa (Figure 3.1). Mafikeng lies at approximately latitude 25° 48' S and longitude 25° 38' E. The municipal area slopes from 1410 m asl in the east and 1210 asl in the west (Schulze, 1984). The area has a typical savanna climate (Anon, 1999). The vegetation around the area consists of a mixture of grasses and other small plants with an upper layer of scattered trees and shrubs. The dominant grass species include *Cynodon dactylon*, *Chloris virgata*, *Eleusine africana*, *Panicum maximum* and *Urochloa mosambicensis*. The most common trees that are found in the area include *Acacia erioloba*, *Acacia karoo*, *Acacia tortilis*, *Terminalia sercia* and *Ziziphus mucronata* (Morake, 1983).

Figure 3.1 Map of Mafikeng showing the study areas and the location of the University of North-West



S1 = Fallow (Group 20 army battalion)

S2 = Grazing (University farm)

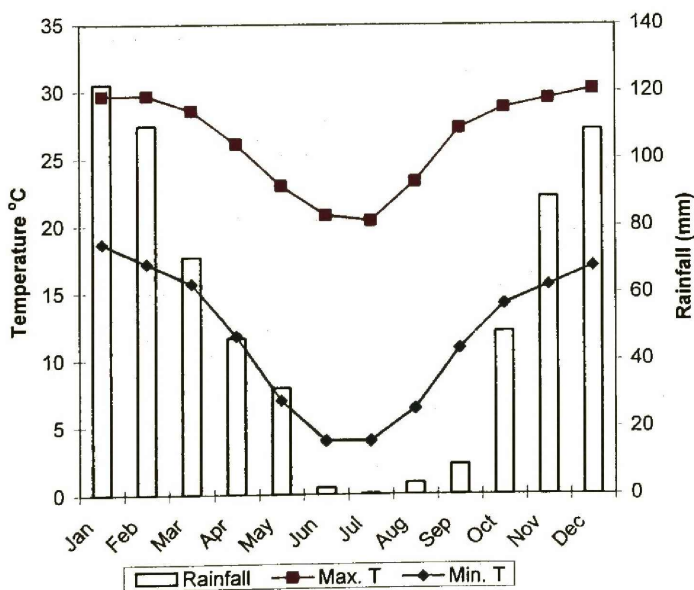
S3 = Bare (Lokaleng)

S4 = University of North-West

3.2.1.2 Climate

The greater Mafikeng area has a dry and semi-arid climate. It is characterized by low rainfall (475 mm yr⁻¹). More than 90 % of the rain falls in the summer months from November to April. It also has a clear atmosphere that allows high absorption and radiation of solar energy leaving little moisture available for plants (Pritchett, 1979). The winter is dry and night frost occurs. The dry season extends from May to October. The mean monthly minimum and maximum temperatures vary from 4.0 °C in July to 17.1 °C in January and 20.4 °C in July to 29.7 °C in January respectively. The long-term (12 years) mean rainfall and temperature for the area are presented in Figure 3.2

Figure 3.2 Long-term (12 years) rainfall and temperature for Mafikeng



Source: Data was obtained from the University of North-West's Molelwane farm meteorological station for the period 1989-2000

3.2.1.3 Soil type

The predominant soil found in the study area is a red sandy loam classified by the South African classification system as a Hutton series. The soils are usually deep and display a rapid drainage (Soil Classification Working group, 1991). The water holding capacity is very low and plants usually suffer moisture stress. Both crusting and hard setting are common in the soil. Soil pH ranges from 5.5 - 6.8 and is favourable for growth of most arable crops. Soil bulk density values can range from about 1.5 - 1.8 g/cm³ due to poor soil structure and susceptibility to compaction (Kowal & Kassam, 1978). The cation exchange capacity of these soils is very low and ranges from 3-20 meq 100 g⁻¹. Because of their mineralogy, those soils are inherently low in phosphorus (0-15 mg kg⁻¹). Nitrogen is also relatively low (0.08-1.5 %) and the cultivated soils are usually very low in organic matter (Kowal & Kassam, 1978). Table 3.1 shows a general description of a typical soil profile in the area.

Table 3.1 Description of a typical soil profile in the study area

HORIZON	DEPTH (mm)	COLOR ^a			STRUCTURE	CONSISTENCY	
		Hue	Value	Chroma		DRY	MOIST
A	0 -300	YR	4	6	CRUMB	LOOSE	LOOSE
B	300 -750	YR	5	6	BLOCKY STRUCTURE	HARD	FRIABLE

Source: Obtained from a soil profile dug at Molelwane farm in 1999

^a Munsell soil color chart

3.2.1.4 Land-use practices

The major land-use and management practices in the study areas are shown in Table 3.2. Trees are planted around homesteads for shade. Most of the land in the study area has traditionally been used for the cultivation of crops such as maize, millet, sorghum and sunflower. Some pieces of land are used for livestock grazing (mostly cattle, goats and sheep) off the natural vegetation while some is left fallow (to regain soil fertility after a period of cultivation). The shaded cells in Table 3.2 represent the land-use practices that were used in this study. A common feature in all the land-use practices in the study area is the presence of *Acacia erioloba* trees that are selectively and deliberately protected and left to grow within the systems.

Table 3.2 The major land-use practices and their descriptions in the study area

Land-use practices	Description
Bare land	Land around Homesteads where the leaves and other inputs are removed by raking and brushing. Trees are left especially for shade
Cropping	Land is used for cultivation and growing of different crops especially maize.
Fallow	A rested land that was previously used for cultivation and grazing
Grazing (Veld)	Land where livestock is communally grazed without any control. Uncontrolled veld fires usually burn the veld annually late winter.

The fallow was selected to test the claim that nutrients are recycled much better in a rested or undisturbed piece of land compared to other land-use practices (Radwanski & Wickens, 1981; Young, 1989). There is a lot of land that is under fallow in the study area. In the veld, animals tend to deposit dung and urine beneath tree canopies during grazing. The interaction between animals and vegetation in the grazing land was considered important in the cycling of nutrients. Areas beneath tree canopies in homesteads were used as a control

as there was no addition of organic matter to the soil from any sources, since the areas are always kept clean.

The three land-use practices common to the study area that were targeted include: grazing, fallow and bare area (control). The land-use practices were located within close proximity (< 7.0 km) of Molelwane Farm of the University of North-West and from each other (Table 3.3). Each land-use practice had been under the same management for at least past seven years and covered an area of at least 3.5 km². *Acacia erioloba* trees are found in all the study areas.

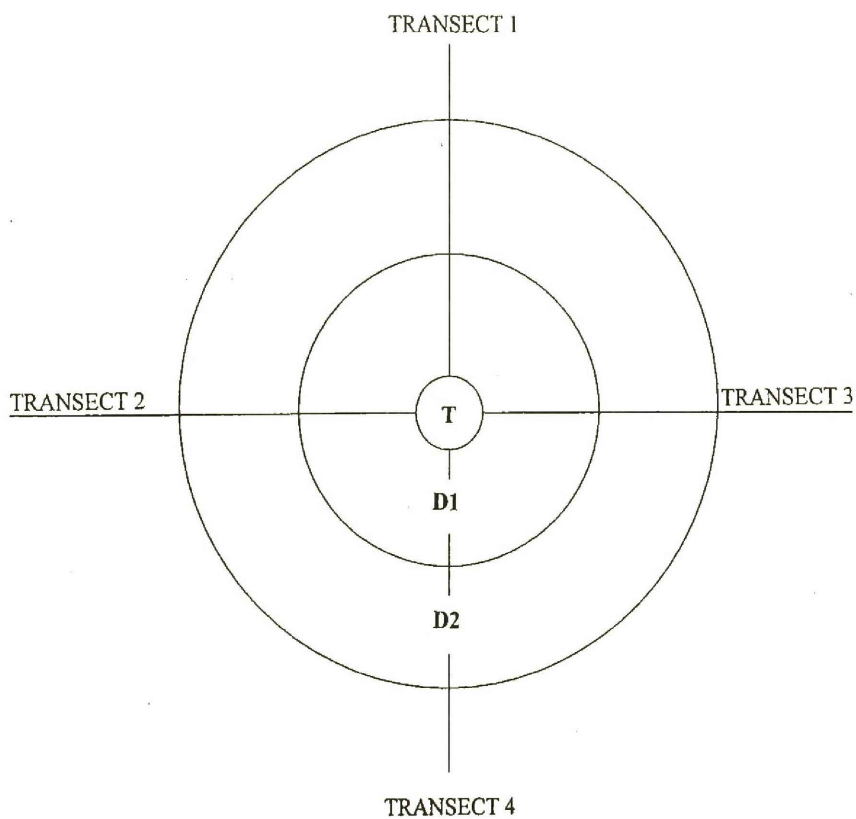
Table 3.3 Distance (km) from one land-use practice to another

Land-use practice	Distance (km)
Grazing to Fallow	1.5
Grazing to Bare (control)	5.0
Fallow to Bare (control)	6.5

3.2.2 Experimental units and design

At each land-use practice, three mature trees of *Acacia erioloba* were randomly selected for the study. A tree – soil – transect method was utilized for collecting soil samples at each tree (Figure 3.3). The approach involved drawing four lines at right angles to each tree across the tree trunk (T) and area covered by the tree canopy (D1). The transects were extended beyond the tree canopy by the same distance of the beneath tree canopy (D2). The locations D1 and D2 are hereafter referred to as ‘beneath’ and ‘beyond’ *Acacia erioloba* canopies respectively. For purposes of statistical analysis, the study was considered to be a factorial design. A three level factorial design was used. There were three levels of land-use practice, two canopy locations (D1 and D2) within each tree and two soil depths (0-10 and 10-20 cm) within each canopy location.

Figure 3.3 Tree – soil – transect method used for soil sampling within each tree



T = TREE TRUNK

D1 = BENEATH THE TREE CANOPY

D2 = BEYOND THE TREE CANOPY

3.2.3 Characteristics of selected *Acacia erioloba* trees within each land-use practice

Before commencing soil sampling, the characteristics (height, collar diameter and canopy diameter) of the individual trees in each land-use practice were measured. Tree height was measured by using 10 m calibrated poles and standing them along the tree. Stem and canopy diameters were measured by using a measuring tape. Two similar trees that were not selected for the study were cut down in order to estimate annual biomass production. Annual biomass production was estimated by weighing all the leaves that were collected from the branches of each of the two trees. Both stem rings and knowledge of the local people was used to estimate the ages of trees used in the study. The characteristics of the trees used in the study are presented in Table 3.4.

3.2.4 Soil sampling procedure

Soil samples were collected between March and May 2001 using a bucket auger 6.5 cm in diameter. At each depth, 12 sub-samples were collected randomly from the quadrant between two transects (Figure 3.3) in each canopy location of a tree within each land-use. The sub-samples were bulked to obtain about 3.0 kg soil. The four samples from the four quadrants of each tree were used as replicates. The bulk soil was air dried and sieved through a 2.0 mm sieve and stored in plastic bottles for analysis.

3.2.5 Collection of leaf samples for analysis

Leaf samples were collected from three *Acacia erioloba* trees in each land-use practice. Leaf samples were collected between March and May 2001. A pruning shear was used to cut branches of trees and all the leaves were removed by hand. The leaves were stored in plastic bags. The leaves from the three trees within each land-use practice were mixed to form one bulk sample. The bulk leaf sample was dried in the oven at 60°C for 48 hours, ground in a Willey mill with a 1.0 mm mesh and analysed for nutrient content.

Table 3.4. Characteristics of *Acacia erioloba* trees selected for the study within each land-use practice

Land-use practice	Tree Number	Height (m)	Collar Diameter (m)	Canopy Diameter (m)	Estimated age (year)	Tree leaf biomass (kg yr ⁻¹)
Fallow	1	8.00	0.73	3.90	42	41.50
	2	7.50	0.50	3.00	38	38.30
	3	7.40	0.46	2.05	27	23.00
	<i>mean</i>	7.63	0.56	2.98	36	34.27
Grazing	1	7.40	0.55	3.35	30	33.00
	2	6.60	0.30	3.80	37	34.50
	3	7.50	0.55	3.60	38	36.50
	<i>mean</i>	7.17	0.47	2.58	35	34.67
Bare	1	7.80	0.54	3.40	37	34.20
	2	7.50	0.40	3.15	35	32.00
	3	7.25	0.35	3.55	33	30.45
	<i>mean</i>	7.52	0.43	2.19	35	32.22

3.2.6 Methods of analysis

3.2.6.1 *Leaf tissues*

Total nitrogen was determined by the micro-Kjeldahl procedure outlined by Okalebo *et al.*, (1993). The procedure involved digesting a sample of leaves with sulphuric acid (H_2SO_4). This was followed by steam distillation in the presence of excess alkali (NaOH). The distillate was titrated with 70 %HCl until the colour changed from green through grey to a definite pink. Total phosphorus, extractable zinc and manganese were determined in a perchloric acid digestion. Total phosphorus was determined by a spectrophotometer at a wavelength of 660 nm while zinc and manganese were determined by atomic absorption spectrophotometer. The carbon content of the leaves was determined by the sulphuric acid and aqueous potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) mixture (Okalebo *et al.*, 1993).

3.2.6.2 *Soil*

Soil samples were analyzed for particle size distribution, pH, available phosphorus (P), extractable calcium (Ca), Magnesium (Mg), potassium (K), zinc (Zn), manganese (Mn) and total nitrogen (N) using the following procedures:

3.2.6.2.1 Particle size distribution

A 50 g sample of air – dried soil was dispersed in calgon and distribution of particles sizes was measured with a hydrometer using the method outlined by Okalebo *et al.*, (1993). A mechanical shaker was used to achieve a complete dispersion. Soil texture was obtained from the particle size distribution by using a textural triangle.

