CONTRIBUTION TO SOIL FERTILITY BY LITTER OF SELECTED SUB-TROPICAL FRUIT TREES IN THE EHLANZENI DISTRICT MUNICIPALITY OF MPUMALANGA PROVINCE, SOUTH AFRICA

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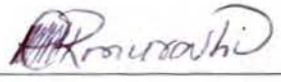
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ABSTRACT

Small scale farmers' agricultural production in Mpumalanga Province of South Africa is limited by poor soil fertility. The majority of these farmers do not apply or use very limited quantities of inorganic fertilizer due to financial constraints. Consequently, the use of organic materials including leaf litter, offers an option for managing soil fertility. The Ehlanzeni District Municipality (EDM) is located in a sub-tropical climate which favours growth of many tropical and sub-tropical trees. The trees shed their leaves every year and thus provide an organic biomass resource that can be used to supply soil nutrients. The objective of this study was to explore the utilization and management of the leaf litter biomass from selected fruit trees to manage soil fertility in small scale farmer's fields. The conceptual frame work for the study was based on the biological approach to soil fertility management.

The first step in the study involved establishing local farmer's knowledge about the utilization of fruit tree litter for soil fertility management. This was important because indigenous knowledge has widely been recognised as a tool that can be used to promote technological development and innovation. A survey of 150 randomly selected farming households from within three local municipalities (Mbombela, Nkomazi and Bushbuckridge) was conducted and a structured questionnaire was used to collect data. The results indicated that the majority (70%) of the farmers utilized leaf litter from fruit trees within their households to manage soil fertility. Most of the leaf litter was applied on high value crops especially vegetables. About fifty percent of the farmers collected between 0.13-1.3 t $ha^{-1}yr^{-1}$ of leaf litter from their fruit trees. Farmers indicated that there was a seasonal and species variation in the amount of litter collected. The highest amounts were collected during autumn and from litchi trees. The majority (62%) of the responding farmers composted the litter biomass while 24% incorporated it into the soil. It was found that the majority (57%) applied less than 50 kg ha^{-1} $year^{-1}$ of leaf litter biomass to the soil. The farmers recognized temperature (82%), termites (52%) and water (52%) as the major factors that influenced decomposition of leaf litter biomass. Although many of the respondents did not seem to identify the quality factors of litter biomass, 52% mixed the litter with kraal manure while 68% mixed it with other amendments (wood ash, chicken manure and crushed bones) in order to increase its nutrient content.

In order to determine the factors that influenced the farmers' use of leaf litter biomass for soil fertility management, a LOGIT model was used and its statistics variables were specified. The results showed that the model correctly classified 83% of the farmers that used leaf litter biomass. The LOGIT model parameter estimates of the maximum likelihood for leaf litter biomass utilization by farmers were income (0.57*), gender (0.05*), age (0.75*), education (-0.01*), farm size (-0.56*), land tenure (1.35ns) and labour (1.15ns). It was concluded that indigenous knowledge played an important role in the utilisation and management of leaf litter biomass for soil fertility management among small scale farmers in the study area. However, there were gaps in knowledge regarding amount of litter to apply, leaf litter quality and decomposition processes. These aspects are important if leaf litter is to be managed optimally for soil fertility management and thus warranted further scientific investigation.

The quantity and quality of leaf litter biomass produced under three tree species avocado (*Persea americana*), mango (*Mangifera indica*) and litchi (*Litchi chinensis*) were measured in an experiment conducted at the ARC-ITSC research station during the period 2007-2008. Nylon mesh litter traps (3.5 x 4 x 3 m) were constructed around five randomly selected trees for each of the three species and the litter falling within the mesh was collected continuously for two years. The yield of litter was determined for each of the four seasons of the year and a sample of the litter was analysed for polyphenols, carbon, cellulose, lignin, ash and nutrient content in order to establish its quality. The results showed that in both years, litchi trees produced the highest (8.3 t $ha^{-1}yr^{-1}$) amount of leaf litter followed by mango (6.3 t $ha^{-1}yr^{-1}$) and avocado (4.7 t $ha^{-1}yr^{-1}$). In both years, the highest amount of litter biomass was collected during autumn while the winter season produced the lowest litterfall biomass in all the species. Correlation studies indicated that the litter biomass yields were influenced by wind speed ($r=-0.438$) and air humidity ($r=0.343$).

The leaves of avocado trees had significantly higher ($P<0.05$) quality (low polyphenols and high nitrogen) compared to those of litchi and mango. It was generally observed that quality of litter biomass was inversely related to quantity. Furthermore, litter biomass had higher quality (low lignin, low cellulose, low polyphenols but higher nutrient contents) during the spring and winter seasons than autumn. It was further observed that, although the highest amounts of leaf litter biomass were produced in autumn, farmers in

the study area did not usually apply it to the soil at this time but waited until spring when planting rains start. This implies that the litter had to be stored for some time before it was applied. It was concluded that the quality of litter from the three tree species was generally low and require appropriate management in order to improve its quality.

Decomposition of leaf litter biomass is the main process by which nutrients are recycled into the soil. The quality of litter biomass has been shown to be a major factor that influences the decomposition and nutrient release from organic material. Consequently, the decomposition and nutrient release pattern of the litter biomass from the three selected tree species was studied in field plots located at the ARC-ITSC experimental station in Nelspruit. About 10 g of dry litter mass from each tree species were packed in black polythene litterbags with 1.0 mm screen mesh and incorporated into the soil at a depth of 10 cm. The treatments consisted of combinations of three tree species with ten litterbag retrieval days (14, 28, 42, 88, 118, 134, 180, 206, 272, and 364) and were laid in a completely randomised design with three replicates. On each retrieval day the litter remaining in the litterbag was cleaned, dried, weighed and analysed for polyphenols, ash, cellulose, lignin and mineral elements content. The experiment was conducted for two years (2007 and 2008). The results indicated that in both years, leaves of avocado decomposed faster than those of litchi and mango. The rates of decomposition were estimated to be 0.14, 0.005 and 0.006 g day^{-1} for avocado, litchi and mango leaves respectively. The time it took for 50% of the litter biomass to disappear was 226 and 318 days, for avocado and mango, respectively, while for litchi 50% of the biomass had not yet been lost when the trial was terminated after 364 days. In all the species, the decomposition process consisted of a relatively short phase with very rapid loss of mass followed by a long phase with a slow rate of decomposition.

The nutrient release pattern from the litter biomass mirrored that of decomposition. Litter decomposition increased with time while for some nutrients the release was declining with time. Both decomposition and nutrient release from the litter biomass were influenced by climatic factors (temperature and rainfall) and quality variables (C:N, lignin, and cellulose). The results have shown that the physiological nature of the leaves with respect to amount of lignin, cellulose and polyphenols affected the rate of decomposition and release of nutrients especially nitrogen, sulphur, magnesium and manganese. It was however observed that some nutrients (nitrogen, sulphur, magnesium

and manganese) were immobilised during the initial period of decomposition. The implication of this is that if crops were grown on that soil at that time, there would be insufficient amounts of these nutrients for growth unless other sources of nutrient such as fertiliser, wood ash and animal manure were added together with the litter biomass. The results also revealed that the decomposition of the litter biomass proceeded at a very slow rate and thus required a long time for decomposition to complete. This implies that the leaf litter from these fruit trees requires longer incorporation periods for them to decompose and release nutrients before crops are planted. It was concluded that the litter biomass from the three tree species had different quality characteristics and decomposition trends which requires proper management when the litter is incorporated into the soil to supply crops with nutrients.

The last experiment in the study was conducted to quantify the effect of the litter quality on growth and nutrient uptake by maize grown in a soil amended with litter from the three tree species. Litter biomass collected from under the trees was mixed with soil and incubated in pots at field capacity soil water content in order to allow decomposition to take place. The design was a 3x3x3 factorial laid in a completely randomised design with five replicates. The factors consisted of litter from the three tree species (avocado, mango and litchi), three rates of litter application (0. 1.6 and 3.3 t ha^{-1}) and three incubation periods (0, 6 and 12 months). A maize hybrid (cv. PAN 6671) was grown in a greenhouse for 48 days under controlled day and night temperatures. Plant height and dry matter yields of the maize were measured at the end of growth and the plant tissue materials (shoots and roots) were analyzed for nitrogen, phosphorus, sulphur, calcium, magnesium, zinc and manganese and used to calculate nutrient uptake during growth.

The results indicated that in some of the treatments the zero (0) rate of application was better than that where litter was applied which confirmed that there was immobilization of nutrients. It was further confirmed that, for the high quality litter (avocado), increasing rate of litter application resulted in increasingly high growth and dry matter yield. In the low quality litter on the other hand, increasing rate of litter application was associated with reduced growth, yield and purple coloration of leaves. The pattern of nutrient uptake mirrored that of growth and dry matter yields. Based on the responses of maize growth observed in this study, it suggests that the amount of litter applied by farmers in the study area might not be enough to sustain yields of food crops grown by

the farmers. The farmers' practice of leaving leaf litter underneath the tree from autumn to spring might be useful in assisting the materials to break down. However, there might be need to enhance nutrient release in this low quality litter by judicious application of fertilizers along with the litter. There is therefore a need for further studies to establish the appropriate depth and time of leaf litter incorporation.

The following recommendations are made from the study:

- There is need to enhance knowledge about litter quality and its management among small scale farmers' community
- Studies on the amount of leaf litter collected from litterfall needs to be extended over many years in order to capture the influence of extreme climatic and weather conditions
- The amount of litter applied in the farmers' fields is relatively low to provide sufficient nutrients to crops and therefore farmers must be advised to increase the amount of litter which they apply in the field.
- Since the maximum amount of leaf litter is collected during autumn but incorporated during spring, it is recommended that the quality of leaf litter must be improved through composting or mixing with high quality resources such as wood ash, crushed bones and animal manure
- More decomposition studies need to be conducted over longer periods than the 365 days used in this study in order for the decomposition of all the leaf litter to be completed.
- There is need to determine the microbial community, population, and types that are responsible for the decomposition of litter for each of the three tree species in both above and below ground of the tree in order to understand how they could be managed to optimise decomposition and nutrient release processes.
- Studies of this nature should be undertaken preferable on the small scale farmers' fields to determine the effect of different leaf litter management strategies on the decomposition and nutrient release.
- In order to avoid the negative consequences of immobilization, leaf litter should be mixed with high quality material such as fertilizers, wood ash, termite mound soil and animal manure.

LIST OF ACRONYMS AND SYMBOLS

AA	Atomic adsorption
ADF	Acid detergent fibre
ANOVA	Analysis of variance
ARC	Agricultural research council
CEC	Cation exchange capacity
CELL	Cellulose
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of variation
Df	Degree of freedom
DSS	Decision tree support system
EDM	Ehlanzeni District Municipality
EDUC	Education levels for responding farmers
FAO	Food and Agriculture Organisation of the United Nations
FSSA	Fertilizer association of South Africa
FYM	Farm Yard Manure
GLM	General linear model
ICRAF	International Centre for Research in Agroforestry
IK	Indigenous knowledge
IKS	Indigenous knowledge system
ITSC	Institute for tropical and sub-tropical crops
K_2O	Potassium oxide
KCl	Potassium chloride
L:N	Lignin Nitrogen ratio
LAN	Lime Ammonium Nitrate
Li	Lignin
NDF	Non detergent fibre
OC	Organic carbon
OLS	Ordinary least square
OM	Organic matter
P:N	Phosphorus Nitrogen ratio
P_2O_5	Phosphorus oxide
PP	Polyphenols
ppm	Parts per million
PVC	Polyvinyl chloride
SAS	Statistical analysis system
SD	Standard deviation
SEM	Standard error of the mean
SG	Standard grade
SPSS	Statistical package for social science
SSA	Sub Saharan Africa
Temp	Temperature
Tmax	Maximum temperature
Tmin	Minimum temperature
UN	United Nations
USA	United States of America
WB	World Bank

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CHAPTER ONE

GENERAL INTRODUCTION AND STUDY OBJECTIVES

Mpumalanga province covers an area of 76 495 km^2 and is the second smallest of the nine provinces in South Africa (Statistics South Africa, 2002). It shares borders with Swaziland and Mozambique on the eastern side. The province comprises three district municipalities *viz*: Ehlanzeni, Gert Sibande and Nkangala. Agriculture, mining, manufacturing and electricity constitute the backbone of the provincial economy (South African Yearbook, 2002). However, agriculture's contribution towards the provincial economy decreased by 1.6% between 1996 and 2005 (Mpumalanga Provincial Government, 2007). Although the decline in agriculture's contribution towards the provincial economy is attributed to many factors, low soil fertility is one of the major contributors.

There are two major agricultural sectors in the province *viz*: commercial and small scale sectors. This study targeted the latter sector in the Ehlanzeni District Municipality (EDM) because of the large numbers of small scale farmers who grow food crops on homestead gardens. Small scale farmers operate on small farm sizes of approximately 1.0 hectare, use little or no inorganic fertilisers and their average productivity of food crops is 68% lower than that of the commercial sector (Table 1.1). The most commonly grown crops by small scale farmers in the EDM include: maize (*Zea mays*), groundnuts (*Arachis hypogaea*), sweet potatoes (*Ipomoea batatas*) and vegetables such as beetroot (*Beta vulgaris* L.), green pepper (*Capsicum annuum* L.), cabbage (*Brassica oleracia* L.) and spinach (*Spinacia oleracia* L.).

Table 1.1 Differences in productivity levels of commonly grown food crops between commercial and small scale farmers in the EDM

Farming sector	**Crop yield (t ha^{-1})**						
	Maize	Ground-nuts	Bambara-nuts	Cowpeas	Sweet-potato	Beetroot	Green-pepper
Commercial	3.85	3.50	0.60	0.30	22.0	25.3	8.0
Small scale	0.50	0.55	0.25	0.15	10.0	9.15	1.5
% reduction	84.4	84.3	58.3	50.0	54.5	63.8	81.3

Source: Statistics South Africa (2002); Mpumalanga Provincial Government (2002)

Monocropping of maize is widely practiced by the majority of small scale farmers in the EDM. Studies from elsewhere have shown that maize monocropping contributes to declining soil fertility (Lal, 1997; Reda *et al.*, 2005, Jeranyama *et al.*, 2007). Other important cropping systems in the EDM include inter-cropping and crop rotation. The number of livestock in the EDM has declined in recent years because of population growth and lack of grazing land (Mpumalanga Provincial Government, 2002).

There is a growing concern about the declining soil fertility in the EDM. An analysis of soil samples from selected small scale farmers' fields around the EDM by the Agricultural Research Council's Institute for Tropical and Sub-tropical Crops (ARC-ITSC) revealed that the soil concentration of most nutrients, especially nitrogen, potassium, calcium and magnesium declined considerably over an eight year period (Table 1.2). Similar decline in soil nutrient levels were also shown by Omnia Laboratory in the Delmas area of Mpumalanga (Scotney and Dijkhuis, 1990). Deficiencies of micro nutrients such as iron, boron and zinc are also common especially in orchards (Laker, 1976; Scotney and Dijinkhuis, 1990). The majority of small scale farmers in the EDM are poor and cannot afford to buy mineral fertilizers to improve soil fertility. As a results, they dependent on organic materials for maintaining soil fertility. However, most of the organic materials that are used to maintain soil fertility are often poor and high variability in quality or nutrient content, particularly nitrogen, and therefore cannot sustain crop productivity.

Table 1.2 Soil nutrients and pH in selected small scale farmer's field around EDM over an eight year period (1999-2007), n = 8

	Soil fertility index						
Period (Years)	N (%)	P (Bray-1) (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})	pH
1999	0.45	3.3	85	421	177	10	6.72
2007	0.05	2.1	51	362	100	21	5.66
% decline	21.92	5.70	6.50	1.90	6.73	16.49*	

* = % increase

Source: ARC-ITSC (1999; 2007)

Small scale farmers in the EDM are aware of the decline in soil fertility in their fields and use local knowledge to improve it. The approaches that are most often used to maintain soil fertility among small scale farmers in the EDM include: livestock manure, compost, and crop residues. Although the use of livestock manure is preferred, however, the quantity and quality is dwindling due to reduced numbers of livestock that are kept on the land which itself is reduced by the high population growth (Mpumalanga Provincial Government, 2002).

The farmers have thus turned to using organic materials (compost, crop residues and tree leaf litter) to manage soil fertility. Consequently, there has currently been an increase in interest in the use, by small scale farmers, of leaf biomass from various trees for soil fertility management in the EDM. Farmers collect leaf biomass from either the forest or under their fruit trees and apply it as mulch or incorporate it into the soil in their home gardens. However, the quantity and quality of leaf biomass that is used is not known and therefore farmers have no guide on the amount and time to apply the biomass to the soil. Biomass quality is described by the nitrogen %, C:N ratio, lignin, and polyphenol content of the leaves (Melillo *et al.*, 1989; Cadisch and Giller, 1997). The influence of quality of biomass on soil fertility and crop yield has been quantified by many researchers (Swift *et al.*, 1979; Jama *et al.*, 2000). The amount of nutrient released by leaf biomass varies among species and has a direct effect on the fertility status of soil (Cadisch and Giller, 1997).

Because of its sub-tropical climate, the EDM is home to a variety of tropical and sub-tropical fruit trees (Mpumalanga Provincial Government, 2003a). The most dominant fruit trees are litchis (*Litchi chinensis*), mangoes (*Mangifera indica*), and avocados (*Persea americana*). It is estimated that each household within the EDM area has on average ten different fruit trees on their farm (Mpumalanga Provincial Government, 2003a). Being evergreen, these trees shed their leaves throughout the year (Cameron *et al.*, 1952; Musvoto and Campbell, 1995) which release nutrients when they decompose (Musvoto *et al.*, 2000; Aggarwal *et al.*, 2005). However, as has been observed by Vitousek (1984) and Jordan (1985), nutrient cycling in agricultural ecosystems is not efficient compared to natural ecosystems due to human intervention. Thus, in order to be able to manage leaf biomass produced by the sub-tropical fruit trees in the EDM, there is a need to understand issues associated with: amount and quality of leaf biomass that falls from each tree in a season, the decomposition rate and nutrient release pattern from different leaves under local climatic conditions, the uptake of the released nutrients by food crops and their contribution to crop growth. This understanding is important in order to be able to know how to efficiently use leaves for soil fertility management in the EDM.

Although small scale farmers in EDM use traditional approaches to deal with the soil fertility problem, most of this indigenous knowledge is not recorded. There is a genuine concern about the possible extinction of this knowledge as older people die without passing the knowledge to young ones. The World Bank (1998) declared that indigenous knowledge is important and there is a need to document it so that both researchers and local communities have access and use it for planning sustainable development. Hitherto, there has been very little work done on the quality and the soil fertility value of leaf litter from fruit trees in EDM, but also the indigenous knowledge associated with its use and management. This study was aimed at exploring the management and efficient utilization of leaf biomass from sub-tropical fruit trees by small scale farmers for soil fertility management in home gardens. The specific objectives were to:

1) Determine the existing indigenous knowledge among small scale farmers and the factors influencing the utilization of leaf litter biomass for managing soil fertility;
2) Quantify the amount and quality of leaf biomass falling from three selected common sub-tropical fruit tree species and the factors that influence litterfall;
3) Determine the decomposition rate and nutrient release pattern of leaf litter biomass of sub-tropical fruit trees under local climatic conditions;
4) Establish the nutrient uptake by maize grown on soil amended with leaf biomass from selected sub-tropical fruit trees.

The thesis is divided into seven chapters. Following this introduction is the holistic definition of soil fertility and an overview of soil fertility research in South Africa. This is followed by results of a survey that was aimed at establishing the knowledge base underpinning the utilization of leaf litter biomass for maintaining soil fertility by small scale farmers. Following this chapter is the quantification of the amount and quality of leaf litter biomass produced from selected sub-tropical fruit trees at a research station. This quantification is then followed by the determination of decomposition and nutrient release pattern of the decomposing leaves under incubation studies. After this, comes the investigation of nutrient uptake by a maize crop grown on soil amended with leaf litter from the selected sub-tropical fruit trees. It concludes by outlining the general discussion and recommendations drawn from the study.

CHAPTER TWO

A CONCEPTUAL FRAMEWORK OF SOIL FERTILITY AND ITS MANAGEMENT

2.1 Introduction

The theory of soil fertility is full of instances in which thoughts, research and management practices changed from time to time following discoveries of fundamental importance (Nath, 1940). Such discoveries, eventually directed experiments and thought into new fields, leading to new knowledge and expansion in scientific outlook, without at the same time, invalidating previous knowledge and experiences. Although the focus of this study is on South African research, this chapter will also review some of the work done in the other parts of the world in order to gain an understanding of the paradigms in soil fertility research. The objective of this review is to provide an overview of the thoughts underpinning the definition of soil fertility and the conceptual frameworks under which soil fertility management practices have been developed. The point of departure is that an understanding of soil fertility and its processes is important in designing viable sustainable management systems.

2.2 Definition of soil fertility

The term soil fertility has come to mean different things to different people. There are currently a wide range of terms (e.g. soil quality, soil health and soil productivity) that are used by different authors as being synonymous to soil fertility (Gregorich and Carter, 1992; Karlen *et al.*, 1997; Abbott and Murphy, 2003). Soil fertility is a dynamic concept and the manner in which it has changed depended on new discoveries made by the scientists and farmers. This dynamic nature of the concept of soil fertility has made it difficult for authors to agree on a single definition that accommodates all the characteristics of a fertile and productive soil. In this review an attempt is made to reflect the trends in the paradigm shifts associated with the concept of soil fertility and its management.

The earlier definitions of soil fertility were associated with the "Humus theory" which postulated that plants obtain nutrients from the humus or organic matter from decomposed plant and animal matter. Cooke (1967) for example, defined the fertility of soil as its capacity to support a climax population of plants and animals above ground, and the associated flora and fauna below ground. Under this natural ecosystem, plants obtain nutrients from organic matter or humus formed from

plant and animal residues (Waksman, 1938). The humus theory lasted for about 30 years until Sprengel and Liebig introduced the "mineral theory" and formulated the "Law of the minimum" (Millar, 1955; Russell, 1961; Van der Ploeg *et al.*, 1999)

The scientific knowledge and ideas introduced by Sprengel and Liebig resulted in the shift of paradigm from "humus" to "mineral theory" (Van der Ploeg *et al.*, 1999). The "mineral theory" of plant nutrition stated that inorganic nutrients are responsible for plant growth, and led to the manufacturing of artificial fertilizers in order to supply the nutrients (Russell, 1973; Van der Ploeg *et al.*, 1999). The establishment of this theory changed the way in which people thought and defined soil fertility. It also brought new challenges that required a different research approach. In response, Brady (1974) defined soil fertility as the inherent capacity of soil to supply nutrients to the plants in adequate amounts and in suitable proportions.

The above two definitions described soil fertility narrowly in that they considered only the capacity of soil to supply essential nutrients to a plant either in the form of humus or chemical fertilizers. According to Swift and Palm (2001) such narrow definitions of soil fertility ignore the complex nature of the roles of soils by reducing them to sources of nutrients alone. Stocking and Murnaghan (2001) further suggested that a broader and more holistic definition of soil fertility must encompass the vital roles of soils in providing the physical and biological environment that supports crops by providing factors such as moisture required by plants and beneficial organisms that reduce pest and disease pressure. Garforth and Gregory (1997) have claimed that if the term "soil fertility" is used without the qualifiers 'biological', 'physical' and 'chemical' it gives insufficient information about the state of the soil.

The above sentiments have led to the birth of the new school of thoughts on soil fertility which is known as the 'ecological agriculture' theory. This paradigm provides a working holistic definition of soil fertility that interacts the physical, chemical and biological processes of the soil (Stocking and Murnaghan, 2001; Abbott and Murphy, 2003; Vanlauwe, 2004). Consequently, Ingram (1990) defined soil fertility as the capacity of soil to support plant growth and is determined by the physical, chemical and biological properties of the soil.

The concept of soil quality emerged during the 1990s as an outcome of increased emphasis on sustainable land-use. Various studies have attempted to identify soil biological criteria that can be used as indicators of soil quality (Arshad and Coen, 1992; Visser and Parkinson, 1992; Gregorich *et al.*, 1994). This has led to the introduction of biological soil fertility management

paradigm. Consequently, Abbott and Murphy (2003) defined biological soil fertility as the capacity of organisms living in soil (microorganisms, fauna and roots) to contribute to the nutritional requirements of plants and foraging animals for productivity, reproduction and quality while maintaining biological processes that contribute positively to the physical and chemical state of soil. A summary of the paradigm shifts in the definition of soil fertility as influenced by the theory over the past four decades is presented in Table 2.1.

2.3 Conceptual framework of soil fertility management

This section provides a conceptual framework of how soil fertility management has been influenced by paradigms in the theory and definition of soil fertility over time. These changes are shown in Figure 2.1 and reflect that the approaches used by farmers to manage soil fertility have been influenced by the four major theories of soil fertility. For instance, animal and green manures were the mainstay of soil fertility under the humus theory whereas chemical fertilizer and lime were the sole provider of nutrients under the mineral theory.

Table 2.1 Changes in definitions of soil fertility concepts over the past four decades

Period	Theory	Definition	References
1950s	Humus Theory	The nutrient supplying properties of the soil which enhance plant growth.	Blanck (1955)
		The capacity of soil to support climax populations of plants and animals above ground, and the associated flora and fauna below ground.	Cooke (1967)
1960s	Mineral Theory	The inherent capacity of soil to supply nutrients to plants in adequate amounts and in suitable proportions.	Brady (1974)
1980s	Ecological Theory	The capacity of soil to support plant growth and which is determined by the physical, chemical and biological properties of the soil.	Ingram (1990)
		The ability of soil to provide physical, chemical and biological requirements for the growth of plants for productivity, reproduction and quality relevant to plant type, land use and climatic conditions.	Abbott and Murphy (2003)
2000s	Biological soil fertility	The capacity of organisms living in soil (microorganisms, fauna and roots) to contribute to the nutritional requirements of plants and foraging animals for productivity, reproduction and quality while maintaining biological processes that contribute positively to the physical and chemical state of soil.	Abbott and Murphy (2003)

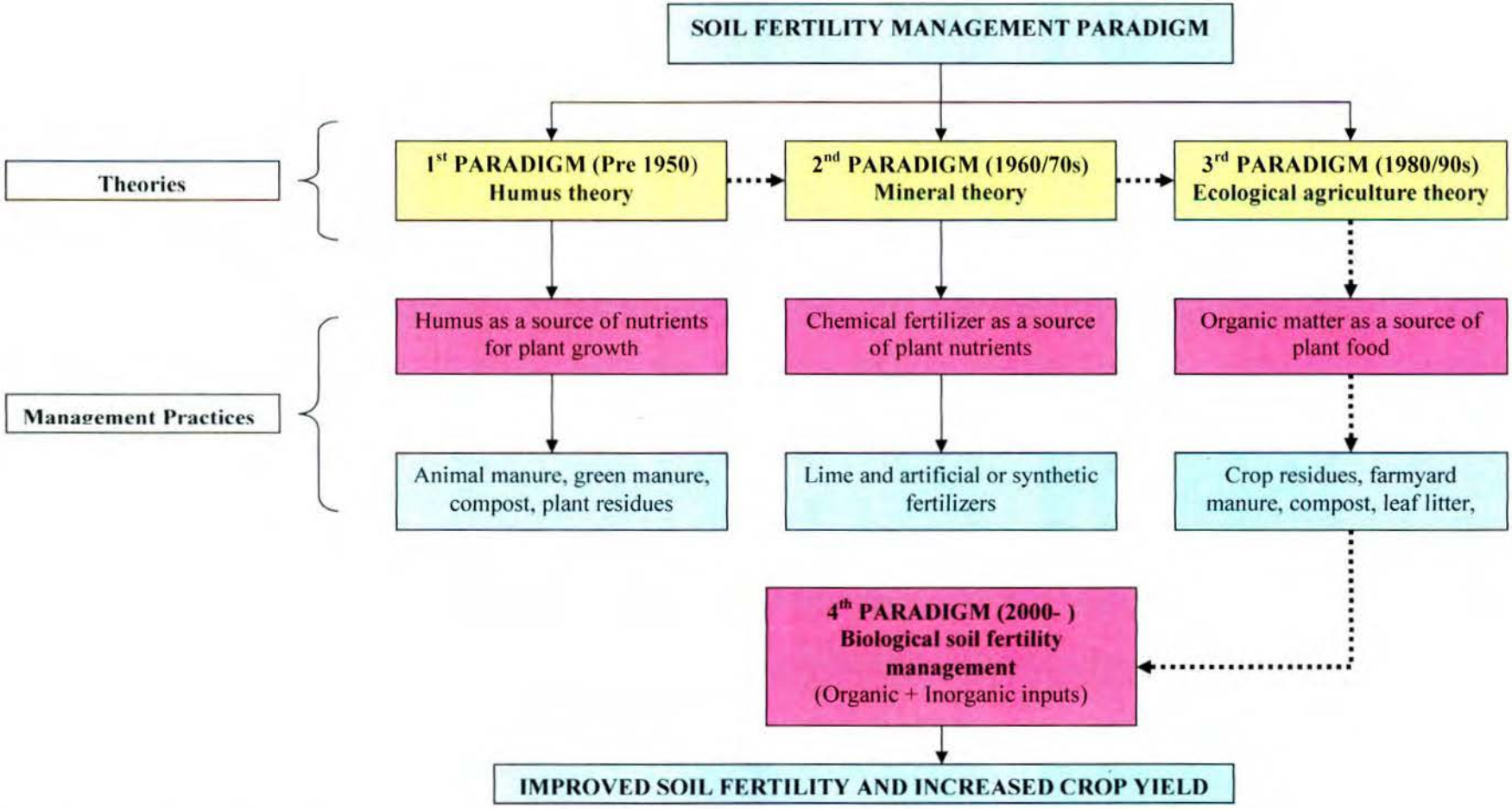


Figure 2.1 Soil fertility management: a conceptual framework

The dotted lines indicate the change in management practices as informed by the shift in paradigm.

2.3.1 Soil fertility management under the "Humus theory"

There are three important functions of humus in relation to soil fertility, *viz*: i) it acts as a storehouse of plant nutrients, ii) it promotes the activity of soil micro-organisms, and iii) it improves the physico-chemical properties of the soil (Bhowmick and Raychaudhuri, 1953). Nitrogen and carbon content are the indicators of humus content (Jenny, 1933; Waksman, 1936; Millar, 1955). In order to improve the fertility of a soil, humus has to be added in the form of animal manures, green manures, crop residues and compost (Millar, 1955). During decomposition, animal manure is transformed into humus which acts as a source and sink of nutrient elements (Millar, 1955).

Bear (1947) presented evidence from Rothamsted Experimental Station that showed the value of animal manure in maintaining soil fertility and crop yields. A plot that received an annual dose of 15.7 t ha^{-1} of animal manure between 1932 and 1942 produced 930 kg of wheat as compared to 430 kg from a control plot. In a ten year study conducted in India, Shinde and Ghosh (1971) found that an annual application rate of 5.6 t ha^{-1} of animal manures increased yields of rice as much as nitrogen and phosphorus fertilization (Table 2.2). Both manure and fertilization treatments increased soil organic carbon and organic nitrogen as compared to the control.

Table 2.2 Effects of manure and fertilizer applications on Lowland rice production and the properties of a Vertisol in Bgwai, India

Annual application	Rice yields (t ha^{-1})	Organic C (%)	Total N (%)	Available P Olsen (ppm)
None	0.88	0.07	0.063	10
Manure	1.49	1.15	0.066	12
N	1.55	1.12	0.066	11
P_2O_5	1.57	1.09	0.066	12

Source: Shinde and Ghosh (1971)

Green manure is also used as source of nutrients particularly where there are no animals (Millar, 1955; Sanchez, 1976). Green manure involves the incorporation of leaves and twigs of various trees and shrubs into the soil. Green manure crops include both legumes

and non legume crops. However, legumes are preferred because apart from adding organic matter to the soil, they also fix nitrogen (Millar, 1955). A field trial at the South Carolina Agricultural Experiment Station reported an 11-year average yield of 1849 kg of seed cotton on soil amended with green manure of rye (Millar, 1955). Although the green manure crop of rye did not increase the cotton yield as much as the animal manures (2027 kg), the combination of green manure and animal manure produced the largest (2474 kg) yield.

Several workers reported that crop rotation system played a major role in increasing the humus content of the soil (Salter and Green, 1933; Millar, 1955). Crop rotation is a system where different plants are grown in recurring defined sequence on the same piece of land. By rotating crops, the humus content of the soil can be increased as a result of the decomposition of biomass of roots that are left by different crops (Salter and Green, 1933). Legume crops are usually included in crop rotation because besides adding humus, they also fix atmospheric nitrogen (Millar, 1955). Figure 2.2 shows a long-term effect of crop a rotation system on humus (measured as organic carbon) at Morrow Experimental Station (1904–1990) (Millar, 1955). There was a difference in the decline of organic carbon among the three cropping systems.

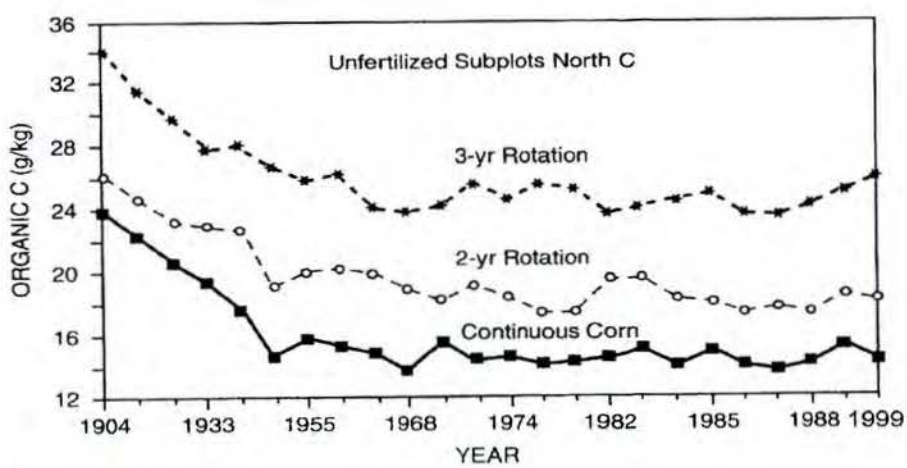


Figure 2.2 Effects of crop rotation on humus content over time (as organic carbon) at Morrow Experiment Station in Illinois, U.S.A

Source: Millar (1955)

Although several research results have shown that humus plays a major role in maintaining soil fertility and improving crop productivity, the introduction of chemical

fertilizers under the mineral theory overshadowed the vital role played by humus in soil fertility management. Furthermore, it has been more difficult to supply organic residues mainly because of: the shortage of man-power to collect and apply organic manure, increased cost in transporting such bulky materials, and the difficulty in obtaining organic residues such as crop residues as they have been consumed by livestock, or in situation of high human density as in most smallholder farming communities.

2.3.2 Soil fertility management under the "Mineral theory"

Ever since the pioneering works of Liebig on the "Law of the minimum", which demonstrated that crop yield was determined by the minimum amount of the nutrient, it has been a standard practice to supply soil with the missing or deficient plant nutrients in order to achieve maximum yield. The missing nutrients have been supplied in the form of chemical fertilizers (Rechcigl, 1995). For years, fertilizers have been the key to successful management of soil fertility in agriculture. According to a report by FAO (2005), the global fertilizer use was merely 27 million metric tons in 1959 and 1960; it increased five times to 141 million metric tons over the forty-year period ending in 2000. In the U.S.A, Havlin *et al.* (2005) reported that the consumption of nitrogen increased from about 240 000 metric ton in 1960 to 1.3 million metric ton in 1980 (Figure 2.3). Similarly, in Sweden the utilization of phosphorus increased from 12 kg P ha^{-1} in 1950 to 24 kg P ha^{-1} in 1974 (Gunnarsson, 1982). As a consequence, many excellent fertilizer trials have been conducted showing the importance of mineral fertilizers on crop production.

Soil fertility research during this period emphasised on the management of fertilizer in supplying crop nutrients. This included studies of sources, rate of application, time of application and methods of application (De Freitas *et al.*, 1972; Gunnarsson, 1982). De Freitas *et al.* (1972) tested the effect of different levels of sulphur on the yield of coffee on a red-yellow Latosol of Brazil. They reported 82% increase in yield of coffee which received an annual rate of about 30 kg S ha^{-1}. There was a further increment in yield at a rate of 132 kg S ha^{-1}, but this higher rate was not economically feasible. There is enormous evidence that the response of crops to chemical fertilizers is also influenced by the source of the nutrients (De Freitas *et al.*, 1972; Sanchez, 1976; Gunnarsson, 1982).