3.2.6.2.2 pH (H_2O)

pH of the soil was measured in a supernatant of 1:5 (soil:water) ratio using a glass-calomel electrode. Ten (10) g of air-dried soil was weighed and 50 cm^3 of de-ionised water was added in a beaker. The solution was stirred rapidly for five seconds with a glass rod, and allowed to stand for 30 minutes. After 30 minutes, the solution was stirred again and allowed to stand for 10 minutes. pH was measured by dipping electrodes in the supernatant.

3.2.6.2.3 Available phosphorus (P)

Available P in the soil was determined using Bray-1 method (Bray & Kurtz, 1945). Each sample was extracted with 50 ml of Bray-1 extracting solution ($0.03\text{N NH}_4\text{F} + 0.025\text{HCl}$) and the filtrate was stored in extracting bottles. Phosphorus concentration was determined in the filtrate by the reduction of phosphomolybdic acid that yields an intense blue colour using a spectrophotometer at the wavelength of 660 nm.

3.2.6.2.4 Extractable Ca, Mg and K

Extractable cations (Ca, Mg and K) were extracted with 1 mol dm^{-3} ammonium acetate (NH_4OAc , pH 7.0) and filtered through a No. 42 Whatman filter paper. Ca and Mg were determined by atomic absorption spectrophotometer while K was determined by flame photometry.

3.2.6.2.5 Extractable Zn and Mn

Zinc and manganese were studied because several studies have shown that the deficiencies of these two elements is usually occurs in soil rich in organic matter and at pH values of 6.5-8.0 (Alexander, 1961). About 2.5 g of soil was mixed with 25 ml of EDTA solution. Each sample was stirred for 10 minutes using a magnetic stirrer. After 10 minutes of stirring, the soil solution was filtered into extracting bottles (100 ml) with Whatman No 42 filter papers. Zinc and manganese were determined directly on the undiluted extract with an atomic absorption spectrophotometer (AA).

3.2.6.2.6 Total nitrogen (N)

Total nitrogen was determined by micro-Kjeldahl procedure outlined by Okalebo *et al.*, (1993). A 0.2 gram sample of soil was digested in 4.4 ml of digestion mixture ($0.42\text{ g Se} + 14\text{ g Li}_2\text{SO}_4\cdot\text{H}_2\text{O} + 350\text{ ml of } 30\% \text{ H}_2\text{O}_2 + 420\text{ ml conc. H}_2\text{SO}_4$). Hydrogen peroxide (H_2O_2) was added as an additional oxidising agent. Selenium (Se) powder was used in order to raise the boiling point. Free ammonia was liberated from the solution by steam distillation in the presence of excess alkali (NaOH). The distillate was transferred into a conical flask containing boric acid (H_3BO_3) and titrated with $0.0025\text{-mol dm}^{-3} \text{H}_2\text{SO}_4$ in the distillate until the colour changed from green to faint pink.

3.3 Analysis of data

Analysis of variance (ANOVA) was conducted on each data using Statistical Analysis System (SAS) programme (SAS Institute Inc., 1985). The model used was:

$$Y_{ijkl} = \mu + Li + Sj + Dk + (LS)_{ij} + (LD)_{ik} + (SD)_{jk} + (LSD)_{ijk} + E_{ijkl}$$

Where:

μ = overall mean

Li = effects of the i^{th} land-use practice

Sj = effects of the j^{th} canopy location

Dk = effects of the k^{th} depth

$(LS)_{ij}$ = interaction of the i^{th} land-use and j^{th} canopy location

$(LD)_{ik}$ = interaction of the i^{th} land-use and k^{th} depth

$(SD)_{jk}$ = interaction of the j^{th} canopy location and k^{th} depth

$(LSD)_{ijk}$ = interaction of the i^{th} land-use, j^{th} canopy location and k^{th} depth

E_{ijkl} = residual

Duncan's Multiple Range Test and Student's t-tests were used to compare the means where significance was indicated (Sokal & Rohlf, 1969).

3.4 Results

3.4.1 Nutrient content in leaves of *Acacia erioloba*

There were obvious variations in the contents of nutrients from the trees under different land-uses (Table 3.5). It is suggested that these differences reflect the tree characteristics (age, canopy size) and the interaction with land-use.

3.4.2 Particle size distribution

There were no large differences in the particle size distribution between the soil beneath and beyond tree canopies (Table 3.6). This suggests that there was no effect of canopy location on texture. Similarly, the texture was the same on all the land-use system, which makes the comparison of the trees more meaningful.

Table 3.5 Nutrient content in *Acacia erioloba* leaves

Land-use practice	Tree No.	Total N (%)	Total P (mg kg ⁻¹)	Extractable Zn (mg kg ⁻¹)	Extractable Mn (mg kg ⁻¹)	Total C (%)	C : N ratio
Fallow	1	2.43±0.06	540.00±72.11	175.00±10.00	40.00±0.00	36.7±0.00	15:1
	2	2.40±0.00	420.00±72.11	223.33±5.77	38.33±2.89	37.1±0.35	16:1
	3	2.40±0.00	473.33±30.55	145.00±0.00	35.00±5.00	36.9±0.35	15:1
	Mean	2.41±0.02	477.78±58.26	181.11±5.26	37.78±2.63	36.9±0.12	15:1
Grazing	1	3.40±0.00	273.63±30.55	171.67±7.64	75.33±9.24	37.4±0.12	11:1
	2	3.40±0.00	500.00±34.64	166.67±10.41	55.00±0.00	37.3±0.12	11:1
	3	3.10±0.52	420.00±34.64	213.33±7.64	76.67±2.87	38.0±0.87	12:1
	Mean	3.30±0.17	397.78±33.28	183.89±8.56	69.00±4.04	37.6±0.37	11:1
Bare	1	3.40±0.00	453.33±61.10	183.33±5.77	41.67±2.87	39.0±0.00	12:1
	2	3.40±0.00	526.67±41.63	183.33±7.64	20.00±0.00	39.0±0.00	12:1
	3	3.40±0.00	626.66±30.55	181.67±15.28	45.00±0.00	39.0±0.00	12:1
	Mean	3.40±0.00	528.89±44.43	182.78±9.56	37.22±0.96	39.0±0.00	12:1

Values are means ± standard deviation

Table 3.6 Particle size distribution of soils in the study area

Land-use	Canopy location	Sand (%)	Silt (%)	Clay (%)	Texture
Fallow	Beneath	81	8	11	Loamy sand
	Beyond	83	8	8	Loamy sand
Grazing land	Beneath	82	7	11	Loamy sand
	Beyond	84	7	9	Loamy sand
Bare land	Beneath	82	12	6	Loamy sand
	Beyond	87	8	5	Sand
Mean	Beneath	82	9	9	Loamy sand
	Beyond	85	8	5	Loamy sand

3.4.3 Concentration of nutrients and pH in soil from *Acacia erioloba* trees

A summary of the ANOVA (Table 3.7) showed that the main factors had a significant influence on the concentration of nutrients although canopy location showed not to have a significant influence on the concentration of K, Ca, and Mg. Generally, the interactions of the main factors showed no significant different except in some few cases. For example, the interaction of canopy location and depth (S*D) was found to had no significant influence on the concentration of all nutrients that were measured while the interaction of land-use practices and canopy locations (L*S) showed to have a significant influence on the concentration of N, P, K, and Zn.

The effects of land-use practices on the concentration of nutrients and pH are presented in Table 3.8. Concentration of nutrients was significantly influenced by land-use practices. The results showed that fallow had significantly higher ($P<0.05$) concentration of almost all nutrients compared to land under grazing and bare. As expected, bare land was found to have significantly lower ($P<0.05$) concentration of all nutrients that were measured.

Table 3.7 Mean squares of analyses of variance for N, P, K, Ca, Mg, Zn, Mn and pH in soil from beneath and beyond *Acacia erioloba* trees

Source	df	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
				K	Ca	Mg	Zn	Mn	
Land-use practice (L)	2	0.005**	3510.59**	202345.89**	142128.95**	1718573.17**	380.10**	6482.45**	0.69
Canopy location (S)	1	0.0003**	355.81	116251.74**	213.36	8798.83	43.69**	806.55**	2.42**
Depth (D)	1	0.0206**	1698.29**	44326.85**	1276920.77**	217845.84**	37.70**	4147.31**	0.01
L*S	2	0.0004**	750.72**	30970.34**	235103.15	8822.94	36.70**	119.39	8.83**
S*D	1	0.000001	3.42	10960.39	817.85	111953.24	1.72	2.46	0.09
L*D	2	0.0009**	253.03	1937.07	97623.83	63514.75	7.13**	710.05**	0.20
L*S*D	2	0.00003	3.27	1582.76	143337.44	869.67	4.13	9.87	0.59
Error	96	0.00003**	100.54**	4792.47**	78758.97**	24368.67**	1.56**	119.40**	0.39**

** P < 0.01

Table 3.7 Mean squares of analyses of variance for N, P, K, Ca, Mg, Zn, Mn and pH in soil from beneath and beyond *Acacia erioloba* trees

Source	df	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
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Error	96	0.00003**	100.54**	4792.47**	78758.97**	24368.67**	1.56**	119.40**	0.39**

** P < 0.01

Table 3.8 Effect of land-use practices on the concentration of soil nutrients and pH in soils from *Acacia erioloba* trees

Land-use practice	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
			K	Ca	Mg	Zn	Mn	
Fallow	0.03±0.01a	16.2±15.9a	124.5±20.3a	958.8±331.0 a	582.4±263.5a	1.7±0.9a	49.6±15.3a	6.3±0.9a
Grazing	0.05±0.02b	21.4±11.6b	244.4±122.1b	873.8±370.1a	319.5±93.2b	6.9±2.9b	50.1±16.6a	6.5±0.5b
Bare	0.02±0.01c	2.3±1.9c	106.4± 68.6c	80.1±182.1b	148.7±13.8c	1.1±0.6c	26.6±3.0b	6.2±0.6c

Values are means ± standard deviation; n=36

Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

The effect of canopy location on the concentration of nutrients and pH is indicated in Table 3.9. The results show that the presence of tree canopies had a significant influence on the concentration of some nutrients (K, P and Zn as well as pH). Canopy location showed not to have any significant influence on the concentrations of N, Ca, Mg, and Mn.

Table 3.10 shows the influence of depth of sampling on the concentration of nutrients and pH in soils from under *Acacia erioloba* canopies. The results showed that the concentration of nutrients differed from one soil layer to the other. Soils that were collected from the surface layer (0-10 cm) were found to have significantly higher ($P < 0.05$) concentrations of all nutrients compared to those that were collected at 10-20 cm depth.

The influence of land-use practices and canopy location on the concentration of nutrients and pH is shown in Table 3.11. The results showed that there was a significant difference ($p < 0.05$) on the concentration of some of the nutrients on soil from beneath and beyond *Acacia erioloba* canopies under the different land-use practices. Concentration of nutrients beneath and beyond *Acacia erioloba* canopies showed no significant differences except for phosphorus. The concentration of N, K, Zn and Mn in land under grazing showed to be significantly higher especially beneath tree canopies. Bare land shows a similar trend as those in fallow, but the concentration of nutrients was much lower compared to fallow and grazing lands.

The influence of soil of soil depth on nutrient concentration in the different land-use practices is presented in Table 3.12. Generally, the concentration of nutrients was significantly higher ($p < 0.05$) in soils from the 0-10 cm depth compared to those soils that were collected at the depth of 10-20 cm in all the land-use practices. The pH of soil under grazing land was however higher in the 10-20 cm layer compared to the 0-10 cm layer.

There was also a significant effect of canopy location and soil sampling depth on the concentration of nutrients in the soils (Table 3.13). In both canopy locations (beneath and beyond), significantly high ($p < 0.05$) nutrient concentrations were found in the 0-10 cm compared to 10-20 cm depth. The interaction of canopy location and depth was however not significant for soil pH.

Table 3.9 Effect of canopy location on the concentration of soil nutrients and pH

Canopy location	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
			K	Ca	Mg	Zn	Mn	
Beneath canopy	0.04±0.02	15.1±15.2	191.3±114.7	805.7±283.3	341.2±248.6	3.9±3.4	44.8±16.6	6.2±0.8
Beyond canopy	0.03±0.02	11.5±12.4	125.6±74.2	802.8±397.6	359.3±233.7	2.6±2.3	39.3±17.2	6.5±0.7
t - test	ns	*	**	ns	ns	**	ns	*

Values are means ± standard deviation; n=54

* = P < 0.05

** = P < 0.01

ns = not significant

Table 3.10 Effect of soil depth on the concentration of nutrients and pH in soils from under *Acacia erioloba* canopies

Soil depth (cm)	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
			K	Ca	Mg	Zn	Mn	
0-10	0.05±0.02	17.2±15.3	178.7±112.8	912.9±341.2	395.1±267.5	3.8±3.4	48.3±18.9	6.4±0.8
10-20	0.02±0.01	9.3±11.3	138.2±85.4	959.4±421.9	305.3±202.3	2.7±2.9	35.9±12.3	6.3±0.7
t - test	**	**	*	**	*	*	**	ns

Values are means ± standard deviation; n=54

* = P < 0.05

** = P < 0.01

ns = not significant

Table 3.11 Nutrient concentration and pH of soils from beneath and beyond *Acacia erioloba* trees

Land-use practice	Canopy location	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
				K	Ca	Mg	Zn	Mn	
Fallow	Beneath	0.03±0.01b	23.1±19.6c	124.7±16.9b	958.3±218.2b	576.4±283.8c	1.8±1.0a	53.1±13.9bc	5.7±0.7a
	Beyond	0.03±0.01b	9.2±6.1b	124.3±23.7b	959.4±421.9b	588.4±249.6c	1.5±0.6a	46.1±16.1bc	7.0±0.8c
Grazing	Beneath	0.05±0.02d	19.7±8.5c	301.5±137.9d	995.4±350.7b	293.5±112.0b	8.8±2.5c	54.1±12.8c	6.4±0.6b
	Beyond	0.04±0.02c	23.1±14.0c	187.3±68.9c	952.2±382.1b	345.5±52.6b	5.2±2.1b	45.9±19.2b	6.5±0.5b
Bare	Beneath	0.02±0.01a	2.5±2.2a	147.6±46.1bc	663.3±182.9a	153.6±12.3a	1.0±0.3a	27.2±3.3a	6.5±0.7b
	Beyond	0.02±0.01a	2.1±1.6a	65.3±63.2a	496.9±142.2a	143.8±13.8a	1.2±0.8a	25.9±2.7a	5.9±0.4a

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

Table 3.12 Influence of soil depth on the concentration of nutrients and pH in soils from *Acacia erioloba* trees under different land-use practices

Land-use practice	Depth (cm)	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
				K	Ca	Mg	Zn	Mn	
Fallow	0-10	0.05±0.051d	19.9±16.5c	137.8±15.7b	1078.9±285.7c	671.3±267.6d	2.1±0.9b	54.9±15.3c	6.4±1.1a
	10-20	0.02±0.061b	12.3±14.8b	111.3±15.3ab	838.6±336.7b	493.6±233.6c	1.2±0.5ab	44.2±13.5b	6.3±0.9a
Grazing	0-10	0.07±0.009e	20.1±11.1c	272.3±140.4d	1027.9±357.1c	360.2±86.9b	8.1±2.3d	61.1±15.8c	6.4±0.5a
	10-20	0.03±0.006c	14.7±7.6bc	216.5±96.6c	719.6±322.8ab	278.8±82.7b	5.9±3.0c	39.1±7.8 b	6.5±0.6a
Bare	0-10	0.03±0.003c	3.7±1.7a	126.1±75.9ab	632.0±144.2a	153.9±13.1a	1.4±0.6ab	28.8±1.6a	6.2±0.8a
	10-20	0.01±0.003a	0.9±0.9a	86.8±57.8a	528.2±188.8a	143.5±12.9a	0.8±0.5a	24.3±2.4a	6.2±0.5a

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

Table 3.13 Effect of soil depth on nutrient concentration and pH as influenced by the location of canopy within *Acacia erioloba* trees

Canopy location	Depth (cm)	Total N (%)	Available P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)					pH
				K	Ca	Mg	Zn	Mn	
Beneath	0-10	0.05±0.02c	18.9±16.4c	221.7±126.3c	911.6±291.9b	396.6±283.7b	4.4±4.0c	51.2±17.7b	6.2±0.8a
	10-20	0.02±0.01a	11.3±13.1ab	160.9±94.5b	699.7±234.8a	285.7±197.8a	3.4±3.7bc	38.5±12.8a	6.2±0.7a
Beyond	0-10	0.05±0.01b	15.6±14.2bc	135.8±78.6ab	914.3±389.2c	393.6±255.6b	3.3±2.7b	45.4±19.8b	6.5±0.8a
	10-20	0.02±0.01a	7.3±8.7a	115.5±69.6a	691.4±379.9a	324.8±208.6ab	1.9±1.5a	33.3±11.5a	6.5±0.7a

Values are means ± standard deviation; n=27

Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

3.5 Discussion

The observation from this study shows that the soil from beneath *Acacia erioloba* canopy had significantly higher concentration of some of the nutrients than that from beyond the canopy. This is consistent with findings of other studies elsewhere. Several authors have studied soil properties in paired soil samples taken beneath and beyond *Acacia albida* trees (Dancette & Paulain, 1969; Weil & Mughogho, 1993; Roos & Allsopp, 1997). Weil and Mughogho (1993) reported approximately twice as much concentration of total nitrogen, exchangeable cations and organic carbon beneath *Acacia albida* canopies. Dancette and Paulain (1969) found that the *Acacia* tree they studied contributed 5.3 tons of dry organic matter and 300 kg of nitrogen to the soil beneath their canopies. In this study, quantification of nutrient concentration by *Acacia erioloba* trees was achieved by comparing the concentration of nutrients in soils from beneath and beyond canopy of each tree (*Acacia erioloba*) that was selected.

It was found that the concentration of nutrients differed from one land-use practice to the other depending on their management. Only two soil layers (0-10 and 10-20 cm) were examined and the results showed that the concentration of nutrients beneath and beyond *Acacia erioloba* canopies differed from one soil layer to the other. The question of the sources and mechanisms of soil enrichment beneath *Acacia erioloba* canopies remains largely unexplained. Both the literature and results of this study suggest that there are important mechanisms that had contributed to the higher concentration of nutrients beneath *Acacia erioloba* canopies. These mechanisms include: Organic matter from grass and leaf litter, nitrogen fixation by *Acacia erioloba* trees and the continuous presence of grazing animals. These mechanisms will be discussed separately.

3.5.1 Contribution of nutrients made by organic matter from leaf litter and grass

Organic matter from grass and leaf litter from *Acacia erioloba* trees are being suggested as the possible sources of the higher nutrient concentration in soils from beneath the tree canopies. Organic matter contains every element that is essential to plant growth. These elements are released and made available to plants as the organic matter decomposes, but not all at the same time and rate. Smit (1999) estimated that *Acacia tortillis* tree produced about 2.32 ton litter per hectare annually. This litter was found to contain 29 % leaves, 14

% flower, 26 % pods and 31 % shoots. An analysis in this study showed the leaves of *Acacia erioloba* trees to contain 3.2 % nitrogen, 471.7 mg kg⁻¹ phosphorus, 47.1 mg kg⁻¹ manganese and 182.5 mg kg⁻¹ zinc. By using the approximate annual leaf biomass production of a tree given in Table 3.4, it is estimated that the amounts of nutrients that can be returned into the soil from leaf litter of a single *Acacia erioloba* tree were, 1.07 kg N, 0.02 kg P, 0.002 kg Mn, 0.01 kg Zn. Leaf litter from *Acacia erioloba* trees and grass residues played an important role in the contribution to the available phosphorus in soils from beneath the tree canopies. Therefore, any material that can help in increasing phosphorus concentration in soil is considered very important in the cycling of phosphorus in this savannas environment.

Liberation, concentration and cycling of nutrients are largely dependent on the rate of organic matter decomposition. Decomposition is the process by which litter is oxidized or broken down and its rate determines how quickly nutrients like nitrogen are made available to plants and animal growth (Swift *et al.*, 1979; Jenkinson, 1965). Decomposition of organic matter is an important source of other nutrients such as phosphorus and sulphur. During the decomposition of organic matter, acids and other substances are produced that cause soil minerals to decompose and release plant nutrients. The rate of decomposition and nutrients mineralisation are largely influenced by the C:N ratio of plant materials. *Acacia erioloba* trees that were used in this study were found having an average C:N ratio of 13:1. Because of their low C:N ratio compared to 80:1 of grasses, *Acacia erioloba* leaves decomposes rapidly and nutrients are liberated back into the surface layers of the soil beneath tree canopies. An advantage of litter with low C:N ratio is that it decomposes very rapidly and release nutrients for plant growth (Scholes & Walker, 1993). Plants that grow beneath *Acacia erioloba* canopies could use the nutrients that are released from the decomposition. This is one of the reasons why *Acacia erioloba* trees have the potential of cycling nutrient very rapidly.

From literature and the results of this study, it was suggested that the dense canopy of *Acacia erioloba* tree creates a microclimates such as low temperature, high moisture content that favours microbial activities (Gliesmann, 1989). Microorganisms play a significant role in the decomposition of organic matter. For the organic matter to be decomposed and nutrients to be released, there should be microorganisms. The three most important groups of those microbes are bacteria, fungi and actinomycetes (Paul & Clark,

1989). During decomposition, a number of important reactions occur that have important implications for soil chemical and physical conditions. These include nutrient mineralisation, acidification (which result in enhanced phosphorus availability), and production of sticky polysaccharides that help in soil aggregation (Paul & Clark, 1989).

The transformation of nutrients due to organic matter decomposition is limited by a number of factors including: soil moisture, temperature, and the nature of the microorganisms and soil fauna active in the composition process (Witkamp, 1971). The low soil organic matter content (0.2-2 %) of savanna soils has been attributed to high temperatures, which lead to a high rate of organic matter decomposition. Low organic matter content is also due to the frequently sandy nature of savanna soils, and the predominance of low clay content, which does not encourage organic matter stabilisation. The results of this study showed that the soil contains high percentage (84 %) of sand and low (8 %) clay content. Relative higher soil moisture (1.56 %) was found in those soils that were collected beneath *Acacia erioloba* canopies at a depth of 20 cm compared to those that were collected from beyond the tree canopies (1.00 %). This may implies that the microbial activity may have been different between the two canopy locations due to the moisture.

3.5.2 Contribution of nitrogen by biological nitrogen fixation (BNF)

Although the exact amounts of nitrogen that was contributed to the soil by *Acacia erioloba* trees is not known, it is however expected that there was some, albeit small contribution. *Acacia erioloba* is a leguminous tree that is capable of fixing nitrogen from the atmosphere. Masutha *et al.*, (1997) found that *Acacia albida* produced 10.3 nodules per plant in 43 days after germinating compared to *Acacia erioloba* tree that produced only 2.0 nodules per plant. From these results, they also found that these two trees differ in their capacity to fix nitrogen. *Acacia albida* was reported to have fixed 55 mg N per plant while *Acacia erioloba* was able to fix only 6 mg N per plant. Bernhard-Reversat (1982) have shown that symbiotic nitrogen fixation by some savanna tree species is likely to increase the availability of nitrogen in soil beneath the tree canopies. These results indicate that the process of BNF also act as an important input of nitrogen because it fixes nitrogen from the atmosphere and bring it to the ecosystem (Dommergues, 1995).

3.5.3 Contribution of nutrients from grazing animals

Grazing animals have a significant contribution to the movement of nutrients through the soil-plant-animal system and thus on the fertility of soil under grazing land. This is because animals use only small proportion of the nutrients they ingest and return a large proportion (60-99 %) of the ingested nutrients to the soil in the form of dung and urine (Haynes & Williams, 1993). The amount of nutrients returned to the soil in dung and urine vary widely between farming systems. Some of the nutrients (e.g. K) are excreted mainly in urine whereas others (P, Ca, Mg, Mn and Zn) are excreted mainly in dung. Other nutrients, such as N and S are excreted in significant proportions in both dung and urine (Haynes & Williams, 1993). Nutrient partitioning between dung and urine can also vary depending on the nutrient content of the diet. Similarly, the nutrient content of the dung and urine can vary greatly between individual animals grazing the same herbage and for individual animals on different days and at different times of the same day (Haynes & Williams, 1993).

It was estimated that the grazing land in the study area (± 45 ha) accommodated at least 200 cattle at the time of the study. According to Safley *et al.*, (1984) cited by Haynes and Williams (1993) an average of 11.9 kg of dung and 5.28 litres of urine can be deposited by one animal per day. It was therefore estimated that an amount of 857 ton of dung and 380 160 litre of urine can be expected to be deposited over the grazing land annually. More than half of this dung and urine could be concentrated beneath *Acacia erioloba* canopies because the animals spent much of their time there. The approximate nutrient composition of dung and urine as suggested by Safley *et al.*, (1984) cited by Haynes and Williams (1993) is presented in Table 3.14. Using this composition and the estimated production of dung and urine from the animals, the estimated nutrient contribution by the two sources is given in Table 3.14. However, not all of these nutrients can be recycled back into the soil, some proportion would be lost due to leaching and volatilisation.

Table 3.14 Nutrient composition of cattle dung and urine and the estimated contribution to soil nutrients

Nutrient	Content (%)		Estimated Annual Contribution to the soil (kg yr ⁻¹) ^b		
	Dung ^a	Urine ^a	Dung	Urine	Total
N	29	1.2	124.2	21.9	146.1
P	12	0.02	51.4	0.38	51.8
K	8.4	0.8	36.0	15.1	51.1
Ca	12.8	0.02	54.8	0.32	55.1
Mg	6.3	0.06	27.0	1.09	28.1
Zn	0.2	0.002	20.9	0.0004	20.9
Mn	0.2	0.0002	20.9	0.0004	20.9

Source: ^aSafley *et al.* 1984 (Cited by Haynes & Williams, 1993)

^b An estimated amount of nutrients contributed from dung and urine of a mature cattle

Several authors have reported that the loss of nutrients particularly calcium, nitrogen and magnesium is greater under grazing land where there is manure compared to fallow land (Haynes & Williams, 1993). This can partly explain the reason why fallow was found to have higher concentration of calcium and magnesium compared to land under grazing. In land under fallow, many grasses also help in preventing excessive leaching of nutrients unlike in land under grazing where animals consumed many grasses.