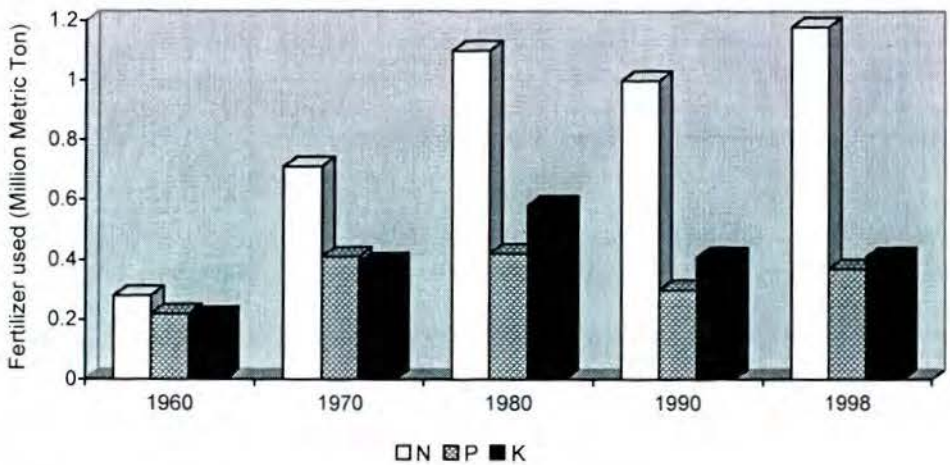


Figure 2.3 Chemical fertilizer use in the U.S.A, (1960–1998)
Source: Havlin *et al.* (2005)

A field experiment was conducted by Víllazar and Lotero (cited in Sanchez, 1976) to evaluate the effect of annual applications of urea, ammonium sulfate and sodium nitrate on the yield of Pangola grass for five years in Andept, Colombia. Optimum yield of 30 t ha^{-1} a year of Pangola grass were obtained with an annual application rate of 500 kg ha^{-1}. Sodium nitrate proved to have a significant effect on yield compared to urea and ammonium sulfate. In another study, Goedert (Cited in Millar, 1955) investigated the effect of different sources of phosphorus on the yield of wheat grown on Oxisols in Brazil. The results indicated that rock-phosphate (Olinda) was inferior as compared to the other phosphorus sources. Thermo-phosphate out-yielded all other treatments by producing high wheat yield of about 218 t ha^{-1}. It was concluded that the sources of nutrient influence the crop response.

The timing and methods of applying chemical fertilizer play a very crucial role in determining the production potential of the crop (Richards *et al.* 1984). Richards *et al.* (1984) tested the timing of application of nitrogen on the yield of cabbage crops grown on a Westleigh soil. There was a significantly better yield when half of the nitrogen was applied before planting and half from four weeks after transplanting, in comparison with all other application times (Table 2.3). In India, Sandhu and Gill (1971) found that a single basal application was desirable at 40 kg N ha^{-1}, two split doses when 80 to 120 kg N ha^{-1} is applied and three split doses when 160 to 200 kg N ha^{-1} is required. A proper time to apply nitrogen reduces the incidents of nutrient losses from the soil.

Table 2.3 Effects of time of application of nitrogen on yield of cabbage

Method of application	Yield (t ha^{-1})
All before planting	103.0
½ before planting, ½ at 4 weeks after transplanting	115.4
⅓ before planting, ⅓ at 4 weeks, ½ at 8 weeks	99.8
¼ before planting, ¼ at 4 weeks, ¼ at 12 weeks	96.8
L.S.D 5%	*6.1*

Source: Richards *et al.* (1984)

In summation, although it was proven beyond any doubt that chemical fertilizers played a major role in increasing crop yields in most areas of the world (Smaling, 1993), a range of factors mitigate against the widespread use of chemical fertilizers particularly by small-scale farmers (Smaling and Braun, 1996). The practice of over-fertilization is not only unnecessary and inordinately costly, but may also be detrimental to the crop itself and even more so to the surrounding environment (Rechcigl, 1995). Out of this concern has developed the new school of thought of ecological agriculture, which rests on the principle that while people meet the needs of the present they should not compromise the ability of future generations to meet their own needs.

2.3.3 Soil fertility management under the "Ecological agriculture theory"

The ecological agriculture theory rested upon the utilization of traditional practices to restore soil fertility and improve crop yields and some authors referred to this theory as the new-old paradigm (Ayala and Rao, 2002; Manlay *et al.*, 2007). However, lack of understanding of the nature and dynamics of organic matter as an agent of nutrient cycling had a negative impact both on soil fertility and crop productivity (Havlin *et al.*, 2005). Over the last two decades the effects of organic matter on soil properties have received renewed attention (Feller *et al.*, 2003). Organic matter refers to the sum total of all organic carbon-containing substances in soils (Schnitzer, 1991). Organic matter influences plant growth through its effect on the physical and chemical properties of soils (Stevenson, 1982). Furthermore, organic matter has a biological function in that it provides carbon as an energy source to nitrogen-fixing bacteria, enhances plant growth, root initiation and nutrient uptake (Duxburry *et al.*, 1989; Schnitzer, 1991; Feller *et al.*,

2003). Several studies have shown that organic matter is an important soil component in improving the chemical, physical and biological properties of soil and crop productivity (Maskina *et al.*, 1993; Barzegar *et al.*, 2002; Feller *et al.*, 2003). Barzegar *et al.* (2002) investigated the influence of 0, 10 and 15 Mg ha^{-1} of different organic materials on soil physical properties and yield of winter wheat in Iran. Application of organic materials significantly increased aggregate stability and decreased soil bulk density (data not shown). Wheat grain yield progressively increased as the amount of the organic materials increased (Table 2.4). The effectiveness of composted bagasse, FYM and wheat straw on wheat grain yield was 22, 14 and 3% respectively over the control.

In a 3-year study, Maskina *et al.* (1993) reported that returning 0, 50, 100, and 150% of the residue produced by the previous crop to the soil resulted in SOM contents (to 30 cm) of 24.7, 25.3, 26.2, and 27.4 g kg^{-1}, respectively. The authors attributed high crop yields in the plots treated with residue to improved water relations in the soil for both plant growth and microbial activity, which enhanced nutrient cycling. In general, organic matter plays a very crucial role in nutrient cycling within the farm. However, lack of understanding about the biological nature of organic matter and processes that enhance the activities of microorganisms in the soil have an impact on soil fertility and crop yields.

Table 2.4 Effect of different amounts and type of organic materials on wheat grain yield (Mg ha^{-1})

Rate of OM (Mg ha^{-1})	FYM	Wheat straw	Composted bagasse	*Mean*	Control
0	5.45d	5.77bcd	5.93bcd	5.72b	5.39
10	570bcd	5.79bcd	5.96bc	5.81b	5.39
15	6.14b	5.57cd	6.60a	6.10a	5.39
Mean	5.76b	5.71b	6.16a		
L.S.D (0.05) = 0.258					

Means in rows followed by the same letter do not differ significantly at (P=0.05)

Source: Barzegar *et al.* (2002)

2.3.4 Biological approach to soil fertility management

The biological approach recognizes the importance of soil biological processes and populations in addition to the physicochemical means of managing soil fertility (Woomer and Swift, 1994; Palm and Swift, 2002). This approach involves understanding the properties and processes within the soil, biota, and vegetation components as well as the interaction among them (Palm and Swift, 2002). One of the key features of biological soil fertility management is the managing of soil fertility through the combination of organic matter and inorganic fertilizers (Pieri, 1992). The use of organic manure in combination with chemical fertilizers is seen as a viable alternative to chemical fertilizers and an option to reduce reliance on chemical fertilizers.

However, the application of organic materials into the soil does not guarantee an immediate supply of nutrients to crops since it involves a lot of other processes such as decomposition, mineralization and / or immobilization of nutrients which are not known to most of the small-scale farmers (Woomer and Swift, 1994; Cadisch and Giller, 1997). This lack of understanding has prompted researchers to find possible ways of managing organic matter to the benefit of both soil and crops. The inability to predict the outcome of change in agricultural management on soil biological processes was a major constraint to the successful design of farming systems that harness the biological potential of soil (Abbott and Murphy, 2003). It is within the concept of soil biology management whereby the Tropical Soil Biology and Fertility programme (TSBF) was established in 1984 (TSBF, 1984). Many studies have attempted to define the biological status of soil using simple indicator measurements (Doran and Parkin, 1994; Gregorich *et al.*, 1994).

Soil quality and all indicators that are used to measure soil quality hold a key to a successful utilization of various organic materials for improving soil fertility. Doran and Parkin (1994) defined soil quality as the "capacity of the soil to function within ecosystem boundaries in order to sustain biological productivity, maintain environmental quality, and promote plant and animal health". Central to the concept of soil quality is the consideration that soil is a living system (Doran *et al.*, 1996). The soil quality concept provides a tool that assists in quantifying the combined biological, chemical and physical response of soil to crop management practices (Masto *et al.*, 2007). Doran and Parkin (1994) identified biological indicators of soil quality as the most critically

important factors because soil quality is strongly influenced by microbiologically mediated processes (nutrient cycling, nutrient capacity, aggregate stability). Biological indicators of soil quality that are commonly measured include soil organic matter, respiration, microbial biomass (total bacteria and fungi) and mineralizable nitrogen. Soil microbial biomass responds more quickly to changes in agricultural practices than organic carbon or total nitrogen (Karlen *et al.* 1997) and, therefore, may be an indicator of early trends in changes to total organic matter.

Several researchers have studied the effects of organic matter on soil quality (Haynes, 1997; Haynes and Hamilton, 1999; Kaur *et al.*, 2005). In Quebec, Martel and MacKenzie (1980) compared the effect of different land use practices on soil quality and showed that the conversion of forest soils into agricultural soils was accompanied by a loss in both SOM and structural stability and, under some conditions, an increase in soil compaction. Use of continuous grass (>5 yr), however, tended to reverse the decline in soil quality. After about 130 years on the Broadbalk experiment at Rothamstad Experimental Station, biomass carbon content had reached an equilibrium of 128 μg C g^{-1} with no fertilizer application and 189 μg C g^{-1} with annual application of N, P, K, Mg and Na (Sparling, 1985). Under a seven year trial, Kaur *et al.* (2005) observed higher microbial biomass C and N in a plot receiving organic manures only and with the combined application of organic manures and chemical fertilizers compared to soils receiving chemical fertilizers only. These results showed that balanced fertilization using both organic and chemical fertilizers is important for the maintenance of soil organic matter content and long-term soil productivity.

2.4 Soil fertility research in South Africa

2.4.1 Introduction

Throughout the course of agricultural history in South Africa, soil fertility has played an increasingly important role of being an indicator of the soil capacity to produce food crops (Laker, 1976; Scotney and Dijkhuis, 1990; Barnard and Du Preez, 2004). However, little quantitative information is available regarding soil fertility patterns which exist in the various agricultural regions and areas of South Africa. Also less available, are changes in fertility levels which might have occurred with time (Eisenberg *et al.*,

1985). The value of such information to agriculture and fertility advisers in particular, is considerable. Without this information, it cannot be possible to design viable soil fertility management strategies. During the past five decades (1950–2000), the paradigms underlying soil fertility management and research in South Africa have undergone substantial change because of experiences gained with specific approaches and changes in the overall social, economic, and political environment (Scotney and Dijkhuis, 1990; Laker, 2005). This section attempts to develop an understanding of how the paradigm shift underlying soil fertility in South Africa has led to changes in the definition of soil fertility and their associated research and management practices.

2.4.2 Definition of soil fertility

As is the case with other countries, the definition of soil fertility in South Africa has also undergone paradigm shifts. Before 1950s soil fertility was simply defined as the capability of soil to support plants (Juritz, 1910). Between 1960 and 1970s, the appropriate application of chemical fertilizers was driving the research and development agenda. During this period, soil fertility was narrowly defined as the overall ability of soil to support crop growth by ensuring adequate plant nutrients (Scotney and Dijkhuis, 1990). Chemical fertilizer was seen as the solution to any soil fertility constraints and this resulted in little attention given to the value of organic materials and cropping systems that help in building-up soil fertility (Scotney and Dijkhuis, 1990). From the early1980s to 1990s the awareness has been growing of the many potential problems caused by the heavy use of chemicals in modern agriculture. This, combined with the rapid rise in the cost of fertilisers, has led many farmers to seek ways of reducing their reliance on chemical-intensive methods of farming (Scotney and Dijkhuis, 1990; Barnard and Du Preez, 2004; Laker, 2005). Consequently, agricultural researchers in South Africa began to focus on ways of maintaining environmental quality while producing acceptable crop yields (De Villiers, 2005). In response to this paradigm shift, Anon (1980) defined soil fertility as a synthesis of the chemical, physical and biological components of soil which are influenced not only by the supply of nutrients, but also by the climate and management factors. This definition attempted to integrate almost all factors or properties that are considered as the characteristics of soil fertility.

2.4.3 Soil fertility research and management under different paradigms

2.4.3.1 Soil fertility management under the "Humus theory"

Soil fertility was managed under the belief that a plant obtains nutrients from humus of organic matter. Organic materials such as guano, animal manure, compost and green manures were commonly used by farmers to replenish soil fertility and providing nutrients to the growing crops (Altona, 1980). Sawer (1909; 1911) investigated the effect of manure on different field crops at Cedara, Natal. The yield increased due to manure application in all crops investigated. Retief (1948) investigated the effects of different application methods and levels of animal manure on tobacco and found that tobacco yield increased linearly with the levels of kraal manure (Table 2.5). Banding of animal manure produced higher yields compared to other application methods. Van Vuuren (1949) reported that by 1945 about 250 000 tons of compost was produced in South Africa. Although no data is provided, Pearson (1958) reported on the benefits of velvet beans, sunn hemp, cowpeas, lupin, rape and mungbeans in replenishing old cane land in South Africa. Several constraints such as labor requirements, lack of transport, unavailability and poor quality of organic materials has led to the downfall of the humus theory as people became more interested in chemical fertilizers.

Table 2.5 Effects of rate and application methods of animal manure on the yield (bags/morgen) of tobacco

Application rate		**Application method**	
Rate (kg morgen^{-1})*	Yield (bags morgen^{-1})	Methods	Yield (bags morgen^{-1})
136.08	11.85	Broadcast	10.28
272.16	13.06	Rows	13.22
408.23	15.30	Maize planter	11.63
		Banding	18.02
Mean	*13.40*	*Mean*	*13.4*
Significant difference	*0.33*	*Significant difference*	*0.61*

* = 1 morgen = 0.8567 ha

Source: Retief (1948)

2.4.3.2 Soil fertility management under the "Mineral theory"

The pattern of chemical fertilizer consumption in South Africa between 1955 and 2007 followed the paradigm shifts. Between 1955 and 1984 fertilizer consumption grew at a steady rate, from 168 400 metric ton (MT) $N + P_2O_5 + K_2O$ to almost 690 000 MT (Figure 2.4). This growth in fertilizer consumption was among other things made possible through fertilizer subsidies from the government (Altona, 1980; FSSA, 2002-2007). However, in the mid-eighties, fertilizer consumption fell by thirty percent before reaching a new equilibrium in the late-eighties (Figure 2.4). This was attributed to withdrawal of fertilizer subsides by government. The less usage of fertilizer led to the need for researchers to find alternative means of supplying soil nutrients including the use of organic materials.

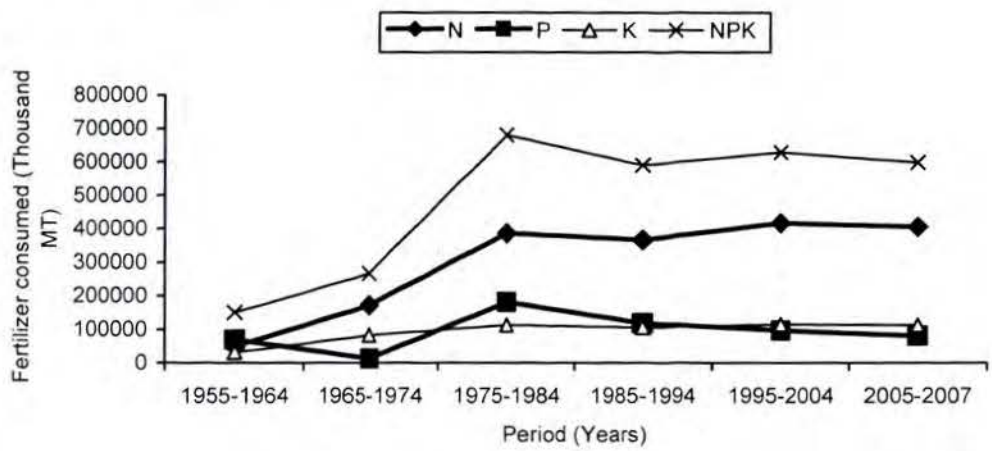


Figure 2.4 Long-term trend of fertilizer consumption in South Africa (1955–2007) Source: FSSA (2002-2007)

The effect of different rates of chemical fertilizers on production and crop quality has been investigated intensively throughout South Africa (Klein, 1986; Farina and Channon, 1986; Robbertse *et al.*, 1990). Smith (2000) tested six levels of nitrogen (LAN) on a matured Tommy Atkins mango on a sandy loam soil in Malelane, Mpumalanga for three seasons (1994/95, 1995/96 and 1996/7). The results showed significant differences in yield between the levels of nitrogen application. High mango yields were obtained at the rate of 900 and 1350 g N $tree^{-1}$ $year^{-1}$. High levels of nitrogen (1800 and 2250 g $tree^{-1}$ $year^{-1}$) resulted in lower yields than was expected. Terblanche (1986) found that the application of potassium at the rate of 95 mg K $100g^{-1}$ increased fruit size of apples and

also ensured maximum calcium uptake and minimized the risk of bitter pit on the apple fruits. Klein (1985), on the other hand, found that 300g K ha^{-1} increased the leaf K level in three apple cultivars compared to 600g K ha^{-1} which had no additive effect on leaf K level. However, increased fruit yield (220 t ha^{-1}) was found when 600g K ha^{-1} was applied compared to 178 t ha^{-1} from 300g K ha^{-1}. Melis and Farina (1984) carried out a study on Mertz silt clay soil at Cedara, Natal to investigate the effect of four levels of potassium fertilizers on the soil and leaf potassium and yield of white maize (cv PNP473). The effects of potassium on growth were dramatic and grain yield increased owing to potassium application. Maize yield increased linearly with the rate of potassium. Farina and Channon (1986) recommended an application rate of 45 kg K ha^{-1} for achieving 6000 kg ha^{-1} grain from a maize crop and about 100 kg K ha^{-1} to obtain a comparable yield on a silage crop.

Coetzer *et al.* (1990) conducted an experiment in order to see the effect of boron on reproduction in tomato and bean plants. The study was carried out in a greenhouse at the University of Pretoria. Seedlings of tomato and beans were grown in a plastic container placed on a rotating platform in natural sunlight in a green house. The study concluded that leaf boron content of bean should be maintained at around 50–100 mg kg^{-1} for optimum production. In tomato, leaf boron of between 80–120 mg kg^{-1} should be most favourable for good yields. A liming experiment conducted by Smith *et al.* (1992) in the ARCs Burgeshall experiment station indicated that the production of banana, as determined by bunch mass, was considerably higher with an application of 4 t ha^{-1} of lime while an application higher than 4 t ha^{-1} had no positive or negative effect on yield. Du Plessies and Koen (1987) found that different sources of calcium have different influences on the yield of citrus. Moderate levels of dolomitic lime (4.2 t ha^{-1}), calcium silicate (5.0 t ha^{-1}) and gypsum (9.2 t ha^{-1}) resulted in higher yield compared to the control and higher levels of applications. De Villiers *et al.* (1988) compared the effect of split nitrogen applications of 150 kg N ha^{-1} (applied at different growth stages) with a single nitrogen application of 50 kg N ha^{-1} given at sowing on the quality of barley. The growth stages at which supplementary nitrogen was applied significantly affected all malting parameters of barley. Du Plessies (1986) investigated the effect of different times of spraying potassium nitrate on the yield and fruit size of citrus (cv. Valencia). The results indicated that potassium sprayed early in the season increased yield but not fruit size (Table 2.6).

Table 2.6 Effect of different times of applying potassium on yield and fruit size of a citrus crop

Time of spray	fruit size (%) (%)	Yield (kg tree^{-1})
Control	70.2	151.8
October/November	60.0	188.1
November/December	49.2	182.9
P = 0.05	*13.2*	*20.2*

Source: Du Plessies (1986)

2.4.3.3 Soil fertility management under the "Ecological agriculture theory"

During the last two decades (1980-2000), the importance of the biological management of soil and integrated soil fertility management gained ground in South Africa. These approaches take cognizance of interacting soil biological, physicochemical, managerial, socio-cultural-economic and climatic factors affecting soil fertility (Laker, 2005). With a more integrated and conserving approach towards soil fertility management, organic matter management is controlled to achieve breakdown and as a pulse of available nutrients in synchrony with crop demand (Woomer and Swift, 1994, Cadisch and Giller, 1997). This approach can benefit the small scale farmers in the sense that it reduces fertilizer costs, conserves the environment without diminishing the productive capacity of a soil for present and future generations. A survey by the Council for Scientific and Industrial Research (CSIR), estimated that about 75 000 and 35 000 tons of cattle and chicken manure, respectively, had been sold as fertilizers in 1986 (FSSA Fertilizer Handbook, 2003).

2.4.3.3.1 The effect of organic materials on soil properties and crop yields

The application of organic materials for maintaining soil fertility has been practiced for many years in South Africa and was widely adapted, before the introduction of chemical fertilizers (Rhodes, 2006). Kotze and Joubert (1992) investigated the effects of organic mulch on the yield of apricots grown on a sandy Clovelly soil in the Western Cape. A 50 mm layer of the coarse waste material from rooibos tea was applied once during the first

spring of 1982 after planting "peeka" apricot trees. Apricot trees which had been mulched produced higher yields during the trial period. The study concluded that the potential of sandy soils for apricot production could be increased by the application of organic materials. Mkhabela and Materechera (2003) suggested that chicken manure is an organic resource available in South Africa, which small scale farmers could use to supply phosphorus to plants. Materechera and Morutse (2009) found that the application of chicken manure led to increased pH and greater residual phosphorus content of the soil than the fertilizer. The authors also found that the combination of fertilizer and chicken manure resulted in higher maize yield. The authors concluded that chicken manure is a viable option for supplying phosphorus to sustain maize crop production particularly in the smallholder farming sector of South Africa.

In a study by Neluheni *et al.* (2008) at the Agricultural Research Council (Vegetables and Ornamental Plants Institute) in Pretoria, the combination of Guano + NPK gave higher spinach yields of about 78.8 t ha^{-1} compared to NPK and guano alone which yielded 72.7 t ha^{-1} and 68.9 t ha^{-1}, respectively. Some fertilizer companies such as Ocean agriculture, Sea-Grow, Biofert and Afrikelp have begun to manufacture environmentally friendly organic fertilizers. Baloyi *et al.* (2009) investigated the effect of different industrially manufactured biological amendments on the biological properties of soil and maize grain yield at the Agricultural Research Council (Grain Crop Institute) in Potchefstroom. The results indicated that molcast, promis and K-humates gave an increase in maize grain yields of 12.4%, 1.4% and 0.7% respectively. K-humates, montys, crop care and banbac increased soil microbial biomass to about 0.72, 0.145, 0.385 and 0.180 cm C g^{-1}, respectively.

Apart from supplying nutrients and replenishing soil fertility, some studies have found that organic materials play a crucial role in ameliorating soil acidity (Hue *et al.*, 1994; Mokolobate and Haynes, 2001; Onwuka *et al.*, 2007). Mokolobate and Haynes (2001) compared the effectiveness of different organic residues in combating soil acidity on a soil in KwaZulu-Natal. The authors found that the addition of organic residues generally raised the concentration of exchangeable cations, extractable phosphorus and increased the electrical conductivity in the soil solution. Moreover, residue addition increased the pH and decreased exchangeable aluminium in the order poultry > filter cake > household compost > grass residue. The study concluded that the addition of organic residues to

acid soil was potentially a practical low-input strategy for increasing soil pH, decreasing concentrations of phytotoxic aluminium and reducing lime requirements.

2.4.3.3.2 The effect of organic materials on soil quality

Concerns about the effects of agricultural management practices on the environment have initiated interest on soil quality/health. The emphasis on the requirement of quality of natural resources which must be maintained to ensure sustainable land-use has brought about focus on soil quality management these days (Miller and Wali, 1995). According to Haynes *et al.* (2002) the effects of agricultural land management on soil organic matter status and the size and composition of soil biotic communities in South Africa have received very little attention. Graham *et al.* (2002) investigated the effects of crop residue management and fertilizer applications on soil organic matter content and labile soil organic fractions on a long-term (59 years) field trial under sugarcane situated at Mount Edgecombe, South Africa. Soil organic matter content in the top soil layer (10 cm) increased with increasing inputs of crop residues and with annual fertilizer applications. There was a significant treatment effect on microbial biomass carbon in the 10–20 and 20–30 cm layers. The results demonstrated that greater inputs of organic matter due to increased returns of above-ground crop residues caused a proportionately greater increase in the size of labile pools of organic matter.

A similar observation was reported by Belay *et al.* (2001) on the use of manure at the University of Pretoria. The researchers showed that total carbon and nitrogen and available phosphorus levels, were increased as a result of manure application (Table 2.7). Soil microbial biomass content of carbon, nitrogen and phosphorus and microbial population were also positively affected by the manure application. Manure application also resulted in higher maize yields. The study concluded that long-term application of manure resulted in the build-up of nutrients and their slow release over long periods thus improving or maintaining the fertility level of the soil.

Table 2.7 Influence of manure on total and microbial C, N and P and maize yield under long-term crop rotation

Treatment	Organic C	Total N	Bray-1P	Biomass C	Biomass N	Grain Yield
	---------- (mg kg^{-1})----------					($kg\ ha^{-1}$)
Native	6300b	690b	27.8b	292a	13.5b	No data
Control	5840b	591b	1.7c	140b	14.9ab	1249b
Manure	8890a	1051a	58.5a	236a	25.1a	4465a

Native = natural ecosystem; Control = without manure; Means in columns followed by the same letter do not differ significantly according to Duncan's multiple range test (P=0.05)

Source: Belay *et al.* (2001)

2.4.4 The interaction effect of cultivation on soil organic matter and soil fertility in South Africa

The paradigm shifts in soil fertility management in South Africa have prompted farmers to increase crop yields by expanding cultivated areas and to depend largely on chemical fertilizers in order to improve crop production. It has however been observed that the cultivation of land for crop production has adversely affected soil fertility through the breakdown of organic matter (Theron and Haylett, 1953; Theron, 1951; Prinsloo *et al.*, 1990). The effect of cultivation on soil organic matter has been widely investigated in South Africa (Scotney and Dijkhuis, 1990). Scotney and Dijkhuis (1990) estimated that 12.9 million hectares of land are under cultivation in South Africa, with maize and wheat as the dominant crops. Between 1911 and 1981, the total area under maize increased from 960 000 ha to 4 million ha. The area under sugar cane increased form 170 948 ha in 1951 to 340 780 ha in 1975 (Wood, 1980). Cultivation accelerates the oxidation of soil organic matter at or near the soil surface and results in physical, chemical and biological soil degradation, deterioration of structure, decreased aeration and overall loss of fertility (Mills and Fey, 2003).

Prinsloo *et al.* (1990) found that considerable losses of organic matter followed cultivation which amounted to 66% in the 0-15 cm layer, 29% in 16-50 cm layer and 17% in 51-100 cm layer of a soil in the Free State province. Loss of total nitrogen followed a similar pattern and was 55%, 17% and 6% for the same depths. Nel *et al.*

(1996) found a 50% decline in carbon after 50 years of cropping a Hutton soil in Pretoria. Similarly, Du Toit *et al.* (1994) found that 5–90 years of cultivation in the Free State resulted in a loss of 10–73% of carbon and nitrogen relative to natural grassland. Lobe *et al.* (2001) recorded a 50% decline in carbon after only 3.5 years of cultivation in the Free State. Wiltshire and Du Preez (1993) showed that cultivation in the Free State resulted in the loss of 30–50% of total nitrogen, while Prinsloo *et al.* (1990) found that cultivation reduced nitrogen in the top 15cm of soil from 1.8 t ha^{-1} to 0.5 t ha^{-1}. Du Toit and Du Preez (1995a) investigated the effect of cultivation on the nitrogen fertility of selected dry land soils in South Africa. The authors found 45% decrease of cumulative net mineralization, 37.6% decrease in nitrogen mineralization potential and 22.6% decrease in the rate constant.

Du Toit and Du Preez (1995b) investigated the effect of cultivation on the decline of total sulphur. The rate of sulphur loss was high during the initial period of cultivation, thereafter it decreased until a new equilibrium was reached. On the South African Highveld, Du Preez and Claassens (1999) found that 30% of labile phosphorus was lost as a result of cultivation. Barnard and Du Preez (2004) indicated an overall loss from South African cultivated soils of 87 693 t K between 1965 and 1975. These results clearly demonstrated that cultivation had a significant negative effect on the fertility of dry land soils in South Africa. Cultivation has resulted in a shift in terms of research to focus on finding solutions to correct the situation (Theron, 1951; Grant, 1978; Prinsloo *et al.*, 1990; Haynes, 1997; Haynes and Hamilton, 1999; Lobe *et al*; 2001).

2.4.5 Conclusion

The review has shown that an understanding or interpretation of soil fertility has undergone changes worldwide. Not only was the definition of soil fertility was affected by these paradigm shifts, but the research and management practices were also informed by the paradigm shift underlying soil fertility. Ecological agriculture has proved to be a powerful tool in managing soil fertility on a sustainable manner. It is especially helpful when it comes to resource poor farmers who can not afford chemical inputs. Farmers have therefore developed local knowledge of managing soil fertility which they use. This knowledge can form a basis of soil fertility management and needs to be well understood.

CHAPTER THREE

LOCAL FARMERS' KNOWLEDGE ABOUT THE UTILIZATION OF FRUIT TREE LEAF LITTER FOR SOIL FERTILITY MANAGEMENT

3.1 Introduction

Local knowledge, also known as indigenous knowledge (IK), has been defined as the knowledge that is unique to a given culture or society (Warren, 1991). Indigenous knowledge is derived from man's daily interaction with the environment, observations and experiences, often tested over a long time of use. The use of indigenous knowledge has been seen by many as a means of promoting development particularly in rural communities (Kolawole, 2004). This is because indigenous knowledge serves as a tool for decision making in matters related to social, economic and livelihoods among rural people (United Nations, 1990; Beckford and Barker, 2007). In the field of agriculture, indigenous knowledge is applied in several aspects including soil preparation, planting materials, managing soil fertility, controlling pests and diseases, controlling weeds, harvesting and storage of indigenous root crops.

Small scale farmers use indigenous knowledge to arrive at decisions that influence agricultural management practices because they are left out of the formal agricultural research processes as sources of information and innovation. This exclusion has resulted in inaccurate diagnosis of agricultural problems and creation of technologies that neither meet the needs of the small scale farmer nor are suitable for their production environment (Chambers, 1983). It is often argued that researchers should build upon local knowledge in order to generate timely solutions to agricultural research questions (Mathias, 1995). By basing agricultural development work on local knowledge, farmers and researchers can create ecologically sustainable and economically efficient agroecological systems (De Walt, 1994). This type of development is essential for the empowerment of farmers at the local level (Thrupp, 1987). The importance of local knowledge has become strikingly apparent in the field of soil fertility management. It is imperative that farmers' knowledge and management of soil fertility be understood if researchers are to work with local farmers towards sustainable agriculture.

Over the years, farmers in the Ehlanzeni District Municipality (EDM) have developed some indigenous techniques of replenishing soil fertility. The majority of farmers in the EDM are poor and cannot afford to buy chemical fertilizer to apply to their fields. One such technique involves the use of leaf biomass from fruit trees such as avocado, mango, litchi, macadamia and citrus to manage soil fertility. Despite its use amongst farmers, this technique has not been well studied particularly in South Africa. Proper understanding of this technique could offer more options for soil fertility management to farmers and enhance their capacity to make appropriate litter management decisions. There have been very limited studies, if any, of the indigenous knowledge on the utilization of leaf litter from fruit trees by small scale farmers in the EDM. There is therefore a need to study this indigenous knowledge so that it can be used in the development of sustainable soil fertility management strategies. Soil fertility management requires adaptive responses that consider local knowledge of the farmers as a starting point in addressing soil fertility problems. The basis of this survey was to obtain knowledge from farmers and use it as a base for improving the efficiency of utilization of leaf litter. This study was therefore aimed at establishing the knowledge level among local farmers in the EDM regarding the utilisation of leaf litter from sub-tropical fruit trees for managing soil fertility. The specific objectives of the survey were to:

1) Investigate the production and utilisation of leaf litter from selected sub-tropical fruit trees among small scale farmers in the EDM;
2) Investigate strategies used by the local farmers to recycle nutrients from leaf litter of selected fruit trees;
3) Determine the farmers' knowledge regarding leaf litter quality parameters and its influence on soil fertility;
4) Identify factors that influence farmers' decisions to use leaf litter from selected trees for soil fertility management.

3.2 Literature review

3.2.1 Definition and importance of indigenous knowledge

Indigenous Knowledge is generally used synonymously with traditional and local knowledge to differentiate the knowledge developed by and within distinctive indigenous communities from the international knowledge system generated through universities, government research centres and private industry, sometimes called the Western knowledge system (Warren, 1991). Similarly, Beckford and Barker (2007) defined indigenous knowledge as dynamic and complex bodies of know-how, practices and skills that are developed and sustained by people or communities with shared histories and experiences. Indigenous knowledge is also known as local knowledge, folk knowledge, people's knowledge, traditional wisdom or traditional science (Warren, 1991).

According to Thrupp (1987), incorporating indigenous knowledge into research projects can contribute to local empowerment and strengthening self-determination. The involvement of indigenous people in planning development projects can provide valuable input about the local environment and how to efficiently manage its natural resources. Indigenous knowledge underpins the choice of farming techniques, allowing farmers to manage soil fertility, to rotate crops effectively, to select appropriate crops and crop combinations for local conditions (Warren, 1991). Through indigenous knowledge that was generated overtime, local farmers determined the fertility status of their soils by simply using colour, texture, productivity and moisture content (Beckford and Barker, 2007). This knowledge gives them an edge to successfully apply proper soil management practices in their fields.

Indigenous knowledge has characteristics that distinguish it from other forms of knowledge (Table 3.1). The traditional farming communities, through their wisdom have developed a number of indigenous techniques to replenish soil fertility. However, most of these techniques are unknown to a large section of mainstream society and scientific studies on them are conducted infrequently. The importance of local knowledge has become strikingly apparent in the field of soil fertility management. It is imperative that farmers' knowledge and management of soil fertility be understood if researchers are to work with local farmers towards sustainable agriculture.

Table 3.1 Summary of the characteristics of indigenous knowledge

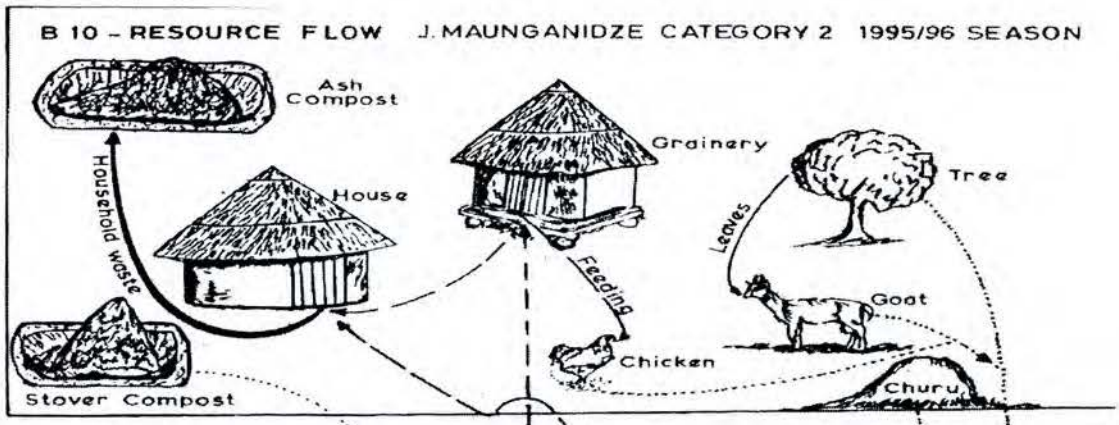
Characteristics of indigenous knowledge	Reference
• Indigenous knowledge is localized in nature and, more often than not, traditional in context.	De Walt (1994)
• Although IK may have commonalities between geographical locales, it is unique to specific environmental and cultural conditions.	Beckford and Barker (2007)
• Indigenous knowledge is knowledge constructed in informal settings; this knowledge is passed from generation to generation, usually by word of mouth and cultural rituals, and has been the basis for agriculture, food preparation, health care, education, conservation and the wide range of other activities that sustain a society and its environment in many parts of the world for many centuries.	Richards (1985)
• It is dynamic, adaptive and holistic in nature and is a significant part of the way of life and subsistence of rural peoples everywhere. Due to its dynamic nature, indigenous knowledge allows people to carry out their daily tasks, and also to adapt and cope with new problems in the face of environmental and economic uncertainties and hardships.	Mascarenhas (2004)
• Indigenous knowledge does innovate from within and also will internalize, use and adapt external knowledge to suit the local situation.	Grenier (1998)
• Indigenous knowledge is not systematically documented, however is rather stored in people's minds and activities and is expressed in stories, songs, proverbs, dances, beliefs, rituals and community languages.	Warren (1991)

3.2.2 Utilisation of indigenous knowledge in the management of soil fertility

There are many techniques and practices that are used by farmers to replenish soil fertility (Edge *et al.*, 1988; Hoffmann *et al.*, 2001; Wickama and Mowo, 2001). These techniques differ from one culture to another. This section will use a few examples to highlight the significance of indigenous knowledge systems in managing soil fertility for improving crop productivity. Although the scope of the study is limited to the promotion of the utilization of leaf litter for replenishing soil fertility by local farmers, other aspects of soil fertility whereby indigenous knowledge was applied by farmers to replenish soil fertility and increase crop productivity will also be highlighted. The section also highlights some of the measures that smallholder farmers take in order to manage the flow of organic resources on their farms. For example, Figure 3.1 illustrates how farmers in some areas of Zimbabwe manage and allocate their organic resources to the various farming components. Farmers collected different organic resources such as manure, leaf litter, compost, and wood ash and distribute them to their gardens. Using this system, about 180 kg of leaf litter is applied to rape while 4 tons of compost is applied to a maize field (Mavedzenge *et al.*, 1999).