3.5.4 Influence of trees on nutrient concentration

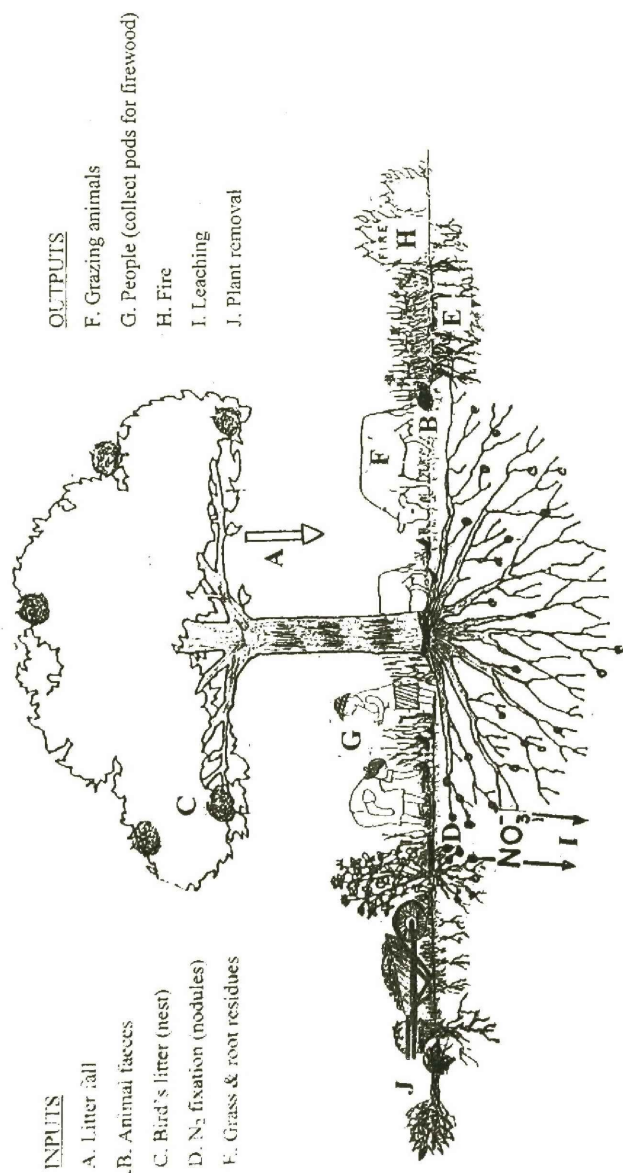
Several studies have indicated that trees play a significant role in the cycling of nutrients in the soil (Young, 1988; Wood & Burley, 1991; Weil & Mughogho, 1993; Masutha *et al.*, 1997; Buresh & Tiang, 1998). The influence of *Acacia erioloba* trees on the concentration of nutrients in soils differed from one tree to another. It was expected that higher amounts of organic matter would be found beneath canopies of older trees compared to smaller trees due to higher biomass production. Thus, the bigger tree, which had larger canopies, produced a larger amount of leaf litter that contributed to organic matter through leaf fall. The oldest *Acacia erioloba* tree (42 years) produced an estimated leaf biomass of 41.5 kg

yr⁻¹ while the youngest (27 years) produced leaf biomass of 23 kg yr⁻¹. Positive correlations between age and leaf biomass of *Acacia erioloba* trees were observed in all the land-use practices as follows: Fallow ($r = 0.995$), grazing land ($r = 0.882$) and Bare ($r = 0.995$). This may emphasise the significance of age and canopy size of a tree in nutrient cycling. Other tree characteristics that have been shown to influence nutrient cycling are the species and quality of the litter (Weil & Mughogho, 1989). Since the amount of leaf biomass produced by *Acacia erioloba* trees affect the pool of organic matter as well as the release of plant nutrients, this in turn would determine the amount of nutrients that can be recycled in the ecosystem by *Acacia erioloba* trees (Smit, 1999). Studies elsewhere have also shown that the amount of organic matter that accumulates beneath tree canopies is dependent on the age and density of the tree canopies. Jung (1970) found that small *Acacia albida* tree (approximately 100 m² canopy) had litter that produced 1.13 kg N, 0.4 kg P and 2.75 kg Ca per tree while big *Acacia albida* trees (approximately 200 m² canopy) produced litter that contained 4.3 kg N, 0.09 kg P and 5.1 kg Ca per tree.

Apart from attracting animals, birds and other insects, Gliessman (1989) reported that big trees tend to create a microclimate beneath their canopies that include reduced temperature, reduced evapotranspiration and increased microbial activities. It is suggested that these microclimates can have a significant influence on the rate of organic matter decomposition, nutrient release and concentration in soils beneath tree canopies. It was further observed in this study that more cattle were usually accommodated beneath the trees with larger canopies than those with smaller canopies. The increased number of animals beneath the tree implies that more dung and urine would be deposited beneath those trees than beyond the tree canopies. Animal manure is considered as one of the major sources of nutrients, particularly nitrogen and phosphorus (Christies, 1975; Belsky *et al.*, 1989).

Big trees are expected to have more extensive and deep root system compared to smaller ones (Ong *et al.*, 1991). The extensive and deep root system of trees could play an important role in retrieving nutrients that had leached to deeper soil layers. This process is referred to as “Nutrient pumping” by Atkinson *et al.*, (1983). Nutrient pumping has been cited as an important mechanism that increases the concentration of nutrients beneath tree canopies (Tiedmann & Klemmedson, 1977; Belsky *et al.*, 1989). Figure 3.4 illustrates the different mechanisms that would have been contributing to the concentration of nutrients in soils under the canopies of *Acacia erioloba* trees.

Figure 3.4 A simplified model showing possible inputs and outputs of nutrients beneath the canopy of *Acacia erioloba* tree in a semi-arid savanna environment



3.5.5 Influence of land-use and management practices on nutrient concentration

It has been reported that the physical, chemical and biological properties of a soil are largely influenced by land-use practices (Materchera & Mkhabela, 2001). Apart from altering chemical properties of the soil, land-use practices may also influence the concentration of nutrients beneath the tree canopies. The results of this study show a significant difference ($P < 0.05$) in the concentration of nutrients and pH in soil from different land-use practices. In the land under grazing, animals were allowed to move and graze freely across the land. The free movement of animals resulted in dung and urine being deposited over the entire place. As it has been already mentioned elsewhere, dung and urine are the good sources of nutrients (Christies, 1975; Belsky *et al.*, 1989). The animals thus act as movers of nutrients because they collect nutrient from other areas within the grazing field and concentrate them beneath the tree canopies. This could partly explain the high concentration of nitrogen and phosphorus that was observed in soil from grazing land (0.05 %, 21.4 mg kg⁻¹) compared to that from fallow (0.03 %, 16.2 mg kg⁻¹) and bare land (0.02 %, 2.3 mg kg⁻¹).

Another interesting observation made in this study was that while nitrogen and phosphorus concentrations were higher in soils from grazing than fallow land, the trend for calcium and magnesium was the opposite. The type of materials that were dominant in each land-use practice could explain this difference. Fallow was dominated by different species of grass while for the land under fallow, large amounts of grass residues were present. It was estimated that about 4114.5 kg ha⁻¹ of grass residues were produced annually in land under fallow compared to 1195 kg ha⁻¹ from land under grazing. The chemical composition of the grass is presented in Table 3.15. This table suggests that the contribution of nutrients made by grasses differ from one land-use to the other. Fallow had more grass biomass compared to grazing land and therefore had more nutrient retention than land under grazing. This is the reason why soils that were collected under fallow had more nutrients concentration than those from grazing and bare land-uses.

Table 3.15 Nutrient composition of grass and estimated nutrients contribution to soil nutrients in land under fallow and grazing

Nutrients	Chemical Composition (g kg ⁻¹) ^a	Nutrient Retention (kg yr ⁻¹) ^b	
		Fallow	Grazing
N	9.9	40.7	11.8
P	5.8	23.9	6.9
K	14	57.6	16.7
Ca	7.1	29.2	8.5
Mg	2.1	8.6	2.5
Zn	99	407.3	118.4
Mn	24	98.7	28.6

Sources: ^aThompson & Troeh (1978); Hagin & Tucker (1982)

^b An estimation of nutrients contributed by grass biomass from land under fallow and grazing

As expected, the results have showed that soil from bare (control) land had significantly lower concentration of all the nutrients compared to that from both fallow and grazing lands. This was due to the low organic materials that were added to the soil. However, this treatment confirmed the possible contribution of nutrients by the rhizosphere of the *Acacia erioloba* since there were significantly higher nutrient concentrations (N, P, Ca, Mg, Zn and Mn) in soils from beneath the canopy than that from beyond the tree canopy. The root biomass may have contributed some organic matter to the soil. Rhizodeposition of organic material occurs in several ways including the exudation of mucilaginous material that is dominated by polysaccharides. Input of organic materials also occurs from sloughing off of root tissues during root senescence. The conversion of very fine roots to those with secondary also thickening releases epidermal and cortical tissue. Root mortality is generally believed to contribute the most to soil organic matter in the rhizosphere. The high root biomass implies that the root density in the soil under grass would also be high. Thus, the contribution of organic matter by roots would be high under fallow and grazing land- use practices.

3.9 Conclusions

The study has answered all the questions that were asked at the beginning in the following manner:

1. How do soil nutrient concentration beneath the canopies of *Acacia erioloba* differ from those beyond the canopies? Do those concentrations change markedly with depth?

The study concluded that concentration of some nutrients (P, K and Zn) was influenced by the presence of *Acacia erioloba* trees. Significantly higher ($P < 0.05$) concentrations of these nutrients were found beneath canopies of *Acacia erioloba* trees. The higher concentrations were likely to be due to addition of organic matter from leaf litter, animal dung and grass residues. The finding that the concentration of nutrients was consistently higher in the surface (0-10 cm) than lower (10-20 cm) layers in all the land-use practices led to the conclusion that since the organic materials, dung and BNF take place mostly in the surface layers, they were the main factors that contributed to the high concentration of nutrients in the top soil. These processes are much less in the sub soil and thus the concentration changed markedly with depth. Tree characteristics such as age and size of canopy affect the concentration of nutrients.

2. How do different land-use practices influence the concentration and distribution of nutrients beneath the canopy of *Acacia erioloba*?

It has been shown that the concentration of nutrients in soils from beneath *Acacia erioloba* trees differed significantly from one land-use practice to another. Significantly higher concentration of some nutrients were found in land under grazing followed by fallow and bare land. It was therefore concluded that the concentration and cycling of nutrients is largely determined by land-use practices. Presence of grazing animals in land under grazing is considered to have played an important role in increasing the concentration of nutrients under this land-use practice.

GROWTH AND UPTAKE OF NUTRIENTS BY WHEAT GROWN IN SOIL COLLECTED BENEATH CANOPIES OF *ACACIA ERIOLOBA* TREES

4.1 Introduction

The degree to which *Acacia erioloba* trees influence nutrient content of soils beneath and beyond the canopy has been reported in Chapter 3. Differences in nutrient concentrations for soils collected from beneath and beyond *Acacia erioloba* canopies were especially pronounced for potassium, available phosphorus, and extractable cations (Zn). The differences in nutrient content of soils from beneath and beyond *Acacia erioloba* canopies can be quantified by measuring nutrient uptake and yields of crops grown in the two soils. Although there are no literature reports on the ability of *Acacia erioloba* to increase crop growth and yields, scientists and farmers have generally observed that crops grow better beneath some *Acacia erioloba* trees than in areas beyond the tree canopies. The influence of *Acacia albida* on growth and yields of crops has however been well documented in several parts of the African continent (Poschen, 1986; Gliessman, 1989; Weil & Mughogho, 1993). Millet, groundnut and sorghum have been reported to yield 1.5 to 3.0 times higher when grown beneath *Acacia albida* canopies than beyond the tree canopies. The better growth and increased yield of crops grown beneath *Acacia albida* canopies implies that there is an increased concentration of nutrients in this soil and that the nutrients are readily available for uptake by the understorey crops.

The objective of the study reported in this chapter was to quantify the uptake by a wheat crop of the nutrients from soils collected from under the canopies of *Acacia erioloba*. The hypothesis was that growth and nutrient uptake by wheat crop grown in soils from beneath *Acacia erioloba* canopy is higher than those wheat grown in soils from beyond the tree canopy

4.2 Methodology

4.2.1 Experimental units and design

The treatments consisted of three land-use practices, viz; fallow, grazing and bare land. Three trees were randomly selected from each land-use practice. Soil samples were collected from two canopy locations (D1 and D2) as described in section 3.2.2. Three pots were used as replicates for each canopy location. For the purpose of statistical analysis, the study was considered to be a two level factorial design. There were three levels of land-use practices and two canopy locations within each tree (D1 and D2).

4.2.2 Soil sampling procedure

Soil samples were collected between March and May 2001. A spade was used to collect the samples. Sub-samples were collected randomly from the quadrant between the transects (refer to chapter 3 Figure 3.3) at each canopy location of a tree within each land-use practice. Soil was collected at a depth of 0-20 cm. The samples from each quadrant were bulked to obtain about 5 kg soil. The bulk soil was air dried and sieved through 2.0 mm sieve.

4.2.3 Potting and seeding

About 320 g of soil was filled into PVC pots measuring 12 cm in diameter and 10 cm deep. A filter paper was placed at the bottom of each pot in order to enhance drainage of excess water. Wheat (*cv SST 57*) was used as a test crop to its high demand for nutrients during early stages of growth. The soil was watered with 20 ml of distilled water and 20 seeds of wheat were planted at a depth of 2 cm in each pot. The technique of using a very large number of seedlings in pots in order to exhaust the available nutrients within a short period of time has been commonly been referred to as the neubauer seedling technique (Kitchen, 1948). The pots were arranged on a large steel bench in a completely randomised design.

4.2.4 Management of pots

Soil in the pots was kept moist by watering daily with de-ionised water. After 5 days of planting, almost all seeds had germinated. Plants were grown for 23 days in a glasshouse at the University of North-West. When yellowing of leaf tops and purple colouration became visible, as evidence of nutrient depletion in the growing media, the experiment was terminated.

4.2.5 Harvesting and data collection

At the end of the growing period, plant height and dry matter yields of wheat seedlings in each pot were measured. Roots were retrieved by washing the soil over a 200 mm sieve. Plant height was measured from the base of each plant to the tallest leaf. Each plant was separated into roots and shoots (stem and leaves). The components were dried in the oven at 65°C for 48 hours and weighed to obtain root and shoot dry weight. A Willey mill with 1.0 mm mesh was used to grind the dry plant materials. All the ground materials were stored in glass bottles for analysis.

4.2.6 Analysis of nutrients in plant tissues

Total nitrogen was determined by the micro-Kjeldahl procedure outlined by Okalebo *et al.*, (1993). The procedure involved digesting a sample of leaves with sulphuric acid (H_2SO_4). This was followed by steam distillation in presence of excess alkali (NaOH). The distillate was titrated with 70 % HCl until the colour changed from green through grey to a definite pink. Total phosphorus, extractable zinc and manganese were determined in a perchloric acid digestion. Total phosphorus was determined by a spectrophotometer at a wavelength of 660 nm while zinc and manganese were determined by atomic absorption spectrophotometer.