3.2.2.1 Indigenous knowledge on the utilization of leaf litter for maintaining soil fertility

On small scale farmers' fields, nutrient cycling has, in many countries, been enhanced by applying leaf litter collected from different trees and shrubs (Musvoto and Campbell, 1995; Jama *et al.*, 2000; Wickama and Mowo, 2001). Depending on the quality and quantity, the collected leaf litter is either applied directly to the fields or subjected to composting before it is transferred to the crop fields. Methods of applying the leaf litter differ from one society to the other and include incorporation, surface application and or mulching (Wickama and Mowo, 2001).



FIELDS	1	2	3	4
AREA	1.30 ha	0.32 ha	0.23 ha	0.02 ha
CROP	maize	groundnuts	sorghum	rape
INPUT 1	nil	nil	nil	nil
INPUT 2	4012 kgs compost		2784kgs termitera stover 1728kgs compost	130kgs goat poultry manure leaf litter 180 kg
OUTPUT 1(grain)	6 bags	3 bags	6 bags	120kgs rape
OUTPUT(stover)				

Figure 3.1 Flow of organic resources within a smallholder farming sector in the communal areas of Zimbabwe

Source: Mavedzenge *et al.* (1999)

In Tanzania, farmers collected leaf litter from local shrubs such as *Venonia subligera*, *Venonia amyridiantha* and *Abizia schiniperiana* and applied the litter to their fields prior to planting. These farmers claimed that the leaves from these local shrubs were rich in nutrients and form a good source of nutrients for their crops (Wickama and Mowo, 2001). To verify the claim made by the smallholder farmers, Wickama and Mowo (2001) conducted a study in Tanzania where selected farmers were asked to select and rank trees/shrubs in the order of their importance in relation to soil fertility and crop productivity. The ranking of the trees was *Venonia subligera* > *Venonia amyridiantha* > *Abizia schiniperiana.* Farmers reported that soil collected from underneath *Venonia subligera* shrubs was an excellent medium for producing more vigorous and faster growing plants. The results of leaf analysis indicated that *Venonia subligera* had the highest levels of nitrogen (3.6%) and potassium (4.7%) compared to leaf biomass from the other two species selected by the respondent farmers (Table 3.2). The study concluded that the knowledge that these farmers had was valid and it was very useful in maintaining soil fertility.

Table 3.2 The concentration of nutrients in plant tissue (leaves) and soil collected from the selected trees in Tanzania

Specie	Nutrient content (%)					
	N		P		K	
	Tissue	Soil	Tissue	Soil	Tissue	Soil
Vernonia subligera	3.6	0.5	0.25	7.8	4.7	0.9
Vernonia amyridiantha	3.4	0.5	0.23	10.3	4.5	1.1
Abizia schiniperiana	3.1	0.4	0.32	13.5	1.3	0.8

Source: Wickama and Mowo (2001)

Several studies have revealed that traditional farmers have knowledge about the quality of organic resources that they use to replenish soil fertility on their farms (Hoffman *et al.*, 2001; Rao *et al.*, 2003). Farmers collected organic materials from different sources and mixed them in order to improve its quality. For example, animal manure was usually mixed with other organic amendments such as grasses, leaf litter, and crop residues as a means of increasing the quantity and quality of manure. In some cases, a small quantity of inorganic fertilizers was mixed with organic materials to enhance the quality.

In the central Himalayans, farmers collect leaves from the forest and use them as bedding materials for their animals. After a while they collect a litter-cattle excreta mixture from the kraals and use them as manure in crop fields (Rao *et al.*, 2003). Rao *et al* (2003) found that farmers collected leaves from forest trees such as Oak and Pines and used them as bedding materials for their animals. An experiment was carried out on poor sandy soils in central Himalayas, India where about 10 t ha^{-1} of manure from each tree was applied on separate plots and worked into the soil before sowing wheat seeds. Some of the manure was collected and analyzed for chemical properties. The manure analysis results showed higher concentration of nutrients in oak manure compared to pine manure. The crop yield results showed the yields in oak manure treatment to be 15% higher than that in pine manure treatment (Table 3.3).

Table 3.3 Biomass (g m^{-2}) production by wheat crop treated with oak and pine based manure

Components	Manure type	
	Oak based	Pine based
Grain	58.5	46.7
Straw	108.8	81.7
Roots	8.5	7.3
Total	***175.8***	***135.7***

Source: Rao *et al.* (2003)

There is evidence which indicates that traditional farmers had knowledge of how to improve the quality of organic resources used to manage soil fertility. Hoffman *et al.* (2001), for example, showed that farmers in Nigeria preferred cattle manure for maintaining soil fertility and increasing crop yields. Farmers indicated that donkey manure caused a fungal disease in millet especially at the seedling stage. However, in order to prevent this, farmers indicated that they mixed donkey manure with the dung from other livestock or sufficient plant litter. Farmers also indicated that cattle manure completely decomposed within 2.5 years, small ruminant droppings after 3.5 years, and donkey manure decomposed even more slowly. In order to ensure a continuous flow of nutrients on their farms, farmers indicated that they mixed manure collected from different animals.

In some cases traditional farmers dug a pit next to the animal kraal in order to collect any slurry that may flow out of the kraaled area. They progressively added plant residues depending on their availability and covered the pit to prevent loss of nutrients into the atmosphere. After 5 to 7 months of composting, the compost was transferred to crop fields. In the field, farmers ploughed in the composted manure soon after spreading in order to reduce the loss of nitrogen into the air. Wherever possible, farmers made sure that they cut multipurpose legume shrubs to feed their animals so that they could collect better quality manure. This review has so far indicated that traditional farmers applied their indigenous knowledge in order to meet their objectives of increasing the quality of organic resources used for improving soil fertility and increasing crop yields.

3.2.2.2 Improving soil fertility and crop yields by applying termite mound soils in crop fields (Termitaria)

Farmers have known and used soil from termite mounds to maintain soil fertility and improve crop productivity (Nyamapfene, 1986; Hulugalle and Ndi, 1992; Siame, 2005). Termites are an important element in traditional land-management practices in the Sahel region (Mando *et al.*, 1999), East Africa, and Southern Africa (Mielke and Mielke, 1982; Nyamapfene 1986). Farmers' use of termite-modified soil in crop production has also been documented in Uganda (Okwakol and Sekamatte 2007), Zambia (Siame 2005), Zimbabwe (Bellon *et al.*, 1999; Nyamapfene, 1986), Niger (Brouwer *et al.*, 1993), and Sierra Leone (Ettema 1994). Farmers plant specific crops on termitaria or spread soil from termitaria in their fields (Nyamapfene, 1986; Logan 1992). A typical example of cropping around termitaria is the *chitemene* agriculture in southwestern Tanzania (Mielke and Mielke, 1982). In Malawi, farmers plant various crops including bananas (*Musa* spp.) around termite mounds (Figure 3.2). Ugandan farmers plant pumpkins (*Cucurbita* spp.), tomatoes (*Solanum* spp.), onions (*Allium* spp.), and maize adjacent to termitaria (Okwakol and Sekamatte, 2007). In Zimbabwe, crops such as okra (*Abelmoschus esculentus*), pumpkins, sweet sorghum (*Sorghum* spp.), and late-season maize, which require good water and nutrient supply, are grown almost exclusively on termitaria (Nyamapfene, 1986). In Niger, farmers preferentially plant sorghum on termitaria (Brouwer *et al.*, 1993).



Figure 3.2 Banana and pigeon pea planted on an Odentotermes mound in the Zomba district of southern Malawi.
Source: Sileshi *et al.* (2009)

Ackerman *et al.* (2007) validated the practice of using termite mounds for replenishing soil fertility by traditional farmers by analyzing twenty-one randomly selected mounds and associated control sites. The results indicated that all nutrient elements in the soils from termite mounds except for phosphorus were significantly ($P>0.001$) higher than in the control (Table 3.4). The study concluded that the utilization of such soil by the local farmers for crop production might reduce the cost of fertilizer inputs, thereby improving economic returns to the smallholder farmers.

The nutrient content of termitaria and the adjacent soils has also been carefully measured by several researchers (Watson, 1977; Steinke and Nell, 1989; Holt and Lepage 2000; Cadet *et al.*, 2004; Masanori and Tooru, 2004; Brossard *et al.*, 2007; Chikuvire *et al.*, 2007). Most of this research shows that termitaria contain significantly higher concentrations of total nitrogen (N) and exchangeable cations than the surrounding area (Watson, 1977; Steinke and Nell, 1989; Jones, 1990; Holt and Lepage, 2000; Chikuvire *et al.*, 2007). Similarly, Steinke and Nell (1989) found higher plant biomass and growth of grass around termitaria compared with the open veld in the Eastern Cape. The increased growth of grass surrounding termitaria was due largely to accumulation of runoff water at the base.

Table 3.4 Mean element and carbon content of the termite mounds and adjacent soil in the secondary forest of the central Amazonia, Brazil

Location	Nutrient elements and carbon content			
	C ($g\ kg^{-1}$)	N ($g\ kg^{-1}$)	P ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)
Termite mound	43.8a	2.47a	3.30a	33.3a
Control	39.2b	1.93b	3.11a	24.1b

Source: Ackerman *et al.* (2007)

3.2.2.3 Improving soil fertility and crop yields by applying the Chitemene land-use system

Indigenous farmers in countries such as Zambia, Sudan and Zaire (Democratic Republic of Congo) practiced what is called the Chitemene land-use system. Chitemene is a Bemba word derived from the verb 'to cut'. Trees and shrubs are cut and piled up in the centre of a cleared area to about 1 m high. In early November the pile is burnt and planting is confined to the burnt area where the ash layer is rich in nutrients, especially phosphorus, calcium and potassium. In December, finger millet is broadcast over the burnt area. Other crops such as maize, sorghum and pumpkin are also planted. Crops are rotated on the same area for about 4 to 5 years. After 5 years, the field was abandoned (Edge *et al.*, 1988). Table 3.5 shows the effect of chitemene, burning and ash on yields of finger millet.

Table 3.5 Effect of the Chitemene, burning and ash on seeds yields of finger millet

System	Seed yield (kg ha^{-1})
Chitemene	1177
Burning alone	944
Ash alone	579
Control	268

Source: Edge *et al.* (1988)

3.2.2.4 Improving soil fertility and crop yields by applying the Guie (soil burning) system

Guie is a traditional system of soil fertility management for crop improvement practiced in the central highlands of Ethiopia. During the short rains in February–April, fallow land that had been grazed is ploughed repeatedly in a criss-cross direction. Soil to which sod is attached is collected into heaps with the sod oriented towards the centre on which loose soil is heaped and packed on the outside. About 850–1630 heaps per hectare were made (Abebe, 1981) and each heap was about 80 cm in diameter and 60 cm high. The heap is lighted by introducing cattle manure into the centre of the heap which then burnt slowly for 10–15 days. The burning created distinct layers of soils that were demarcated

by colour differences (Wehrmann and Legesse, 1965). After cooling, the soil in the heap was spread with a shovel and ploughed so as to mix the burnt soil with the rest of the soil in the field. Barley or wheat was planted in June. Farmers could obtain two to three crops before the field is abandoned and allowed to be fallow for 10–15 years after which the process is repeated. Usually the highest yield was obtained in the first year and declined in subsequent years. Table 3.6 shows the effect of Guie on some physical and chemical properties of soil. Of interest is the change in soil pH from 5.85 in unburnt soil to 7.10 in the burnt soil. There was also a five-fold increase in available phosphorus.

Table 3.6 Effects of the Guie system on the physical and chemical properties of soil

Soil properties	Unburnt soil	Burnt soil
Soil pH	5.85	7.10
Available P (me/100 g of soil)	3.81	18.45
Total carbonates (%)	0.00	2.00
Organic Carbon (%)	2.85	0.31
Texture	Clay loam	Loamy sand

Source: Edge *et al.* (1988)

With the above evidence of the existence of IK among smallholder farmers in various parts of the continent, there is a need to conduct a survey within the EDM in order to gather basic information from the farmers on how they apply indigenous knowledge on the utilisation of leaf litter for soil fertility management. This information will help in establishing strategies that can be used by small scale farmers to manage soil fertility on their respective farms. Conducting a survey was seen by many authors as the best means of gathering reliable and accurate information from the farmers particularly about issues pertaining to their socio-economic life (Franzel and Crawford, 1987; Doorman, 1990).

3.3 Methodology

3.3.1 Location of the study area

The study was conducted within the Ehlanzeni District Municipality (EDM) of the Mpumalanga Province. The EDM is located within Mpumalanga province (latitude 25° 48' S, longitude 31° 15' E) and shares borders with Mozambique to the east and Swaziland to the south. The total area covered by the district is 16 706.15 km^2 (Table 3.7) which is divided into five local municipalities (Figure 3.3). Some of the characteristics of the municipality are given in Table 3.7. The EDM is divided into the Highveld and the Lowveld regions. The Lowveld region is characterized by dry frost free winter while the Highveld is much cooler and often experiences severe frost during winter.

Table 3.7 Characteristics of five local municipalities within the EDM

Municipality	**Area**		**Population**		**Number of households**		**Unemployment**
	(km^2)	(%)		(%)		(%)	(%)
Bushbuckridge	2 589.59	15.50	499 699	33.16	108 886	33.20	60.4
Mbombela	3 411.75	20.42	509 520	33.81	111 814	34.09	40.9
Nkomazi	3 240.37	19.40	358 866	23.81	71 772	21.88	27.4
Thaba Chweu	5 719.06	34.23	81 236	5.39	21 074	6.42	28.2
Umjindi	1 745.38	10.45	57 672	3.83	14 458	4.41	27.4
EDM	**16 706.15**	**100**	**1 506 993**	**100**	**328 004**	**100**	**36.9***

*= average

Source: Statistics South Africa (2003)

The survey was carried out in three of the five local municipalities within the Ehlanzeni District Municipality *viz*: Mbombela, Bushbuckridge and Nkomazi local municipalities (Figure 3.3). The three local municipalities which are all located within the Lowveld region were selected for the study because of their similarities in terms of biotic and abiotic factors. The three local municipalities make up 89% and 91% of the households and population of the EDM respectively. They also have the highest unemployment in the province (Statistics South Africa, 2003).



Figure 3.3 Local municipalities within the EDM that were used for the study.

3.3.2 Climate and seasons within the EDM

The climate of the EDM is characterised by hot, wet summers (December–February) and cold, dry winters (June–August). The EDM receives rain from November to February with a long-term average annual rainfall of 680 mm. Maximum summer temperatures (30.8 °C) occur in January while minimum winter temperatures (7.3°C) occur in July (Figure 3.4). Sunshine is plentiful in EDM varying from 7.5 to 9.5 hours daily. A summary of long-term (17 year) weather elements within the EDM are given in Table 3.8. The average evaporation is 135 mm over the 12 months. The district experiences high maximum relative humidity (93%) during March and April with lower relative humidity in July (30%) and August (32%). There are four seasons, namely spring (September–November), summer (December–February), autumn (March–May) and winter (June–August).

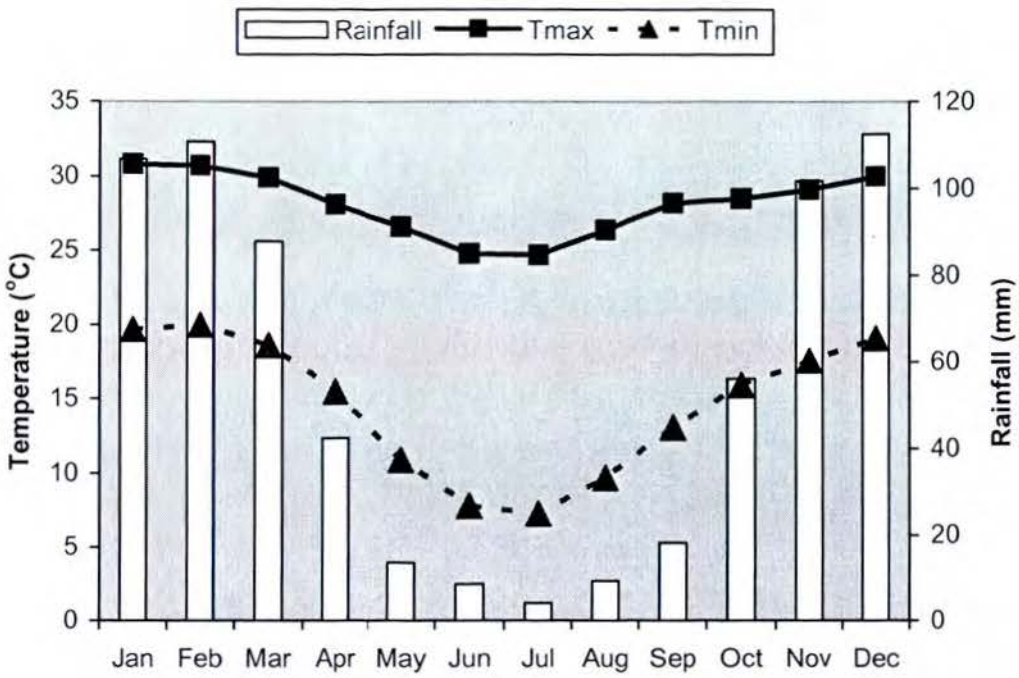


Figure 3.4 Long-term (17 year) mean monthly rainfall and temperature for the EDM

Source: ARC-ISCW (1985–2002)

3.3.3 Geological formations and soil types within the EDM

The EDM is dominated by granitic rocks on the east and a band of shale which stretches from Umjindi in the South to Thabachweu in the North (Figure 3.5). There are a few patches of Gneiss in areas around the Nkomazi local municipality. The predominant soils in Mbombela and Bushbuck-ridge local municipalities are red and yellow soils with weak structure whereas the Nkomazi local municipality is dominated by red yellow and greyish soils with low to medium base status (Figure 3.6).

Table 3.8 Long-term (17 year) data for weather elements in the Ehlanzeni District Municipality

Weather element	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	***Average***
A-Pan Evaporation (mm)	172.1	156.1	139.5	114.9	95.8	84.5	93.0	122.5	140.5	168.9	170.4	157.2	134.6
Wind speed (km day^{-1})	524.9	542.8	533.0	506.5	631.8	663.2	712.0	659.1	713.1	662.9	596.8	562.3	612.0
Maximum relative humidity (%)	92.5	92.6	93.2	93.3	91.5	89.1	87.8	87.0	86.7	89.5	91.2	92.0	90.5
Minimum relative humidity (%)	46.7	44.7	45.1	43.7	35.1	33.5	30.0	31.5	33.0	40.0	44.4	46.7	39.5

Source: ARC-ISCW (1985–2002)

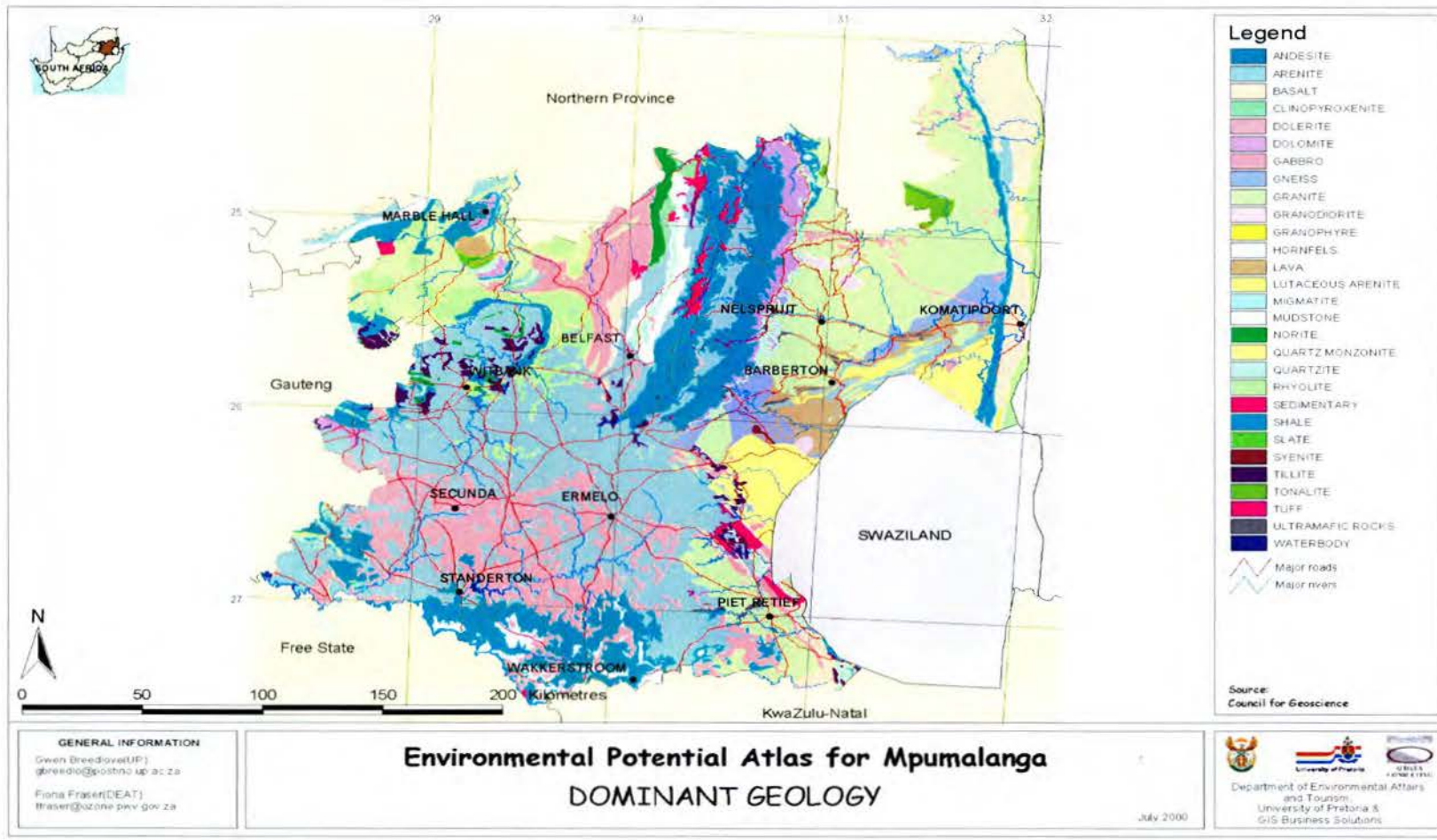


Figure 3.5 Geological profile of Mpumalanga featuring the EDM

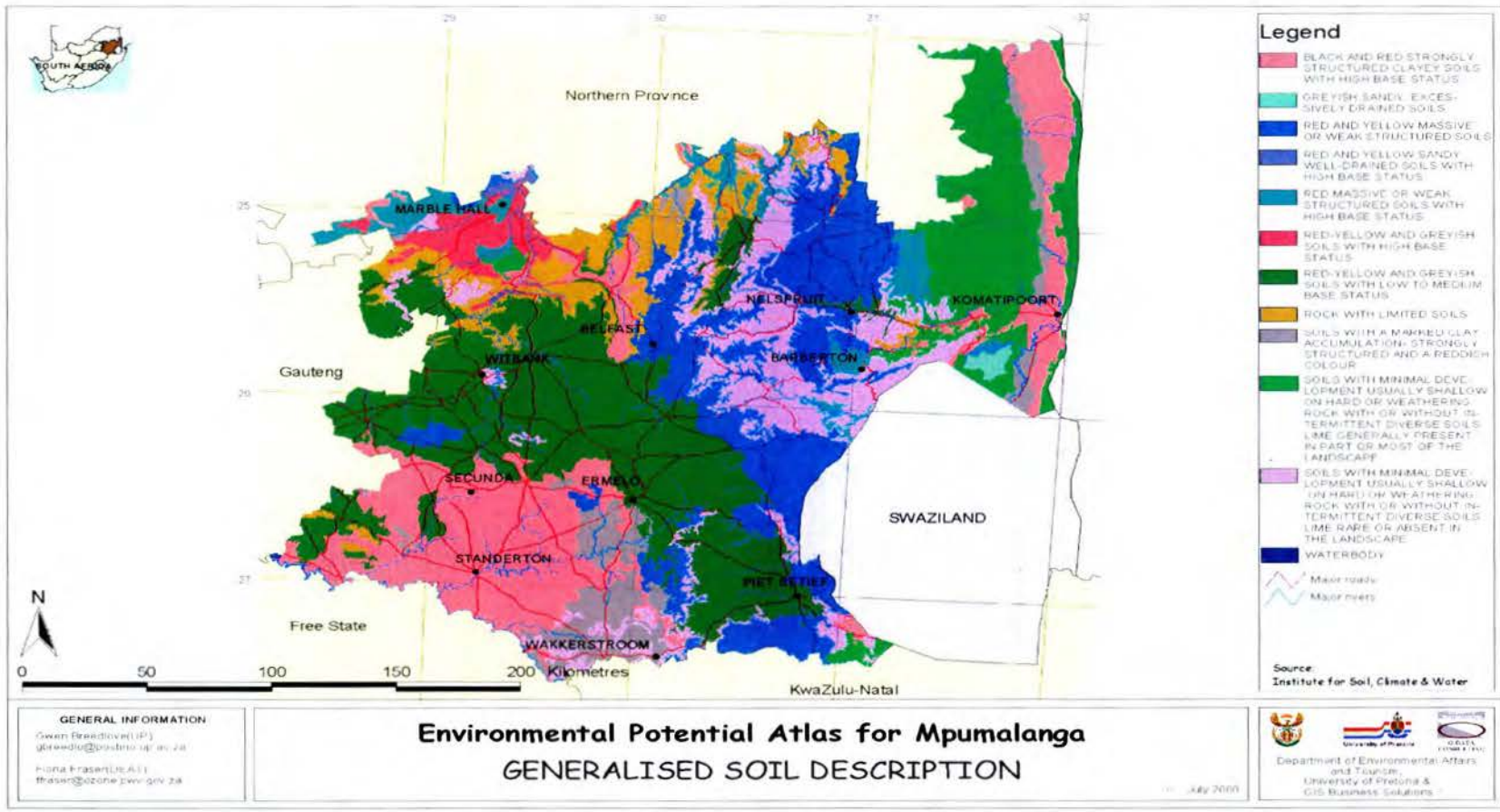


Figure 3.6 Dominant soil types in Mpumalanga featuring the EDM

3.3.4 Vegetation types and land use of the EDM

The vegetation of the EDM was described by Acocks (1975) and Low and Rebelo (1996). The EDM contains three of South Africa's nine biomes: savanna (58%), grassland (29%) and forest (13%). The most dominating vegetation type in Mbombela and Bushbuck-ridge local municipalities is Lowveld sour bushveld whereas Nkomazi local municipality is covered with Lowveld and little patches of Lowveld sour bushveld (Figure 3.7). In general, the dominating grass species include *Urochloa macambicencis*, *Cynodon dactylon* and *Panicum maximum* (Acocks, 1975; Low and Rebelo, 1996). The presence of *Panicum maximum* is used by farmers as an indicator of high soil fertility.

The biggest portion of Nkomazi local municipality is vacant or unspecified with few patches of subsistence farming. Mbombela and Bushbuckridge local municipalities are dominated by cropping areas with few patches under buildings (Figure 3.8). However, between 1994 and 2000 there was a dramatic increase in the area of land used for residential and business development and a decrease in cropping area (Mpumalanga Provincial Government, 2003b). In general, about 18% of land in EDM is used for grazing, including cattle, sheep and game. Cropping accounts for a further 40 % of land use. About 12% of the EDM is used for commercial forestry, mainly in the wetter eastern parts (Mpumalanga Provincial Government, 2003b).

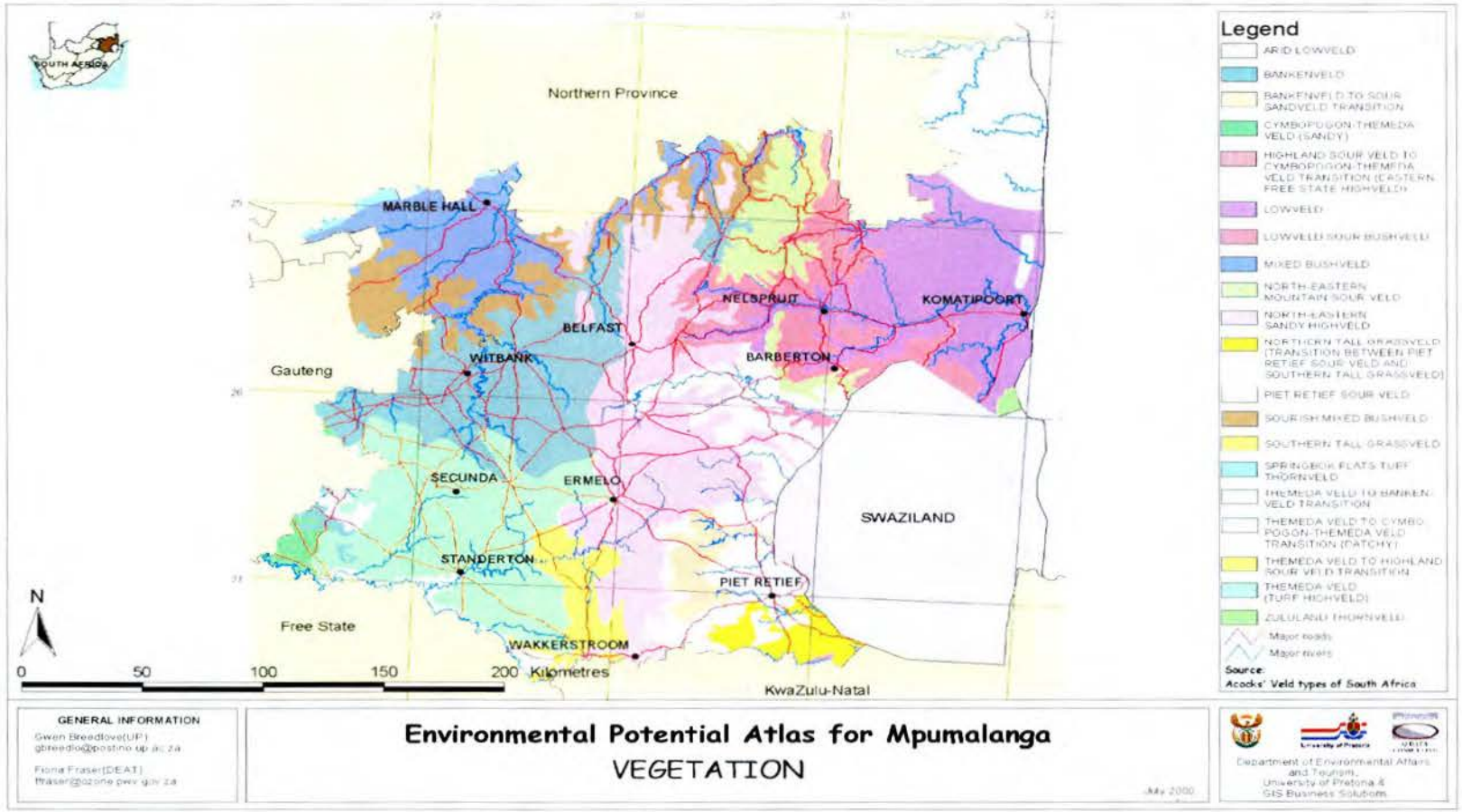


Figure 3.7 Main vegetation types in Mpumalanga featuring the EDM

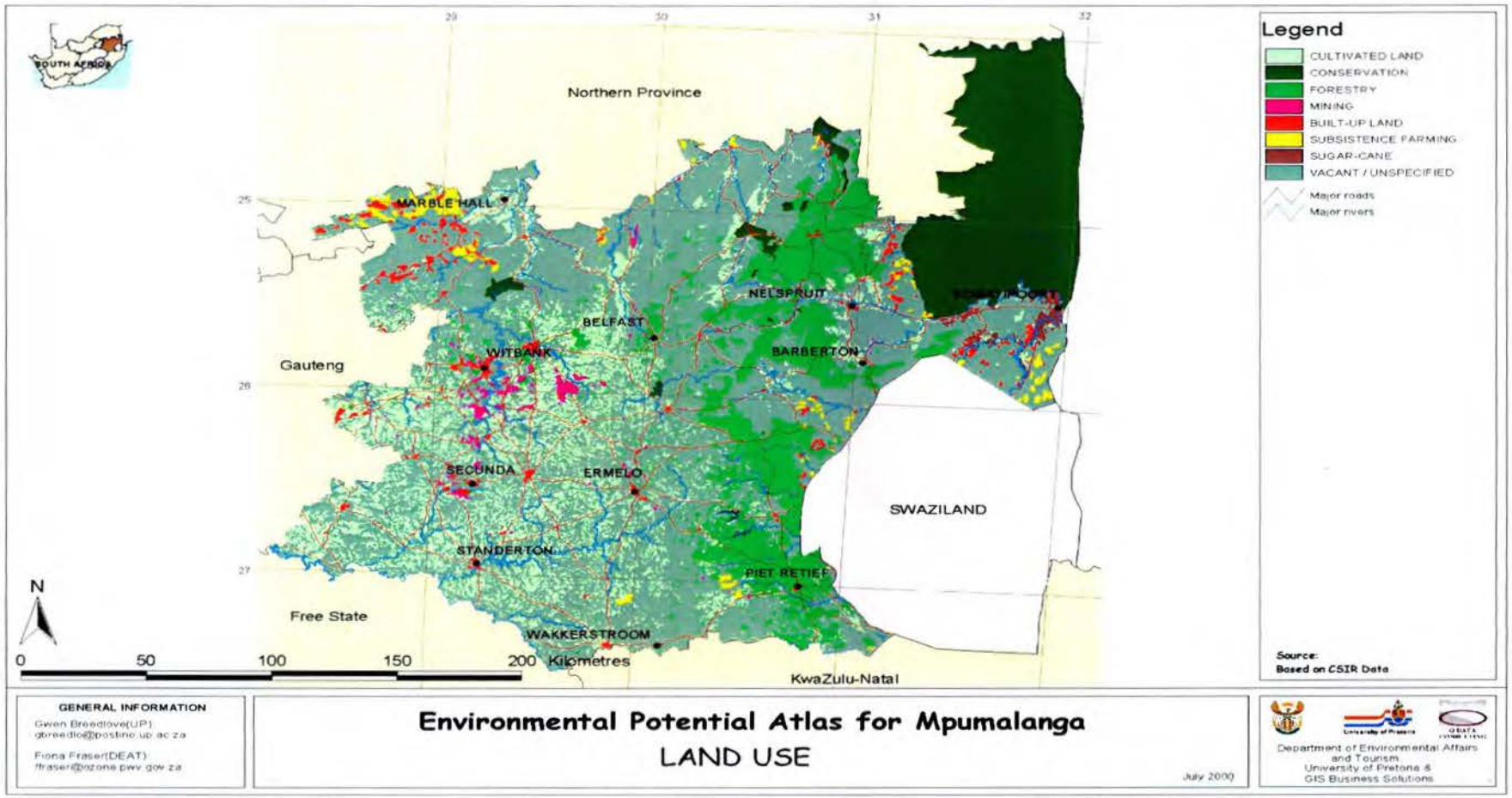


Figure 3.8 Main land-use types in Mpumalanga featuring the EDM

3.4 The survey

This section describes the planning and design of the survey that was used to collect information from the farmers about their knowledge on the utilization of leaf litter from sub-tropical fruit trees for managing soil fertility.