4.2.7 Analysis of data

Analysis of variance (ANOVA) was conducted on each data using a statistical analysis system programme (SAS Institute Inc., 1985). The model used was:

$$Y_{ijk} = \mu + Li + Sj + (LS)_{ij} + E_{ijk}$$

Where:

μ = overall mean

Li = effects of the i^{th} land-use practice

Sj = effects of the j^{th} canopy location

$(LS)_{ij}$ = interaction of the i^{th} land-use and j^{th} canopy location

E_{ijk} = residual

Duncan's Multiple Range Tests at the 5 % level and Student's t-tests were used to compare the means where significance was indicated (Sokal & Rohlf, 1969).

4.3 Results

A summary of ANOVA for nutrients showed that all the factors had a significant influence on the concentration of nutrients in both shoots and roots of the wheat crop (Table 4.1). Generally, the interaction between land-use practices and canopy location ($L \times S$) was significant for almost all nutrients except N, P, and Mn in roots of the wheat crop.

The influence of land-use practices on the concentration of nutrients in roots and shoots of wheat seedlings that were grown on soils from *Acacia erioloba* trees is presented in Table 4.2. The concentrations of nitrogen, manganese and zinc were significantly higher ($p < 0.05$) in the shoots of wheat seedlings that were grown on soils from fallow and grazing. The concentration of nitrogen, phosphorus and manganese were found to be significantly higher ($p < 0.05$) in the roots of wheat seedlings that were grown in soils from fallow land compared to those grown in soils from grazing and bare land. The concentration of nutrients in both shoots and roots of wheat seedlings that were grown on soils from bare land-use was significantly lower ($p < 0.05$) compared to those from fallow and grazing land-use practices.

Table 4.3 shows that the concentration of all nutrients that were measured were significantly higher ($P < 0.05$) in the shoots of wheat seedlings that were grown on soils from beneath *Acacia erioloba* trees compared to those from beyond the tree canopies. A similar trend was observed in the roots of wheat seedlings.

Table 4.1 Mean squares of analyses of variance for N, P, Zn and Mn in plant tissues

Source	df	Total N (%)	Total P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)	
				Zn	Mn
Shoots					
Land-use practice (L)	2	0.17**	448007.41**	7047.69**	14353.24**
Canopy location (S)	1	0.38**	1447140.74**	138016.67**	113896.30**
L*S	2	0.07**	264674.07**	7 534.72**	875.46
Error	48	0.01**	15531.48**	837.27**	722.45**
Roots					
Land-use practice (L)	2	0.04**	305785.19**	50208.80**	88044.91**
Canopy location (S)	1	0.07**	201666.67**	139537.50**	121837.50**
L*S	2	0.01	8066.67	14626.39**	3176.39
Error	48	0.004**	4945.83**	1172.11**	3422.45**

** = $P < 0.01$

A comparison of the influence of canopy location on the concentration of nutrients in shoots and roots of wheat grown on soils from different land-use practices is presented in Figure 4.1. The results show that significantly higher ($p < 0.05$) nutrient concentrations were found in the shoots and roots of those wheat seedlings that were grown on soils from beneath *Acacia erioloba* canopies than those grown in soils from beyond the tree canopies.

Table 4.2 Effect of land-use practices on the concentration of nutrients in shoots and roots of wheat grown in soils from *Acacia erioloba* trees

Land-use practice	Total N (%)	Total P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)	
			Mn	Zn
<i>Shoots</i>				
Fallow	0.5±0.2a	1251.1±350.3a	135.3±59.62a	211.9±60.7a
Grazing	0.5±0.1a	1134.4±167.7b	118.9±59.6a	224.7±79.9a
Bare	0.3±0.1b	938.9± 96.2c	80.3± 41.7b	105.6± 34.2b
<i>Roots</i>				
Fallow	0.3±0.1a	505.4±105.3a	189.4±93.7a	186.7±82.2a
Grazing	0.3±0.1b	415.6±107.3b	265.0±84.6b	196.1±77.5a
Bare	0.2±0.1b	247.8± 64.7c	125.3±35.8c	100.3±21.8b

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at P < 0.05 by the Duncan's Multiple Range Test

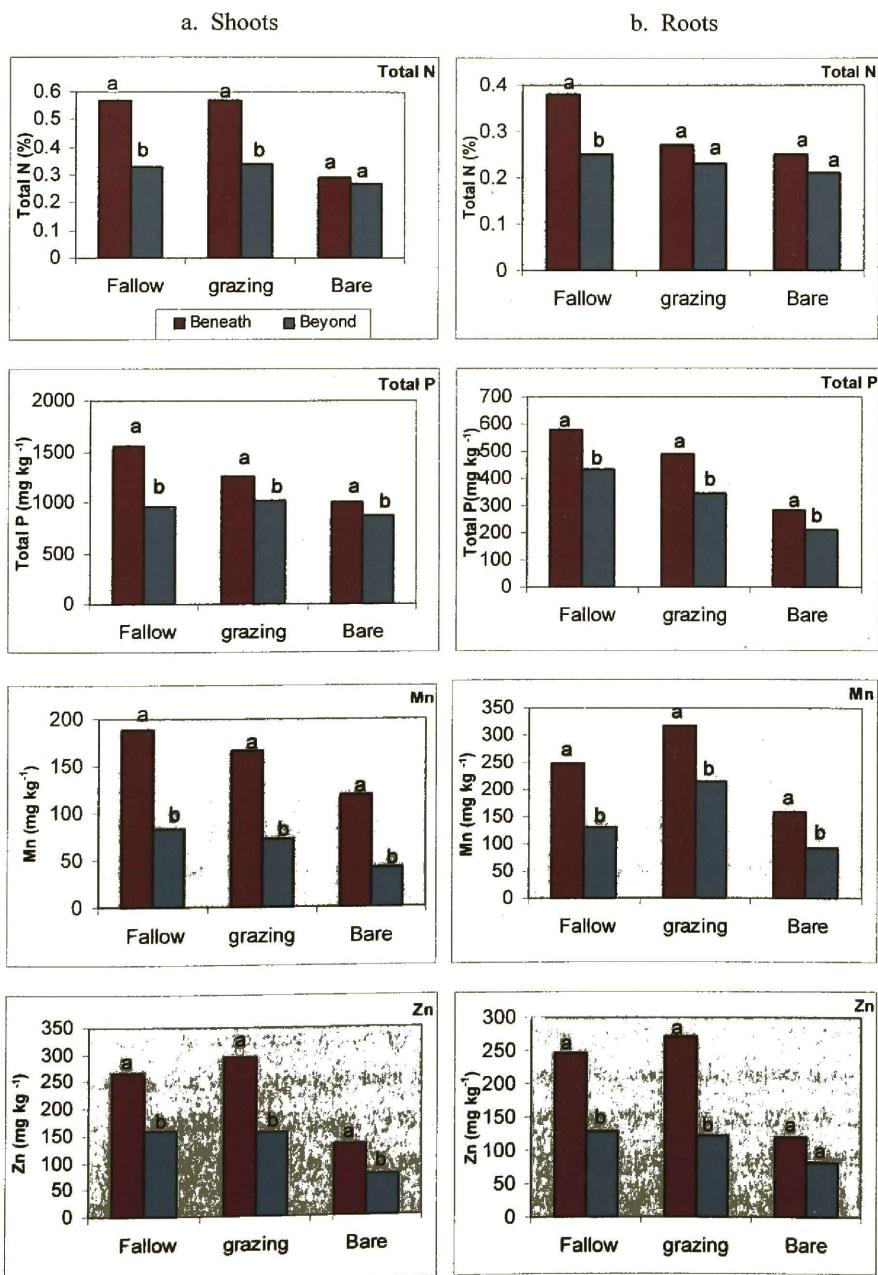
Table 4.3 Effect of canopy location on the concentration of nutrients in shoots and roots of wheat grown in soils from beneath and beyond *Acacia erioloba* trees

Canopy location	Total N (%)	Total P (mg kg ⁻¹)	Extractable cations (mg kg ⁻¹)	
			Mn	Zn
<i>Shoots</i>				
Beneath canopy	0.5±0.2	1271.1±350.3	157.4±45.2	231.3±78.8
Beyond canopy	0.3±0.7	944.4±144.5	65.6±21.4	130.8±42.8
t - test	*	*	*	*
<i>Roots</i>				
Beneath canopy	0.3±0.1	450.4±147.5	240.7±93.3	211.9±80.9
Beyond canopy	0.2±0.1	328.2±107.3	145.7±68.0	110.2±24.8
t - test	*	*	*	*

Values are means ± standard deviation; n=27

* = P < 0.05

Figure 4.1 Effect of canopy location on the concentration of nutrients in shoots and roots of wheat grown in soils from *Acacia erioloba* trees. Means within each land-use practice with similar letters are not significantly different by the Duncan's multiple range tests



A summary of the ANOVA for growth and dry matter yields of wheat (Table 4.4) showed that some of the main factors had a significant effect on the growth (plant height) and dry matter yields of wheat seedlings that were grown on soils from *Acacia erioloba* trees. The interaction of land-use practice and canopy location (L*S) was the only one that showed no significant influence on the growth and dry matter accumulation of wheat seedlings.

Table 4.4 Mean squares of analyses of variance for growth and dry matter yields of wheat

Source	df	Plant height (cm)	dry matter yields (g pot ⁻¹)	
			Shoots	Roots
Land-use practice (L)	2	212.15**	15.69**	5.34**
Canopy location (S)	1	78.00**	2.41	0.10
L*S	2	1.93	0.62	0.46
Error	48	4.00**	0.84**	0.65**

** = P < 0.01

The influence of land-use practices on growth and dry matter yields of wheat seedlings that were grown in soils from *Acacia erioloba* trees is presented Table 4.5. The results show a significant difference ($p < 0.05$) between the three land-use practices with respect to growth and dry matter yields of wheat seedlings. It was found that wheat seedlings that were grown on soils from grazing land had significantly higher ($p < 0.05$) plant height than those from fallow and bare lands. Dry matter yields were significantly higher ($p < 0.05$) in those wheat seedlings that were grown on soils from fallow than those from grazing and bare land-use practices.

Table 4.6 shows the influence of canopy locations on the growth and dry matter yields of wheat seedlings that were grown in soils from *Acacia erioloba* trees. The results show that there was no significant influence ($p < 0.05$) of canopy locations on the growth (plant height) and root dry matter yields. A significant influence ($p < 0.05$) of canopy locations was observed on the shoots dry matter yields of wheat seedlings that were grown in soils from beneath *Acacia erioloba* canopies compared to those from beyond the tree canopies.

Table 4.5 Effect of land-use practices on growth and dry matter yields of wheat grown in soils from *Acacia erioloba* trees

Land-use practice	Plant height (cm)	Dry matter yield (g pot ⁻¹)	
		Shoots	Roots
Fallow	20.9±2.2a	2.6±1.4a	2.6±1.1a
Grazing	16.4±2.9b	1.4±0.7b	1.8±0.7b
Bare	14.2±1.7c	0.8±0.3b	1.5±0.4b

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at $P < 0.05$ by the Duncan's Multiple Range Test

Table 4.6 Effect of canopy location on growth and dry matter yields of wheat grown in soils from beneath and beyond *Acacia erioloba* canopy

Canopy location	Plant height (cm)	Dry matter yield (g pot ⁻¹)	
		Shoots	Roots
Beneath canopy	18.4±3.6	1.8±1.4	2.0±0.8
Beyond canopy	15.9±3.4	1.4±0.9	1.9±0.9
t - test	*	**	ns

Values are means ± standard deviation; n=27

* = $P < 0.05$

** = $P < 0.01$

ns = Not significant

The influence of canopy location on growth and dry matter yields of wheat seedlings grown in soils from beneath and beyond *Acacia erioloba* trees is presented in Figure 4.2. The results show that plant height and dry matter yields from shoots under fallow and grazing land-use practices were significantly higher ($P < 0.05$) in those seedlings that were grown in soils from beneath the tree canopies.

Figure 4.2 Influence of canopy location on growth and dry matter yields of wheat grown in soils from beneath and beyond *Acacia erioloba* trees. Means within each land-use practice with similar letters are not significantly different by the Duncan's multiple range tests

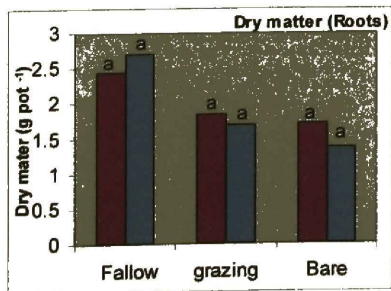
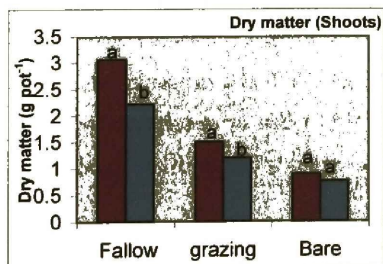
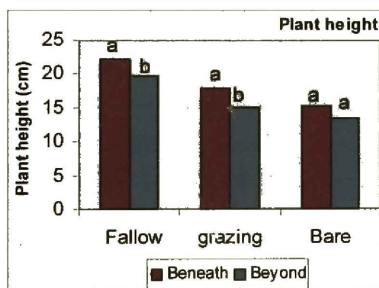


Figure 4.3 shows the performance (growth) of wheat seedlings that were grown in soils from beneath *Acacia erioloba* trees but from different land-use practices. Generally, the results show that wheat seedlings that were grown in soils from fallow had higher plant height compared to those grown in soils from grazing and bare lands.

Correlation coefficients between soil and plant nutrients were calculated for both roots and shoots of wheat seedlings (Table 4.7). The results show a strong correlation between some nutrients in the soil and plant tissues and weak correlations in others. There was a strong correlation between the following nutrients: nitrogen in shoots and phosphorus in soil (0.62*), nitrogen in shoots and manganese in soil (0.73**), phosphorus in shoots and phosphorus in soil (0.73**), phosphorus in shoots and manganese in soil (0.75**), zinc in shoots and phosphorus in soil (0.84**), zinc in shoots and manganese in soil (0.93**), manganese in shoots and phosphorus in soil (0.64*), manganese in shoots and manganese in soil (0.67*).