3.4.1 Design and pretesting questionnaire

A structured questionnaire was developed and used as tool for collecting data. The questionnaire consisted of five sections that dealt with different aspects of leaf litter produced from fruit trees and its utilisation (Appendix 1). The questionnaire was discussed with the researchers and extension officers to ensure that it meet the ethics standard set by the research institute (ARC), Provincial Department of Agriculture (Mpumalanga) and University of North-West. This was done to make sure that the privacy of the responding farmers are protected and respected and that the respondents must fill the questionnaire independently without the influence of other person. Questionnaires were distributed to eight randomly selected local farmers who work within the ARC-ITSC to pre-test them in order to identify the clarity and relevance of the questions. After pre-testing it was realized that some of the questions were not clear while others were not relevant to the survey. The questions which seemed not be clear were modified whereas the irrelevant ones were removed from the questionnaire.

3.4.2 Sampling Procedure

The survey focused on small scale farmers because they are the majority of the total farmers in the province. Furthermore, small scale farmers are greatly affected by soil fertility problems. Planning meetings were held with an extension officer in each local municipality prior to data collection where the total number of small scale farmers in each local municipality was obtained from the extension officers. In each local municipality, 50 respondents from the list were randomly selected (Table 3.9). The selection was done by placing pieces of paper bearing names of all farmers in the local municipality in a box and randomly picking out 50 names which were used as respondents. This procedure ensured that every farmer in the population had an equal chance of being selected to participate in the study.

Table 3.9 Population and sample size of farmers used for the study

Municipality	Total number of farmers	Sample size	% of the total number
Mbombela	479	50	10.44
Bushbuckridge	388	50	12.89
Nkomazi	356	50	14.04
Total	***1223***	***150***	***37.37***

3.4.3 Data analysis

Questionnaires were distributed to the selected respondents to complete over a period of three weeks. The respondent framers filled in the questionnaire independently. However, respondents who could not read English were assisted by extension officers who provided interpretation and filled in the questionnaire. All questionnaires were coded and the responses were entered into an Excel spread sheet on a personal computer. Descriptive statistics for the socio-economic variables obtained in the survey were used. The data collected from the respondents were analyzed using frequencies, percentages, standard deviations, and cross-tabulations using Statistical Package for Social Science– SPSS (SPSS, 2004).

In order to determine the factors that influenced the farmers' decision to use leaf litter for soil fertility management and measure the relationships between the independent variable (leaf litter utilisation) and the explanatory variables, a logit model similar to Williams (1999), Sureshwaran *et al.* (1996) and Mkhabela (2002) was specified and its parameters estimated using STATA 10 (STATACORP, 2008). The logit model that was used in this study was favoured over other similar approaches because it was not possible to accurately quantify the amount of leaf litter used by the farmers and this model does not require quantities to work (Mkhabela and Materechera, 2003). The logit model circumvents the problem of lack of accurate amounts of leaf litter used while capturing leaf litter from all sources by recording leaf litter applied as a dichotomous variable, that is having values of one (if leaf litter is used by the farmer for soil fertility management) and zero (if leaf litter is not used). This is a plausible approach given that the main objective of the analysis in this chapter is not the quantities of leaf litter used but rather the "probability of a positive event (the utilisation of leaf litter) occurring"

(Mkhabela, 2002). The choice of using dichotomous variables is further justified by the way in which the farmers were asked to respond during the interviewing process (Anim and van Schalkwyk, 1996; Garrod and Willis, 1995). Furthermore, ordinary least squares (OLS), the most common and simplest method was rendered inappropriate for the analysis in this study because of the inherent heteroscedasticity of the error term. The empirical model to analyze the farmers' decision for leaf litter utilisation was specified as:

$$LITTER=ß_0+ß_1INCOME+ß_2GENDER+ß_3AGE+ß_4EDUC+ß_5SIZE+ß_6FARM+ß_7LABOUR+0 \quad (1)$$

Where the dependent variable LITTER, is a dummy variable that takes on the value of 1 if a farmer uses leaf litter and 0 if the farmer does not use any leaf litter. B_0 is the constant calculated from the data. INCOME, refers to the farmer's source of income. It is expected that the sources of income for the farmers can determine if they can use or not use leaf litter for maintaining soil fertility. GENDER, refers to the sex of the respondent farmer. Several studies have found that the utilization of leaf litter by smallholder farmers is influenced by the gender of the respondent. For example, females also use leaf litter for cooking while male use leaf litters to feed their animals. All these can have an effect on the amount of leaf litter used for replenishing soil fertility. AGE, refers to the age of the farmer. Experience gained over years of farming plays a crucial role in utilizing leaf litter while young farmers find it more primitive to use leaf litter for maintaining soil fertility. EDUC, refers to the level of education for the respondent farmer. SIZE, refers to the actual size of the respondents' farm. The amount of leaf litter applied on the farm is determined by the size of the plot or farm. FARM, refers to the type of land ownership. Most of the farmers in the rural areas do not own land which restricts them to invest on the farm. LABOUR has been mentioned by several authors as having an effect on the utilization of leaf litter for managing soil fertility. Collecting and applying leaf litter for replenishing soil fertility is labour intensive. The error term, 0, which represents unobservable socio-economic factors and characteristics of the surveyed farmers, was assumed to be independently distributed over the survey period. The parameters of the model specified in Equation (1) were estimated through an iterative maximum procedure (STATACORP, 2008). Parameter estimates for the model were evaluated at the 5 percent level of significance (95% confidence interval).

3.5 Results

3.5.1 Characteristics of the respondent farmers

Of the 150 farmers that were interviewed across the three local municipalities, 61% were females and 39% were males. The distribution of gender among the responding farmers within each local municipality (Table 3.10) was consistent with the trend in the Mpumalanga province as reported by Statistics South Africa (2003). Mbombela local municipality had an equal gender representation while Nkomazi and Bushbuckridge had a higher proportion of female than male respondents. The distribution of age among the respondent within the municipality show a higher proportion of youth (16–35 years) while Bushbuckridge had a higher proportion of older people (> 65 years) (Table 3.11).

Table 3.10 Distribution (%) of gender of the respondent farmers within each local municipality

	Distribution (%)			
Gender	Mbombela	Nkomazi	Bushbuckridge	Mean
Male	50	24	42	39
Female	50	76	58	61
Total	100	100	100	100

Table 3.11 Distribution (%) of age of the respondents within each local municipality

	Distribution (%)			
Age (Years)	Mbombela	Nkomazi	Bushbuckridge	Mean
15 - 35	54	40	10	35
36 - 64	30	28	36	31
>65	16	32	54	34
Total	100	100	100	100

The education levels of the respondents across the study municipalities are indicated in Table 3.12. The results indicated that the respondents education level were 50% (primary), 37% (secondary) and 13% (tertiary). The respondents in Mbombela had higher proportions of secondary and tertiary education levels. The proportion of respondents with primary level education was higher (68%) in Bushbuckridge than in Mbombela (10%) and Nkomazi (46%) local municipalities. Table 3.13 shows the different sources of income. The major source of income across the local municipalities were farm sales (47%), wage salary (38%) and government grant (15%). The fact that the majority of the respondent farmers obtained their income from farm sales implies that they rely on agriculture for survival.

Table 3.12 Level of education of the respondent farmers within each local municipality

	Distribution of education levels (%)			
Level of education	Mbombela	Nkomazi	Bushbuckridge	Mean
Primary	36	46	68	50
Secondary	46	42	24	37
Tertiary	18	12	8	13
Total	100	100	100	100

Table 3.13 Sources of income for the respondent farmers within each local municipality

	Distribution of income sources (%)			
Source of income	Mbombela	Nkomazi	Bushbuckridge	Mean
Grant	18	18	62	33
Salary	40	12	8	20
Farm sales	42	70	38	47
Total	100	100	100	100

In terms of land ownership, only 29% of the respondent farmers owned a title deed to the land they farmed (Table 3.14). The rest (71%) farmed on communal land where the rights were invested in a community and were represented by a chief. In this case, the chief or tribal authority had the responsibility for allocating land to the community though no title deeds were issued. As a consequence the farmers could not access loans from the banks since they do not own the land. Lack of land ownership affects the manner in which farmers invest on their farms. The majority of farmers in Mbombela (80%) and Bushbuckridge (88%) used communal land while in Nkomazi the majority (54%) owned the land.

Table 3.14 Distribution (%) of land ownership within the three local municipalities

	Distribution (%)			
Land ownership	Mbombela	Nkomazi	Bushbuckridge	Mean
Own	20	54	12	29
Communal	80	46	88	71
Total	100	100	100	100

3.5.2 Litterfall, quality and its utilization for soil fertility management

3.5.2.1 Litterfall patterns

Table 3.15 shows that the majority (71%) of the respondents collected large amount of leaf litter during the months of March, April and May (autumn). All the local municipalities indicated that large leaf litter from fruit trees was collected during autumn. The trend in the quantity of leaf litterfall across the municipalities was in the order: autumn > spring = summer > winter. The amount of leaf litter collected by the respondent farmers varies within the seasons. Figure 3.9 indicate which season the farmers collected the highest amount of leaf litter, which was autumn.

Table 3.15 Farmers' response regarding the season of the year in which they collected the largest amount of leaf litter from fruit trees

Season of the year	Frequency	Percent
▪ summer (Dec - Feb)	16	11
▪ winter (Jun - Aug)	7	5
▪ spring (Sep - Nov)	20	13
▪ autumn (Mar - May)	107	71
Total	150	100

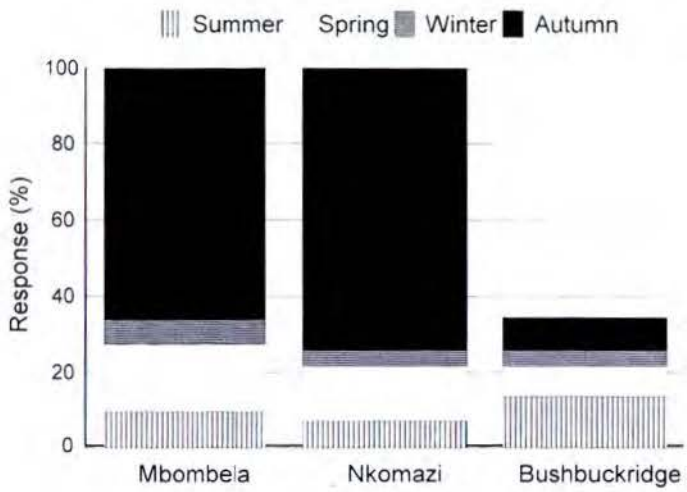


Figure 3.9 The season in which farmers collected the largest amount of litter

The number of fruit trees and estimated amounts of leaf litter by the farmers is presented in Table 3.16. The majority (61%) of the respondent farmers had between 5 and 20 fruit trees of different species on their farms. Only 23% of the responding farmers owned more than 45 trees on their farms. The largest proportion (49%) of the respondent farmers indicated that they collected about 5 to 50 bags of leaf litter from the fruit trees per annum. This represents a yield of 125 to 1250 kg of litter biomass per annum. Only 16% collected > 61 bags of fruit tree leaf litter per annum. The highest amount of litter was indicated to be produced by mango (39%) and litchi (37%) while avocado and other species produced 11% and 13%, respectively. Table 3.17 shows that the majority of respondent farmers within each local municipality indicated having between 5 and 20 fruit trees of different species. More than 30% of the respondents in Nkomazi local municipality have between 21 and 44 fruit trees of different species.

Table 3.16 Number of fruit trees and litter yield collected by the responding farmers

Variable	**Frequency**	**Percent**
A) Number of fruit trees on the respondents farm		
▪ 5 – 20	92	61
▪ 21 – 45	23	16
▪ 46 – 85	14	9
▪ >85	21	14
	150	100
B) Estimated number of leaf litter bags (25 kg) collected per year		
▪ 5 – 50	73	49
▪ 51– 60	53	35
▪ >61	24	16
Total	150	100
C) Proportion of farmers indicating trees with largest leaf litter production		
▪ avocado	17	11
▪ litchi	55	37
▪ mango	59	39
▪ other	19	13
Total	150	100

Table 3.17 Number of fruit trees on the responding farmer's field within each local municipality

Municipality	Number of fruit trees				
	5 – 20	21 – 45	46 – 85	>85	Total (%)
Mbombela	64	6	12	18	100
Nkomazi	46	34	10	10	100
Bushbuckridge	74	6	6	14	100
Mean	*61*	*15*	*9*	*14*	

The amount of leaf litter collected by the respondent farmers varied within the local municipalities (Figure 3.10). The majority (48%) of the respondents in Nkomazi local municipality collected between 5 and 50 bags (125–1250 kg) of litter per year, whereas the majority of the respondent farmers in the Mbombela and Bushbuckridge local municipalities collected between 51 and 60 bags which is equivalent to 1275 and 1500

kg of litter per year. There were other trees and field crops such as macadamia, pecan nut and sugarcane, however, the amounts that were collected from these trees were not large when compared to mango, avocado and litchi trees (Figure 3.10).

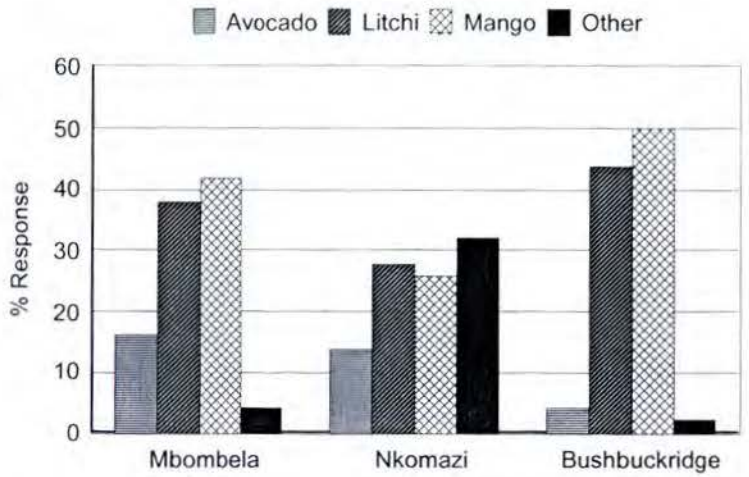


Figure 3.10 Variation in the annual collection of litter from different tree species within each local municipality.

3.5.2.2 Utilization of leaf litter collected from fruit trees

Table 3.18 shows a wide variation in the manner in which the respondent farmers utilized leaf litter on their lands. About 62% of the respondents indicated that they collected litter from fruit trees to make compost. The majority (82%) of the respondent farmers indicated that they made compost for recycling nutrients within the farm. However, about 24% of the respondents indicated that they incorporated leaf litter directly into the soil while only 1 % burn leaf litter as a means of keeping their surroundings clean. Farmers used ash from leaf litter for maintaining soil fertility. About 13% of the respondent farmers used litter as mulching material on their fields. About 7% of the respondents indicated that they made compost to sell while 11% made compost as part of waste management. The majority (45%) of the respondent farmers indicated that they applied leaf litter to vegetables (e.g. spinach, cabbage, onions and green paper) while 28% and 20% applied litter to the fruit trees and field crops respectively. Figure 3.11 shows that there was an even proportion between the farmers who indicated that they collected leaf litter to make compost and those who used leaf litter for mulching in the Nkomazi municipality.

Table 3.18 Respondent farmers' utilization of leaf litter

Variable	Frequency	Percent
A) Respondents use of leaf litter		
▪ burn	2	1
▪ compost	93	62
▪ mulch	19	13
▪ incorporation into soil	36	24
Total	150	100
B) Reasons for making compost		
▪ recycle nutrients for trees	123	82
▪ sell	10	7
▪ waste management	17	11
Total	150	100
C) Crops onto which leaf litter was applied		
▪ fruit trees	42	28
▪ field crops	30	20
▪ vegetables	68	45
▪ any crop	10	7
Total	150	100

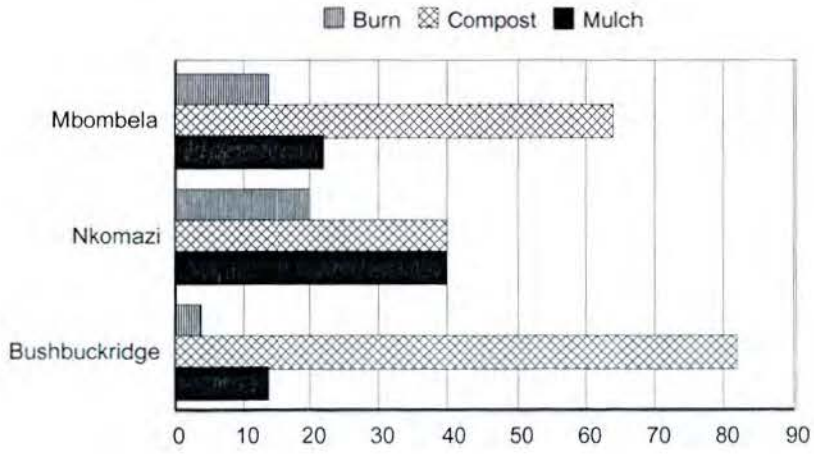


Figure 3.11 Methods used by farmers in the utilization of leaf litter within each local municipality

Majority of the respondents in Mbombela and Bushbuckridge local municipalities indicated that they gave first preference to vegetables when applying litter into the soil (Figure 3.12). Apart from the fact that the majority of the respondents from all three local municipalities gave first preference to vegetables, their response differed when it comes to their second or third options. The respondent farmers in Nkomazi mentioned other crops such as sugarcane and citrus which were not provided for in the questionnaire. The majority of the responding farmers indicated that they applied between 1 and 50 kg of leaf litter per year (Table 3.19). About 8% of the responding farmers in Mbombela local municipality indicated that they applied more than 100 kg of leaf litter per year.