Strong correlations were also observed between phosphorus in roots and phosphorus in soil (0.58*), phosphorus in roots and manganese in soil (0.82**), zinc in roots and phosphorus in soil (0.88**), zinc in roots and manganese in soil (0.83**), manganese in roots and phosphorus in soil (0.72**), manganese in roots and manganese in soil (0.67*).

Figure 4.3 Comparison of growth of wheat seedlings grown in soils from *Acacia erioloba* trees under different land-use practices



- Key:
- 1 Wheat seedlings that were grown in soils from fallow land
 - 2 Wheat seedlings that were grown in soils from grazing land
 - 3 Wheat seedlings that were grown in soils from bare land (control)

Table 4.7 Correlation coefficients between nutrients in soil and plant tissues (shoots and roots)

	Shoot				Root			
	Total N	Total P	Zn	Mn	Total N	Total P	Zn	Mn
Soil								
Total N	0.35ns	0.31ns	0.53*	0.32ns	0.02ns	0.23ns	0.50*	0.68*
Available P	0.62*	0.73**	0.84**	0.64*	0.51*	0.58*	0.88**	0.72**
Zn	0.43ns	0.33ns	0.59*	0.23ns	0.02ns	0.38ns	0.52*	0.23ns
Mn	0.73**	0.75**	0.93**	0.67*	0.42ns	0.82**	0.83**	0.67*

* = P<0.05

**= P<0.01

ns= Not significant

4.4 Discussion

According to Hagin and Tucker, (1982) the amount of nutrients in a plant tissue is related to the amount of available nutrients in the soil. Ahn (1993) has shown that the addition of one nutrient to the soil increases its uptake in the leaf and may increase or decrease the uptake of other nutrients. The negative correlation coefficients between the nitrogen and plant tissue nitrogen observed here may suggest that the uptake of nitrogen by wheat seedlings did not only depend on the soil nitrogen. A weaker correlation coefficient was observed between soil phosphorus and zinc in plant tissues. This suggests that there could be an antagonist relationship between phosphorus and zinc. A high level of phosphorus reduces the availability and uptake of zinc by plant. High levels of phosphorus impede the uptake of zinc or its translocation within the plant. The interaction between phosphorus and zinc is due to a physiological effect of the crop and not to the formation of a zinc phosphate precipitate (Khan & Zende, 1977).

A positive correlation was found between available phosphorus from the soil and total phosphorus in plant tissues. This suggests that the available soil phosphorus influenced the concentration of total phosphorus in the plant tissues. Hagin and Tucker (1982) have shown that the uptake of phosphorus by roots increased with increasing phosphorus concentration in a soil solution only up to a certain limit. A similar trend was observed on the behaviour of trace elements (Mn and Zn) because they also showed positive correlations. These results differ with the findings of Ohki *et al.*, (1975) who reported that supplying zinc could reduce the manganese content of corn by 40 %. The distribution of nutrients within the plant was different. Nutrients such as manganese were higher in the roots of wheat seedlings while others such as nitrogen, phosphorus and zinc were higher in the shoots. This difference in concentration of nutrients according to the plant parts is likely to be due to the availability and mobility of nutrients as well as the specific functions of each nutrient within the plant. Plant roots have a definite selectivity for uptake of certain ions compared with others. The ionic composition of aerial parts of a plant is different from that of parts in soil solution.

Accumulation of dry matter in wheat crops is determined by the amount of nutrient that are absorbed in the soil. Significantly higher dry matter yields were found in those wheat seedlings that were grown on soil from beneath *Acacia erioloba* canopies. This may imply that high concentrations of nutrients were available in soil beneath *Acacia erioloba* trees compared to that from beyond the canopies. The seedlings grown on soil from land under fallow and grazing had higher dry matter yields than bare land due to the high amount of organic matter content. Similarly, the concentration of nitrogen and phosphorus was higher in wheat seedlings that were grown on soils from fallow and grazing lands practices compared to those from bare land-use practice.

Wheat seedlings that were grown on soils from grazing and fallow had significantly higher ($p < 0.05$) concentration of nutrients in their tissues compared to those from bare land. A similar trend was found for root and shoot dry matter yields. These results were consistent with those of soil test and may support the claim that *Acacia erioloba* tree canopy played a role in concentrating nutrients in the soil beneath its canopy. Apart from increasing organic matter into the soil through leaf litter, the tree also attracted cattle beneath their canopies and thereby increased the nutrient concentration through dung and urine. Nitrogen may also have been added through the fixation of atmospheric nitrogen.

4.5 Conclusion

It is concluded that the nutrient elements that were in soils from beneath *Acacia erioloba* trees were available and taken up by wheat plants. This was reflected by the higher amounts of nutrients in the shoots and roots of wheat seedlings that were grown on soils from beneath *Acacia erioloba* trees compared to those from beyond *Acacia erioloba* canopies. It is suggested that *Acacia erioloba* trees played a significant role in increasing nutrients in the soil beneath its canopy. It is concluded that the uptake of almost all nutrients was significantly higher in land under fallow and grazing compared to those under bare land due to high accumulation of organic matter in the latter.

BIOLOGICAL PROPERTIES OF SOIL BENEATH CANOPIES OF *ACACIA ERIOLOBA* TREES

5.1 Introduction

A canopy of *Acacia erioloba* tree creates a microclimate beneath the tree that can alter the composition and activity of soil biota. Soil biota is the main driving force behind nutrient and energy transformations in soils (Banerjee *et al.*, 1999). Soil biota affect nitrogen availability to plants by transforming organically held nitrogen into inorganic plant-available form (Roper & Gupta, 1995a). Because soil organisms and their activities strongly affect soil properties and processes, and their abundance is largely to be affected by land-use and management practices, they serve as important indicators of soil quality (Karlen *et al.*, 1997). Soil quality is defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries.

Soil organic matter (SOM) refers to all the organic materials found in the soil including litter, light fraction, microbial biomass, water-soluble organics and humus (Stevenson, 1994b). Because of the importance of soil organic matter on soil fertility, it is undoubtedly a key attribute of soil quality (Gregorich *et al.*, 1994). SOM influences other soil characteristics such as nutrient mineralisation potential, cation exchange capacity and aggregate stability. A decrease in soil organic matter is concomitant with a decrease in soil biological activity, which is a cause for concern in agriculture because biologically mediated processes are fundamental to ecological functioning (Gregorich *et al.*, 1994).

Soil microbial biomass (MB) is defined as the small (0-4 %) living component of soil organic matter excluding macro-fauna and plant roots (Dalal, 1998). Although soil microbial biomass constitutes a small proportion of soil organic matter, the composition and activity of soil microbial communities largely determine biogeochemical cycles, turnover processes of organic matter, and fertility of soils (Jenkinson & Ladd, 1981). Microbial biomass is fundamental to organic matter cycling and carbon sequestration by the soil since it is both an agent for decomposition of plant residues and sink for carbon, nitrogen, phosphorus, sulphur and other nutrients (Dalal, 1998). Microbial biomass has

been reported to be useful in determining the changes that occur in soil due to any agricultural management or practice (Roper & Gupta, 1995b). Similarly, POM is closely linked to soil productivity and it has the capacity to furnish plants with nutrients such as nitrogen (Dalal & Mayer, 1986). This fraction is considered more sensitive than total soil organic matter to change due to management practices (Biederbec *et al.*, 1994). The objective of the work reported in this chapter was to quantify the influence of *Acacia erioloba* trees on the biological properties of soil and to establish the role of land-use practices on soil quality.

5.2 Methodology

5.2.1 Experimental units and design

The experimental units and design that were used in this study are similar to those described in chapter 3 (section 3.2.2)

5.2.2 Soil sample collection

Fresh soil samples were collected from the three land-use practices (grazing, fallow and bare land) between March and May 2001. Soil was collected using the method described in chapter 3 (section 3.2.3). Soil samples were placed in airtight plastic bottles and were immediately stored in the refrigerator.

5.2.3 Measurements

5.2.3.1 Soil organic carbon (OC)

Soil organic carbon (OC) was determined by the wet oxidation method (Walkley & Black, 1934). One gram of soil was digested in 20 ml concentrated sulphuric acid (H_2SO_4) and 10 ml aqueous potassium dichromate ($\text{K}_2 \text{Cr}_2 \text{O}_7$). After complete oxidation, the remaining $\text{K}_2 \text{Cr}_2 \text{O}_7$ was titrated against 0.5 N Ferrous ammonium sulphates. The used $\text{K}_2 \text{Cr}_2 \text{O}_7$, the difference between added and residual $\text{K}_2 \text{Cr}_2 \text{O}_7$, was used as a measure of organic carbon content of the soil. Each sample was replicated three times.

5.2.3.2 *Microbial biomass carbon and nitrogen*

Microbial biomass was determined by the chloroform fumigation technique (Jenkinson & Powlson, 1976). Two 10-gram sub-samples were weighed, one of which was extracted (unfumigated) in 0.5 M K_2SO_4 . The other was placed in a vacuum desiccator over alcohol-free chloroform and stored in a dark cabin for 5 days at room temperature (fumigated). After 5 days, the soil was transferred into watertight bottles and extracted with 0.5 M K_2SO_4 . The extracted solution was filtered on a No. 42 whatman filter paper and the clear filtrate was used to measure microbial biomass N and C. Each sample was replicated three times. Microbial biomass carbon (MBC) was determined using the complete 'wet' oxidation method by acidified potassium dichromate (Anderson & Ingram, 1993).

Microbial biomass nitrogen (MBN) was determined using micro-Kjeldhal technique outlined by Okalebo *et al.* (1993). The liberated nitrogen was determined titrimetrically after distillation. MBC and MBN were calculated from the difference between carbon and nitrogen extracted by 0.5 M K_2SO_4 from alcohol-free fumigated and unfumigated soil samples.

5.2.3.3 *Particulate organic matter (POM)*

Particulate organic matter (POM) consists of material which when dispersed in water, floats and which passes a 2 mm, but not 0.25 mm sieve (Cambardella & Elliot, 1992). POM is used as a fraction related to organic matter quality as it is closely linked to soil productivity. Physical fraction of soil to collect the POM fraction was conducted using a modification of the method described by Okalebo *et al.*, (1993). A 20 g sample of soil was first dispersed in 30 ml of 0.5 % calgon solution (sodium hexametaphosphate) by mechanical shaking for 5 minutes. The dispersed soil sample was wet sieved through a set of sieves 2.0 mm and 53 μ m in diameter by running a moderate stream of tap water through the soil. The fraction greater than 2.0 mm was discarded while that retained on the 53 μ m sieve was kept. The wet sieving procedure was repeated until the entire POM was removed. Each sample was replicated three times. The POM fraction was considered as

the particles floating in the suspension that was poured off and dried in an oven at 50 °C for three days.

5.3 Analysis of data

An analysis of variance (ANOVA) was conducted on the, OC, POM, MBC and MBN using a Statistical Analysis System programme (SAS Institute Inc., 1985). The model that was used to analyse this data has been presented in section 3.3. Significant differences between means were determined using Duncan's Multiple Range Tests and Student's t-test (Sokal & Rohlf, 1969).

5.4 Results

A summary of the analysis of variance (ANOVA) for the properties (OC, POM, MBC and MBN) is presented in Table 5.1. Generally, the results show that all the main factors had a significant influence in soil biological properties. The results also show that there were significant interactive effects of the main factors on the properties of the soils.

Table 5.1 Mean square of analyses of variance for biological properties of soil from beneath canopies of *Acacia erioloba* trees

Source	df	OC	POM (%)	MBC	MBN
Land-use practice (L)	2	12.22**	32.60**	4.40**	2.19**
Canopy location (S)	1	0.004	0.05**	3.63**	0.11**
Depth (D)	1	40.07**	37.16**	54.61**	4.97**
L*S	2	0.001	0.02	0.83**	0.29**
S*D	1	0.03**	0.12**	1.08**	0.00
L*D	2	4.56**	3.97**	1.73**	0.03**
L*S*D	2	0.03**	0.31**	0.20	0.00
Error	96	0.00**	0.01**	0.26**	0.003**

**= P < 0.01

Land-use practice had a significant effect on all biological properties of the soil (Table 5.2). The results show that all biological properties were significantly different ($p<0.05$) from one land-use practice to the other. Fallow was found to have significantly higher ($p<0.05$) OC, POM, MBC and MBN than grazing and bare land-use practices. The order of the rating for all the measured properties was fallow > grazing > bare land. Bare land has the lowest of all the measured properties.

Table 5.2 Effect of land-use practice on biological properties of soil from beneath canopies of *Acacia erioloba* trees

Land-use practice	OC	POM (%)	MBC	MBN
Fallow	1.7±0.9a	2.7±0.8a	5.2±0.9a	0.8±0.2a
Grazing	1.2±0.8b	2.0±0.8b	5.6±1.2b	0.8±0.3b
Bare	0.6±0.2c	0.8±0.2c	2.9±0.7c	0.4±0.2c

Values are means ± standard deviation; n=36

Within a column means bearing the same letter are not significantly different at $P < 0.05$ by the Duncan's Multiple Range Test

Table 5.3 shows the effect of canopy location on biological properties of the soil. A significant difference ($p<0.05$) was not found in all parameters that were measured. Soil biological properties were found not to be significantly different ($p<0.05$) in soils collected beneath and beyond *Acacia erioloba* canopies.

The effect of soil depth on the biological properties of the soil is presented in Table 5.4. A significant difference ($p<0.05$) was observed between soils that were collected at a depth of 0-10 cm and those that were collected at 10-20 cm. The results show that soils that were collected at a depth of 0-10 cm had significantly higher ($p<0.05$) values of biological properties than those collected at 10-20 cm.

Table 5.3 Effect of canopy location on biological properties of soil

Canopy location	OC	POM	MBC	MBN
	(%)			
Beneath canopy	1.2±0.8	1.9±1.0	4.8±1.5	0.7±0.3
Beyond canopy	1.2±0.9	1.8±1.1	4.4±1.5	0.7±0.3

Values are means ± standard deviation; n=54

Table 5.4 Effect of depth of sampling on biological properties of soil collected from beneath canopies of *Acacia erioloba* trees

Depth (cm)	OC	POM	MBC	MBN
	(%)			
0-10	1.8±0.77	2.4±1.1	5.3±1.4	0.9±0.2
10-20	0.6±0.22	1.2±0.5	3.9±1.2	0.5±0.2
t - test	**	**	**	**

Values are means ± standard deviation; n=54

** = P< 0.05

Table 5.5 shows the effect of canopy location within each land-use practice on biological properties of soil. The results show that there were no significant differences ($p<0.05$) in all properties that were measured in soils from beneath and beyond tree canopies. Significant higher ($p<0.05$) values of OC and POM were found in soils that were collected under fallow while MBC and MBN were higher under grazing land-use practice.

Table 5.5 Biological properties of soils as influenced by canopy location under different land-use practices

Land-use practice	Canopy location	OC	POM	MBC	MBN
		(%)			
Fallow	Beneath	1.7±0.9c	2.7±0.8c	5.3±0.8b	0.8±0.2b
	Beyond	1.7±0.9c	2.7±0.9c	5.1±1.0b	0.8±0.2b
Grazing	Beneath	1.2±0.7b	2.0±0.7b	5.9±1.0c	0.9±0.3c
	Beyond	1.2±0.8b	2.0±0.8b	5.2±1.2c	0.8±0.3b
Bare	Beneath	0.6±0.2a	0.8±0.2a	3.0±0.6a	0.5±0.2a
	Beyond	0.6±0.2a	0.7±0.3a	2.9±0.7a	0.3±0.2a

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at $P < 0.05$ by the Duncan's Multiple Range Test

Table 5.6 shows the influence of depth of sampling on biological properties in each land-use practice. Organic carbon (OC), particulate organic matter (POM), microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were found to be significantly higher ($p < 0.05$) in topsoil (0-10 cm) under all land-use practices compared to those from subsoil (10-20 cm).

The influence of soil sampling depth on the biological properties of the soil is presented in Table 5.7. In both locations, all biological properties were significantly higher ($p < 0.05$) in soils that were collected at 0-10 cm compared to those that were collected at 10-20 cm.

Table 5.6 Influence of sampling depth on biological properties of soil from *Acacia erioloba* trees under different land-use practices

Land-use practice	Depth (cm)	OC	POM (%)	MBC	MBN
Fallow	0-10	2.6±0.2f	3.5±0.1f	5.9±0.4d	1.0±0.1c
	10-20	0.8±0.1d	1.8±0.1d	4.5±0.7c	0.6±0.1b
Grazing	0-10	1.9±0.1e	2.8±0.2e	6.5±0.5e	1.1±0.2d
	10-20	0.4±0.1b	1.3±0.1c	4.6±0.8c	0.6±0.1b
Bare	0-10	0.8±0.1c	1.0±0.1b	3.4±0.3b	0.6±0.1b
	10-20	0.4±0.03a	0.6±0.1a	2.4±0.5a	0.2±0.1c

Values are means ± standard deviation; n=18

Within a column means bearing the same letter are not significantly different at $P < 0.05$ by the Duncan's Multiple Range Test

Table 5.7 Effect of depth of sampling on soil biological properties as influenced by canopy location

Canopy location	Depth (cm)	OC	POM (%)	MBC	MBN
Beneath	0-10	1.7±0.8b	2.4±1.1c	5.4±1.5c	0.9±0.2d
	10-20	0.6±0.2a	1.3±0.5b	4.1±1.3b	0.5±0.2b
Beyond	0-10	1.8±0.8c	2.4±1.1c	5.2±1.3c	0.9±0.2b
	10-20	0.5±0.2a	1.2±0.6a	3.6±1.2a	0.4±0.2a

Values are means ± standard deviation; n=27

Within a column means bearing the same letter are not significantly different at $P < 0.05$ by the Duncan's Multiple Range Test

5.5 Discussion

Soil biological properties are very sensitive to changes in land-use practices (Dalal, 1998; Gregorich *et al.*, 1994; Miller *et al.*, 1999). Organic carbon (OC), particulate organic matter (POM), and microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were found to be significantly higher in land under fallow and grazing compared to bare land. This is likely due to the higher amounts of organic material returned to the soil under fallow and grazing than that in bare land. High organic matter content under fallow and grazing can be traced to three possible sources, namely: leaf litter from *Acacia erioloba* trees, grass and turnover of roots and also dung from grazing animals. Animal dung tends to enhance microbial activities and therefore influence the process of organic matter decomposition that releases plant nutrients that are essential for plant growth. Microorganisms attack organic matter in search of food. They use carbon as a source of energy. During this process, some of the carbon is lost as CO₂ which is then used by plants again.

It was observed that grass and other plants were common in both fallow and grazing land. High organic carbon content under these two land-use practices was likely to be due to enhanced biomass addition. It was estimated that about 4.0 t ha⁻¹ of grass biomass could be produced annually and 1.2 t ha⁻¹ under grazing. Apart from additions from grass biomass, *Acacia erioloba* could also add some biomass to the soil through leaf fall. The amount of leaf litter biomass from one *Acacia erioloba* tree (42 years) was estimated to be 39 kg per annum. These organic materials contain some carbon and nutrients. The C:N ratio of *Acacia erioloba* leaves was estimated to 13:1. This suggests that the biomass from *Acacia erioloba* trees could easily be decomposed and the nutrients in them released over a short period.

Microbial biomass carbon was significantly higher in land under fallow and grazing than in bare land. The major contributing factor under grazing land is likely to be the large amount of organic materials that are returned to the soil, especially that from animal dung and turnover of grass roots (Campbell *et al.*, 1992). Land-use practices that promote large organic matter inputs tend to have higher soil microbial biomass contents and activities because they provide soluble carbohydrates that are used as sources of energy for the organisms (Dlamini, 2002). Furthermore, the shade provided by *Acacia erioloba* canopy

reduced evaporation losses and maintained higher soil moisture content in the surface soil. These conditions created a microenvironment that favours microbial activity (Gliessman, 1989).

Organic matter under fallow came mainly from senescing plant tops and roots, exudation of organic compounds from grass roots and the turnover of large microbial biomass found in the rhizosphere of roots (Haynes & Williams, 1993). The common practice of burning grass in the veld reduces the soil organic matter content as well as the microbial activity (Rasmussen *et al.*, 1980). This results in a decline of microbial biomass carbon and nitrogen due to smaller return of organic matter (Collins *et al.*, 1992). It was observed that the concentration of almost all biological properties tended to decrease with depth. This was shown by significantly higher values of all biological properties in the topsoil layers (0-10 cm) of the soil compared to sub soil layers (10-20 cm). This variation was due to that fact that the concentration of organic matter is highest in the surface layer and was lower in the sub-soil (Haynes, 1999).

5.6 Conclusions

It was concluded that the quantity and quality of soil organic matter was influenced by land-use practice. This was indicated by significantly higher values of soil biological properties in land under grazing and fallow compared to bare land. Generally, the concentration of soil biological properties were significantly higher in land under grazing and fallow compared to bare land around homestead. This confirms the hypothesis that there were high biological activities and fertility in grazing and fallow lands compared to bare land. The high organic matter on the topsoil layers beneath the tree canopies in all land-use practices contributed to improving the properties of all biological properties of the soil. This was attributed to the fact that much of the decomposition of soil organic matter takes place on the surface layer of the soil where most of the organic materials are added.

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The high concentration of nutrients and better biological properties under fallow and grazing lands imply that the production of agronomic crops can also be possible beneath canopies of *Acacia erioloba* trees. As the nutrients were mostly concentrated in the topsoil (0-10 cm), it implies that crops with shallow roots such as maize and sorghum can use the nutrients with ease (Virginia, 1986; Gliessman, 1989; Weil & Mughogho, 1993; Roos & Allsopp, 1997). The practical implication of the results is that the tree can be integrated into the farming system especially under small-scale production. This can also help to reduce soil erosion which soil erosion is very rampant in rural areas (Esterhuysen, 1989; Smit, 1999). Losses of nutrients from such a system may be reduced since *Acacia erioloba* tree protects the soil from accelerated erosion (Prinsley, 1992). The use of *Acacia erioloba* trees in such a system could also reduce the cost of production as it can reduce the use of the costly inorganic fertilizers.

The justification for adopting agroforestry as an approach to land-use and management practices, especially in the tropics is confirmed by this research in that soil fertility and growth of vegetation was improved in soil form beneath the canopies of *Acacia erioloba*. *Acacia erioloba* trees can play a significant role in maintaining soil fertility since they are able to fix atmospheric nitrogen and contribute nitrogen and other nutrients through leaf fall. In addition, the root systems of *Acacia erioloba* can act as a pump for nutrients by tapping and bringing to the surface nutrients that may have been leached to layers beyond the reach of plant roots (Young, 1988).

Reported estimates of the amount of nitrogen fixed by *Acacia* trees are highly variable and depend on age and size of trees, climatic factors and soil fertility. Other factors that limit N_2 fixation include temperature, relative humidity drought and phosphorus. Schulze *et al.*, (1991 have shown that symbiotic *Acacia* spp. use more water per unit carbon assimilated than non-legumes) in the desert and savanna areas of Namibia. According to Danso *et al.*, (1992) this suggests that, in the dry savanna and Sahelian zones of Africa, availability of water can itself constrain the process of N_2 fixation and reduce biological nitrogen. The high temperatures that are commonly found in countries of sub-Saharan Africa can also

reduce N₂ fixation (People *et al.*, 1989). Phosphorus deficiency in soils is a characteristic of many soils in sub-Saharan Africa (Schulze *et al.*, 1991). This can also limit N₂ fixation and growth of N₂ fixing trees. An optimum supply of phosphorus to nitrogen fixing trees (NFT) has been recognized as an important factor in increasing N₂ fixation (Danso *et al.*, 1992). The quantification of N₂ fixation in especially older trees has proven difficult because of methodological constraints. There are at least two components of N₂ fixation that need special consideration when assessing the amount of nitrogen fixed by nitrogen fixing trees: (a) the total amount of nitrogen in the above ground and below ground components of NFTs, and (b) the fraction of total nitrogen in the plant that was obtained through N₂ fixation. The latter can vary from 10 % to 76 % of the total amount of N₂ fixed (Danso *et al.*, 1992).

Although there are several techniques that are used to estimate the amount of nitrogen fixation by plants (Sanginga *et al.*, 1996), most of these techniques are not easy to apply in mature *Acacia erioloba* trees. A simple and practical method that can be used to estimate the amount of nitrogen fixed by *Acacia erioloba* trees over a period of time is to measure the concentration of nitrogen in the plant tissues and multiply it by the weight of plant material. This method however, only estimates the nitrogen fixed when no other sources of nitrogen are available (Danso, 1986). When this method is applied, the assumption is made that trees are grown in a nitrogen free media and watered regularly with nitrogen free water (Giller & Wilson, 1991). If such a method was to be applied for *Acacia erioloba* trees, they can be grown in an isolated place (e.g. glasshouse) to avoid them coming into contact with other nitrogen sources such as grass residues, animal wastes and fertilizers. Other methods that have been used involve the counting of nodules on roots of *Acacia erioloba* seedlings (Masutha *et al.*, 1997).

The results in this study suggest that *Acacia erioloba* trees in cropland could enhance soil fertility. *Acacia erioloba* trees could thus be integrated into crop land under different appropriate agroforestry systems including dispersed in cropland, improved fallow, home gardens, and planted as shelter belts or single distribution planting. Under these systems, *Acacia erioloba* trees can provide many other benefits including micro-climate for shade-loving plants, trellis for vine crops, and living fence. Such product would benefit a farm or household in a semi-arid savanna environment like that of the North-West province.

A system where *Acacia erioloba* trees are dispersed on cropland involves the growing of trees in the field while agronomic crops are grown in the under-storey. The trees are dispersed widely, spaced systematically in a grid, or scattered in the field at random. Tree species such as *Acacia albida*, *Acacia Senegal*, *Parkia biglobosa*, *Sesbania sesban* and *Croton macrostachys* have been used under this system in other countries on the African continent. Under this system, although the main reason is to improve soil fertility and conserve moisture the trees provide other products such as food, fuel wood, oil, building poles, fodder and gum (Rocheleau *et al.*, 1988).

Farmers can keep *Acacia erioloba* trees in their fields in order to harvest pods that can be used as dry-season fodder or fuel wood. After the crops are harvested, animals (cattle) can be allowed into the field so as to deposit their manure on the fields and under the tree canopies. The density and spacing of *Acacia erioloba* trees in the North-West Province vary widely among farms. However, this may have to be adjusted in order to obtain the most benefits from the trees. The adjustment will have to consider factors like mechanisation and possible competition with crops for nutrients, water and light. If *Acacia erioloba* trees are grown in cropland, they need to be protected from animals, either individually or the entire field. Weeding and soil moisture conservation may also be helpful during establishment in dry areas. Farmers in the Senegal have reported yield improvement when crops were planted with *Acacia Senegal*, *Acacia albida* and *Borassus aethiopum* under this system (Rocheleau *et al.*, 1988).

Improved fallow is a form of agroforestry where fields are left to lie fallow in order to rest and recover some of its fertility. This practice is well known and widely used throughout Africa. Woody tree species and shrubs such as are used to replace crops in the field during fallow period. Unfortunately, in many parts of Africa including South Africa, fallow periods are becoming shorter due to shortage of land. As the fallow period is reduced, it becomes more important to introduce trees and shrubs that could help speed up the recovery of soil, especially through nitrogen fixation. This is where *Acacia erioloba* trees play an important role due to its N-fixing ability. The benefits of utilising *Acacia erioloba* trees in improved fallow system would include protection of soil from erosion, increase in organic matter content of the soil, trapping of nutrients from subsoil, and improvement in soil structure, and tilth. Improved fallow system can be adapted in a variety of ways, and at various stages of the fallow period.

Another agroforestry system where *Acacia erioloba* could be used is the home gardens. This system consists of a diverse mixture of vegetables, fruits, medicinal plants and often fodder grasses, shrubs and trees in small intensively cultivated plots in and around home compounds (Wachiira, 1987). Home gardens can also accommodate small livestock such as chickens and rabbits, and may provide residues or fodder for pig, goats and dairy cows. *Acacia erioloba* trees could be introduced in cases where they are not available in the field. Potential benefits from home garden systems are varied as are the gardens themselves. These may include cost earned from direct sale of vegetables and improved nutrition from new types of food or from increased regular quantities of vitamins, minerals and plant proteins in the household diet (Fernandes *et al.*, 1984). The trees can be planted in patches or strips or can be scattered over the property, depending on the size of the garden.

Another agroforestry system that can be applied is known as sylvopastoral (Agroforestry in pasture and rangeland). In this system, pasture is grown beneath canopies of *Acacia erioloba* trees (Rocheleau *et al.*, 1988). The trees and shrubs may be used primarily to produce fodder for livestock or they may be grown for timber, fuel wood, fruits, pollen and nectar for bees. The sylvopastoral system fits very well in dry savanna zones such as those of the North-West Province in order to meet wood and fodder requirements and to maintain the fertility of soils in grazing lands (Rocheleau *et al.*, 1988). Under this system the trees, shrubs and grass may also be established on contour lines or in patterns predetermined by soil and water conservation structures in (Rocheleau *et al.*, 1988). The system is not new in Africa, in fact, many pastoral and agropastoral people throughout the continent have traditionally used this system to managed woody plants in savanna grazing lands. *Acacia* species, which produce edible pods for livestock, are often widely used in pastureland of many dry areas (Rocheleau *et al.*, 1988).

Due to the highly irregular rainfall in semi-arid areas and the lack of nutritious grasses during the dry seasons, the leaves of trees and shrubs could provide supplemental nutritious seed to animals. According to Rocheleau *et al.* (1988) browsing of woody plants was found to constitute 92 % of dry-season fodder for goats in Kenya's Turkana district. In the case of small-scale farming households of the North-West Province, increased production of pods from *Acacia erioloba* would assist to provide households with much needed feed for cattle especially in the dry season.

Such a system that is based on the use of trees and shrubs in grazing land may be established or improved by protecting and managing existing woody plants and encouraging natural regeneration. Also, the selective removal of less useful species and protection and management of valuable species, and planting new trees and shrubs in pasture could be used. A sylvopastoral system would be more suitable to the semi-arid areas of North-West Province as there are a lot of cattle, goats and sheep. If this system is planned and managed properly, animals can be key components of sustainable farming system because they could help to improve soil fertility status through dung and urine. The numbers of animals should however be controlled to avoid overgrazing and its consequences.

Generally, the study concluded that the presence of *Acacia erioloba* trees has a significant effect on the concentration of nutrients, wheat growth and dry matter yields. The study concluded that concentration of some nutrients especially phosphorus, potassium and zinc influenced by the presence of *Acacia erioloba* trees. Concentration of nutrients was consistently higher in the topsoil (0-10 cm) than in the subsoil (10-20 cm) in all land-use practices and this led to the conclusion that since the organic materials and biological nitrogen fixation (BNF) take place mostly in the surface layers, they were the main factors that contributed to high concentration of nutrients in the topsoil. It has also been concluded that the concentration of nutrients is largely determined by land-use practice.

It was also concluded that the nutrient element that were in soils from beneath *Acacia erioloba* trees were available and taken up by wheat plants. It is suggested that the *Acacia erioloba* trees played a significant role in increasing nutrient uptake, growth and dry matter yields of wheat seedling grown in soils from beneath *Acacia erioloba* trees. Finally, the study concluded that the quality and quantity of soil organic matter was influenced by land-use practices. This was indicated by significantly higher values of biological properties in soils that were collected in land under grazing and fallow compared to those soils that were collected from bare land.

Much work is needed to better understand the physiological aspects and mechanisms involved in the ability of *Acacia erioloba* to enhance nutrient cycling. Considerable work is needed to accurately identify the geographical and ecological range of adaptation for intercropping agronomic crops with *Acacia erioloba* tree. Studies must be conducted in

order to determine the sustainable yield potential of *Acacia erioloba* intercropping under improved crop management. As a leguminous plant, *Acacia erioloba* has the ability to fix nitrogen from the atmosphere, however the exact amount of nitrogen that can be fixed over a period of time is not known. A thorough study on how to estimate the amount of nitrogen fixed by *Acacia erioloba* is needed. Further experiments on growth and nutrient up take by crops other than wheat must also be conducted in the field where performance and production potential of *Acacia erioloba* can be thoroughly investigated and evaluated.

Although it was found in this study that *Acacia erioloba* trees have the ability to enhance nutrient cycling processes, it is obvious that not all of the recycled nutrients could be used by the plants. Other nutrients might be lost due to leaching, volatilisation or denitrification. It is necessary to come out with a strategy of estimating the amount of nutrients that can be lost by these processes. The successful intergration of *Acacia erioloba* trees in agroforestry can be determined by agroforestry research. It is therefore recommended that the implementation of agroforestry systems in the North-West province should be a joint venture by agricultural research departments, educational institutions and the community at large.

CHAPTER 7

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APPENDECIES

1 ANALYSIS OF VARIENCE FOR SOIL NUTRIENTS AND pH

NITROGEN

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	0.01164191	0.00582095	209.80	0.0001
S	1	0.00031008	0.00031008	11.18	0.0012
D	1	0.02063934	0.02063934	743.88	0.0001
L*S	2	0.00072150	0.00036075	13.00	0.0001
S*D	1	0.00000008	0.00000008	0.00	0.9564
L*D	2	0.00199357	0.00099679	35.93	0.0001
L*S*D	2	0.00006317	0.00003158	1.14	0.3246

PHOSPHORUS

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	7021.18385741	3510.59192870	34.92	0.0001
S	1	355.81260093	355.81260093	3.54	0.0630
D	1	1698.28882315	1698.28882315	16.89	0.0001
L*S	2	1501.43574630	750.71787315	7.47	0.0010
S*D	1	3.41688981	3.41688981	0.03	0.8541
L*D	2	506.06803519	253.03401759	2.52	0.0860
L*S*D	2	6.54279074	3.27139537	0.03	0.9680

POTASSIUM

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	404691.78510556	202345.89255278	42.22	0.0001
S	1	116251.73600833	116251.73600833	24.26	0.0001
D	1	44326.85407500	44326.85407500	9.25	0.0030
L*S	2	61940.68907222	30970.34453611	6.46	0.0023
S*D	1	10960.39111204	10960.39111204	2.29	0.1337
L*D	2	3874.14870556	1937.07435278	0.40	0.6686
L*S*D	2	3165.52001296	1582.76000648	0.33	0.7196

pH (H₂O)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	1.38060556	0.69030278	1.77	0.1760
S	1	2.42100833	2.42100833	6.20	0.0145
D	1	0.01182315	0.01182315	0.03	0.8622
L*S	2	17.66407222	8.83203611	22.63	0.0001
S*D	1	0.08955648	0.08955648	0.23	0.6330
L*D	2	0.40842407	0.20421204	0.52	0.5942
L*S*D	2	1.17962407	0.58981204	1.51	0.2258

CALCIUM

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	2842857.88962962	1421428.94481481	18.05	0.0001
S	1	213.36333331	213.36333331	0.00	0.9586
D	1	1276920.77370372	1276920.77370372	16.21	0.0001
L*S	2	470206.30222224	235103.15111112	2.99	0.0552
S*D	1	817.85037035	817.85037035	0.01	0.9190
L*D	2	195247.66740739	97623.83370370	1.24	0.2941
L*S*D	2	286674.87629631	143337.43814816	1.82	0.1676

MAGNESIUM

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	3437146.33527965	1718573.16763982	70.52	0.0001
S	1	8798.83363335	8798.83363335	0.36	0.5493
D	1	217845.83564816	217845.83564816	8.94	0.0035
L*S	2	17645.87020554	8822.93510277	0.36	0.6972
S*D	1	11953.24481481	11953.24481481	0.49	0.4854
L*D	2	127029.49893518	63514.74946759	2.61	0.0790
L*S*D	2	17739.34880185	8869.67440093	0.36	0.6959

ZINC

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	760.19042222	380.09521111	244.26	0.0001
S	1	43.68811204	43.68811204	28.07	0.0001
D	1	37.70107500	37.70107500	24.23	0.0001
L*S	2	73.40669630	36.70334815	23.59	0.0001
S*D	1	1.71511204	1.71511204	1.10	0.2964
L*D	2	14.26126667	7.13063333	4.58	0.0126
L*S*D	2	8.25611852	4.12805926	2.65	0.0756

MANGANESE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	12965.07127222	6482.53563611	54.29	0.0001
S	1	806.55203333	806.55203333	6.75	0.0108
D	1	4147.30507037	4147.30507037	34.73	0.0001
L*S	2	238.78220556	119.39110278	1.00	0.3717
S*D	1	2.46009259	2.46009259	0.02	0.8862
L*D	2	1420.10823519	710.05411759	5.95	0.0037
L*S*D	2	19.74556852	9.87278426	0.08	0.9207

2 ANALYSIS OF VARIANCE FOR NUTRIENT UPTAKE BY WHEAT

KEY: S (Shoots)

R (Roots)

NITROGEN (S)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	0.34481481	0.17240741	30.28	0.0001
S	1	0.37500000	0.37500000	65.85	0.0001
L*S	2	0.14111111	0.07055556	12.39	0.0001

NITROGEN (R)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	0.07703704	0.03851852	8.67	0.0006
S	1	0.07407407	0.07407407	16.67	0.0002
L*S	2	0.02370370	0.01185185	2.67	0.0798

PHOSPHORUS (S)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	896014.81481482	448007.40740741	28.85	0.0001
S	1	1447140.74074075	1447140.74074075	93.17	0.0001
L*S	2	529348.14814815	264674.07407407	17.04	0.0001

PHOSPHORUS (R)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	611570.37037037	305785.18518519	61.83	0.0001
S	1	201666.66666667	201666.66666667	40.78	0.0001
L*S	2	16133.33333333	8066.66666667	1.63	0.2064

ZINC (S)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	154095.37037037	77047.68518519	92.02	0.0001
S	1	138016.66666667	138016.66666667	164.84	0.0001
L*S	2	15069.44444444	7534.72222222	9.00	0.0005

ZINC (R)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	100417.59259259	50208.79629630	42.84	0.0001
S	1	139537.50000000	139537.50000000	119.05	0.0001
L*S	2	29252.77777778	14626.38888889	12.48	0.0001

MANGANESE (S)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	28706.48148148	14353.24074074	19.87	0.0001
S	1	113896.29629630	113896.29629630	157.65	0.0001
L*S	2	1750.92592593	875.46296296	1.21	0.3066

MANGANESE (R)

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	176089.81481481	88044.90740741	25.73	0.0001
S	1	121837.50000000	121837.50000000	35.60	0.0001
L*S	2	6352.77777778	3176.38888889	0.93	0.4023

3 ANALYSIS OF VARIENCE FOR GROWTH AND DRY MATTER YIELDS

SHOOTS

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	31.37762593	15.68881296	18.58	0.0001
S	1	2.40666667	2.40666667	2.85	0.0979
L*S	2	1.24401111	0.62200556	0.74	0.4841

ROOTS

source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	10.67051481	5.33525741	8.16	0.0009
S	1	0.10401667	0.10401667	0.16	0.6917
L*S	2	0.90943333	0.45471667	0.70	0.5037

PLANT HEIGHT

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	424.29592593	212.14796296	53.07	0.0001
S	1	78.00018519	78.00018519	19.51	0.0001
L*S	2	3.85148148	1.92574074	0.48	0.6207

4 ANALYSIS OF VARIANCE FOR SOIL BIOLOGICAL PROPERTIES

OC

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	24.44820741	12.22410370	4349.57	0.0001
S	1	0.00355926	0.00355926	1.27	0.2632
D	1	40.06489259	40.06489259	14255.86	0.0001
L*S	2	0.00045185	0.00022593	0.08	0.9228
S*D	1	0.03203333	0.03203333	11.40	0.0011
L*D	2	9.12465185	4.56232593	1623.36	0.0001
L*S*D	2	0.06828889	0.03414444	12.15	0.0001

POM

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	65.20107222	32.60053611	3498.90	0.0001
S	1	0.05026759	0.05026759	5.40	0.0223
D	1	37.15946759	37.15946759	3988.20	0.0001
L*S	2	0.04714630	0.02357315	2.53	0.0850
S*D	1	0.11537870	0.11537870	12.38	0.0007
L*D	2	7.93513519	3.96756759	425.83	0.0001
L*S*D	2	0.06169074	0.03084537	3.31	0.0407

MBC

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	148.79796296	74.39898148	291.18	0.0001
S	1	3.63000000	3.63000000	14.21	0.0003
D	1	54.61333333	54.61333333	213.74	0.0001
L*S	2	1.65722222	0.82861111	3.24	0.0434
S*D	1	1.08000000	1.08000000	4.23	0.0425
L*D	2	3.45722222	1.72861111	6.77	0.0018
L*S*D	2	0.40166667	0.20083333	0.79	0.4586

MBN

Source	DF	Anova SS	Mean Square	F Value	Pr > F
L	2	4.38977963	2.19488981	757.58	0.0001
S	1	0.10766759	0.10766759	37.16	0.0001
D	1	4.97082315	4.97082315	1715.72	0.0001
L*S	2	0.05756852	0.02878426	9.94	0.0001
S*D	1	0.00187500	0.00187500	0.65	0.4231
L*D	2	0.05939074	0.02969537	10.25	0.0001
L*S*D	2	0.00263889	0.00131944	0.46	0.6355