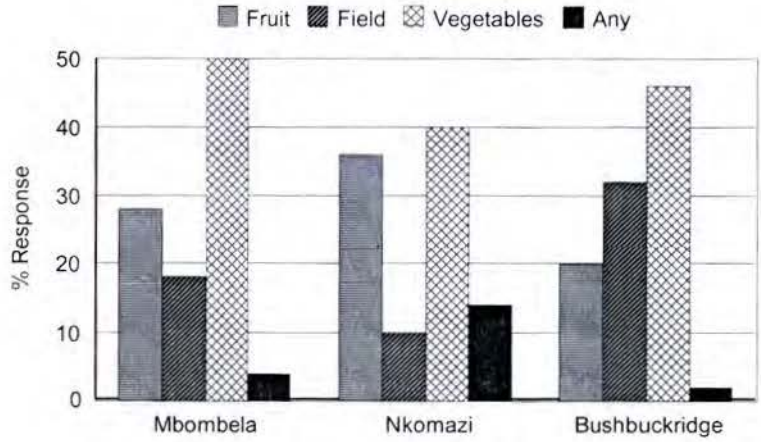


Figure 3.12 Crops onto which leaf litter was applied within the municipality

Table 3.19 Amount of litter (kg ha^{-1} $year^{-1}$) applied by the respondents within the EDM

Municipality	1-50	51-70	71-100	>100	Did not know	Total
Mbombela	56	6	10	8	20	100
Nkomazi	66	10	4	2	18	100
Bushbuckridge	50	18	8	4	20	100
Mean	*57*	*11*	*7*	*5*	*19*	

3.5.2.3 Knowledge about leaf litter decomposition processes

When asked about the factors that influenced decomposition of leaf litter, the majority (82%) of the respondents within the study area believed that temperature had the greatest influence (Table 3.20). The proportion of respondents who knew that litter quality influenced decomposition was very low (8%). The majority (52%) of the respondent farmers said that termites were the major decomposers of leaf litter followed by earthworms (39%) and fungi (9%). The majority (50%) indicated that it took between 3 and 6 months for the tree leaf litter to decompose. The majority (52%) of the respondents applied water in the form of irrigation to either the compost heap or to the spots where they had applied litter as a means of promoting decomposition. On the other hand 31% believed that composting leaf litter before applying it to the crop in the field was the best practice of promoting leaf litter decomposition. Farmers differentiated leaf litter from various trees in terms of decomposition time (43%), leaf colour (32%) and leaf litter yield (25%).

3.5.2.4 Leaf litter application methods

Table 3.21 shows that the main methods used by farmers to apply leaf litter to their fields were incorporation (54%) and surface mulching (41%) within the EDM. Methods used by the respondents to apply leaf litter differ from one local municipality to the other as illustrated on Figure 3.14. The majority of the respondent farmers in Mbombela (48%) and Nkomazi (56%) local municipalities indicated that they incorporated leaf litter into the soil while 53% of the respondents in Bushbuckridge local municipality preferred mulching. However, about 40% of the respondent farmers in the Mbombela local municipality indicated that they preferred both mulching and incorporating fresh leaf litter to the fields.

Table 3.20 Respondents' knowledge about factors that influence decomposition of litter

Variable	Frequency	Percent
A) Factors that influence leaf litter decomposition		
▪ temperature	123	82
▪ litter quality	12	8
▪ no idea	15	10
Total	150	100
B) Organisms responsible for decomposition of leaf litter		
▪ termites	78	52
▪ earthworm	59	39
▪ fungi	13	9
Total	150	100
C) Time taken by leaf litter to decompose (Months)		
▪ > 1	28	19
▪ 1 – 2	24	16
▪ 3 – 4	37	25
▪ > 6	38	25
▪ no idea	23	15
Total	150	100
D) Techniques undertaken to enhancing litter decomposition		
▪ watering	79	52
▪ composting	46	31
▪ incorporating into soil	25	17
Total	150	100
E) Differences between types of leaf litter		
▪ decomposition time	65	43
▪ leaf yield	48	32
▪ leaf colours	37	25
Total	150	100

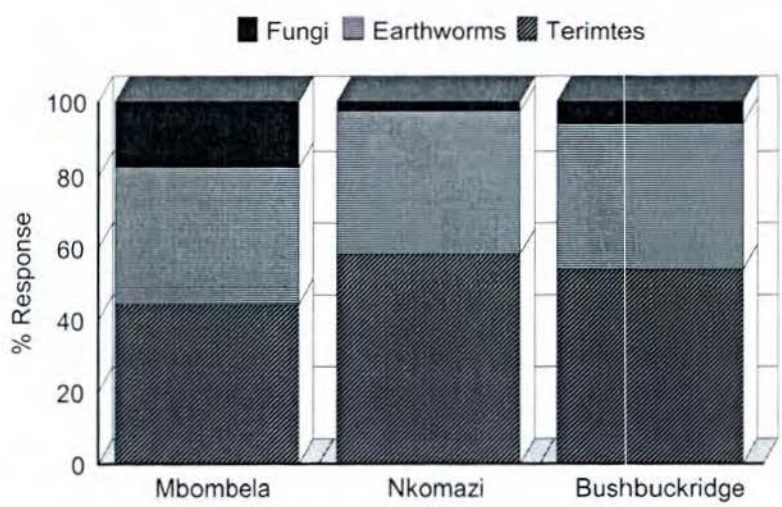


Figure 3.13 The major decomposers of leaf litter across the three local municipalities

Table 3.21 Methods and reasons for applying leaf litter to crops within the EDM

Variable	Frequency	Percent
A) Methods of applying leaf litter		
▪ incorporation	67	54
▪ mulching	61	41
▪ other	22	05
Total	150	100
B) Reasons for selecting a specific method of applying litter		
▪ cheap	40	27
▪ quick	56	37
▪ promotes decomposition process	54	36
Total	150	100

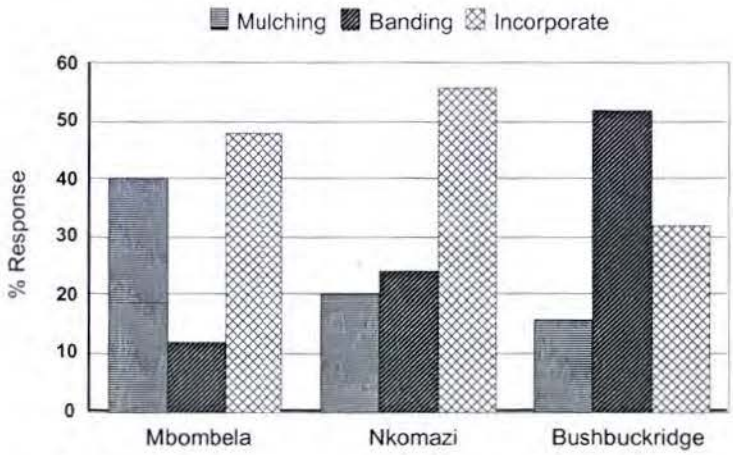


Figure 3.14 Methods of applying leaf litter within the three local municipalities

It was interesting to note that the respondents, had reasons for selecting a specific method for applying leaf litter on their farms and the reasons varied from one municipal area to the other (Figure 3.15). The majority of the respondent farmers in Nkomazi local municipality selected methods of litter application that speeded up litter decomposition while the respondents from Mbombela and Bushbuckridge local municipality selected litter application method based on its affordability and time they could spend applying litter to the field.

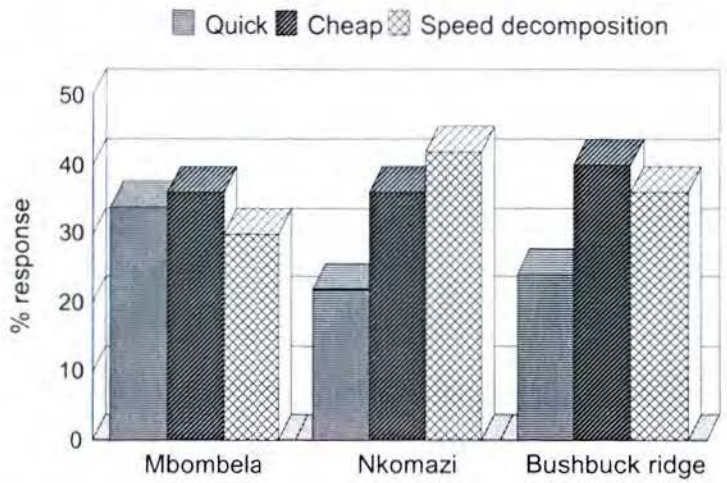


Figure 3.15 Reasons provided by the respondents for selecting specific methods to apply leaf litter within each local municipality.

3.5.2.5 Knowledge about litter quality management

Table 3.22 shows various amendments that the respondents mixed with the leaf litter from the fruit trees as a means of improving leaf litter quality. The majority (52%) of the respondent farmers within the EDM mixed kraal manure with litter from fruit trees as a means of improving litter quality. Very few farmers in the study area have animals where they can access manure for maintaining soil fertility. Some of these farmers sell manure to those who do not have animals. About 68% of the respondents indicated that they mixed leaf litter with other amendments such as chicken and kraal manure in order to increase the nutrient content of the litter. About 13% of the responding farmers indicated that they applied leaf litter biomass in order to prevent soil acidification.

3.5.2.6 Tree management practices to improve yield of leaf litter

Since farmers' livelihood depends on the existence of sub-tropical fruit trees, they make sure that the fruit trees are well managed. Table 3.23 shows that 72% of the respondent farmers pruned their trees in order to stimulate the growth of new shoots and flowering, followed by 19% who pruned their fruit trees to give them good shape. Only 9% of the respondents indicated that they pruned their fruit trees for accessing leaves. Figure 3.16 shows an even proportion between the respondents who indicated that they pruned their trees to access leaf litter and those who pruned trees to give them a desirable shape in the Nkomazi local municipality.

Table 3.22 Amendments used by farmers to improve litter quality within the EDM

Variable	Frequency	Percent
A) Amendments mixed with the litter		
▪ chicken manure	37	18
▪ kraal manure	73	52
▪ wood ash	20	15
▪ crushed bones	20	15
Total	150	100
B) Reasons for mixing litter with amendments		
▪ increase nutrient contents	102	68
▪ prevent soil acidification	19	13
▪ prevent immobilization of nutrients	15	10
▪ other	14	9
Total	150	100

Table 3.23 Reasons provided by the respondent farmers for pruning fruit trees

Reasons for pruning fruit trees	Frequency	Percent
▪ shape the tree	28	19
▪ stimulate new growth and flowering	108	72
▪ accessing leaves	14	9
Total	150	100

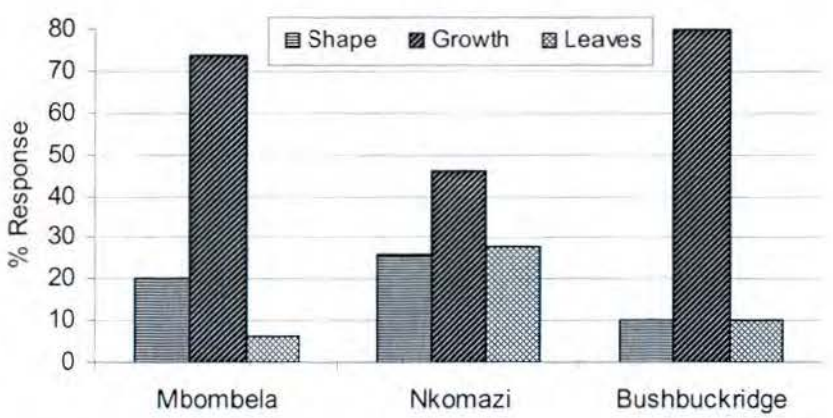


Figure 3.16 Reasons for pruning fruit trees within each local municipality

3.5.3 Factors influencing farmers' decision to use leaf litter for soil fertility

A summary of the statistics for the logit model is presented in Table 3.24. The chi-square statistic reported by Stata in the second line of output is the likelihood ratio chi-squared comparing the current model with the null model and it is 5.65 as shown in Table 3.24. This is the likelihood ratio chi-square with 7 degrees of freedom. One degree of freedom is used for each predictor variable in the logistic regression model. The likelihood-ration chi-square is defined as 2(L1 - L0), where L0 represents the log likelihood for the "constant-only" model and L1 is the log likelihood for the full model with constant and predictors. In this example, Prob>χ^2 is the p-value associated the chi-square with 7 degrees of freedom. The value of .5811 indicates that with the model as a whole is statistically significant. The likelihood ratio test indicates that the specified model explained significant non-zero variations in the factors influencing farmers' decisions to adopt leaf litter utilization for soil fertility replenishment.

The model correctly classified 83% of the farmers that used leaf litter. Technically, R^2 cannot be computed the same way in logistic regression as it is in OLS regression. The pseudo-R^2, in logistic regression, is defined as $(1 - L_1)/L_0$, where L_0 represents the log likelihood for the "constant-only" model and L_1 is the log likelihood for the full model with constant and predictors. The pseudo-R^2 of 0.1084 may look small but it is entirely within the expected range for logistic regression which is a qualitative response model rather than a quantitative one, such as the OLS. Logistic slope coefficients can be interpreted as the effect of a unit of change in the X variable on the predicted logits with the other variables in the model held constant. That is, how a one unit change in X affects the log of the odds when the other variables in the model are held constant.

Table 3.25 shows the estimates of likelihood (often referred to as the odds ratio) of farmers to use leaf litter for soil fertility management according to the logit model and the column is denoted as the coefficient for simplicity purposes. The odds ratio column gives the amount of change expected in the odds ratio when there is a one unit change in the predictor variable with all of the other variables in the model held constant. An odds ratio close to 1.0 suggests that there is no change due to the predictor variable. In Table 3.25, it can be seen that the odds ratio for income is 0.57. Thus, it can be predicted that the odds ratio of utilizing leaf litter would change by 0.57 for every one

unit change in income when gender, age, educ, size, farm and labour are held constant. The results can also be presented as:

$$\text{LITTERUSE} = 9.531458 + 0.56564\text{income} + 0.053062\text{gender} + 0.745854\text{age} - 0.01368\text{educ} - 0.56169\text{size} + 1.332008\text{farm} + 1.147663\text{labour} \quad \textbf{(2)}$$

Table 3.24 Summary statistics of the logit model

Statistic	Value
Number of observations	150
LR χ^2 (7)	5.65
Prob > χ^2	0.5811
Log likelihood function	-25.4619
Pseudo-R^2	0.1084
% of farmers correctly classified	83
Total number of iterations	5.0

Table 3.25 Logit model parameter estimates of the maximum likelihood for leaf litter utilisation.

Variable	Coefficient	Asymptotic standard error	Change in probability
Leaf litter used			
Income	0.56564*	0.798684	0.479
Gender	0.053062*	0.87401	0.952
Age	0.745854*	0.597121	0.212
Education	- 0.01368*	0.674538	0.984
Size	- 0.56169*	0.643718	0.383
Farm ownership	1.332008ns	1.174117	0.257
Labour	1.147663ns	0.653637	0.079
Intercept		4.034348	

*, Significant at the 5% level; ns, not significant

Income, gender and age were all significant at the 5 percent level (0.05) and positive. Not surprisingly, the odds of using leaf litter for soil fertility management were negatively influenced by the size of the cultivated land or the size of the farm implying that as the farm size increases, the likelihood of using leaf litter decreases and this is to be expected as the application of leaf litter is labour-intensive.

3.6 Discussion

The results of the characteristics of the farmers showed a large involvement in farming by both young and older people in the EDM implying a good opportunity for transferring indigenous knowledge from the elders to the youths. Several studies on IK have labelled less involvement in farming by youth as one of the factors that contributed to the extinction of indigenous knowledge (Kolawole, 2004). This finding was in contrast with the results that were found by Kolawole and Laogun (2005) who found that young people in Nigeria were not actively involved in farming. Involvement in farming by youth also increases the manpower which is one of the main constraints particularly in the small scale farming sector. Most of the indigenous knowledge practices on replenishing soil fertility are labour intensive. Shortage of labour sometimes forces farmers to abandon their indigenous techniques on managing soil fertility since most of them are labour intensive. Norbu and Floyd (2001) provided three reasons that lead to labour shortage *viz*: marriage, employment and schooling. There was a seasonal variation in terms of the amount of leaf litter collected by farmers with the largest amount of leaf litter collected during autumn. This coincided with the time when farmers prepared their lands for the summer cultivation implying that farmers collected leaf litter and incorporated it into the soil prior to planting. Contrary to this finding, Nyathi and Campbell (1993) found that farmers in Zimbabwe collected large quantities of plant litter in winter and insignificant amounts in spring. Farmers there collected large quantities in winter because the dominant Miombo species shed their leaves in winter.

Farmers were aware that the trees produced different amounts of leaf litter, with mango and litchi trees considered as the big producers. This comes not as a surprise since these two tree species are the most dominant within the EDM. The dominance by mango and litchi trees in the EDM is attributed to the sub-tropical climate which favours the growth and development of these tree species. Several other reasons can also explain why farmers within the EDM grow more mango and litchi trees than any other tree species. These are that: mango trees are easy to grow and maintain compared to avocado trees. Secondly, apart from fresh fruits, farmers can harvest green mango fruits and make atchar for either selling or home consumption unlike avocado fruits which had no other by-products except for oil which is difficult to extract. In Kenya,

Rocheleau *et al.* (1988) indicated that mango trees can be a source of medicine, fodder, firewood, timber and poles but these uses are not prevalent in the EDM. Although litchi is still a relatively new crop compared to avocados, farmers like it because it is easy to maintain and it produces more fruit with high economic turnover.

It was interesting to note that a large majority of the farmers used either mulching or composting to supply crop nutrients from leaf litter. Very few farmers burnt the leaf litter. This suggests that the farmers were quite aware of the negative environmental effects of burning residue as shown by Oluwole *et al.* (2008). Several authors have recommended composting leaf litter as the best possible means of managing poor quality materials that can take a long time to decompose and release nutrients into the soil (Rodrigueze *et al.*, 2001; Rao *et al.*, 2003; Gajalakshmi *et al.*, 2004). Burning reduces the contribution of leaf litter to soil nutrients (Materechera *et al.*, 1998; Oluwole *et al.*, 2008). Mulching and composting on the other hand are more efficient ways of cycling nutrient from biomass. The majority of farmers farmed on small areas of less than 1.0 ha. This means that the area of soil fertility management is small and therefore small amounts of leaf litter are required. The majority of the farmers applied less than 50 kg ha^{-1} (approximately 0.05 t ha^{-1}) of leaf litter on their agricultural fields. Although this amount of leaf litter applied by farmers seemed far much lower than the application rates recommended by other authors (Musvoto and Campbell, 1995; Mapfumo and Giller, 2001; Maikhuri *et al.*, 2001), farmers in the EDM have other options that are used in order to increase the quantity and quality of leaf litter for maintaining soil fertility. These options include: mixing leaf litter with other amendments such as chicken manure, kraal manure and ashes.

There were niche crops where the leaf litter was applied. This is because for most of the farmers, litter was the only resource available to use for soil fertility management and therefore had to be utilized wisely and efficiently. Consequently, the leaf litter was applied in high value crops such as vegetables and fruit trees where high income could easily be achieved. This selective utilization of scarce inputs is common among small scale farmers worldwide (Musvoto and Campbell, 1995). Small scale farmers in many agroecosystems of the world have been shown to be sensitive in the way they allocate resources for soil fertility (Musvoto and Campbell, 1995; Nyathi and Campbell, 1993). Musvoto and Campbell (1995) found that smallholder farmers in Zimbabwe applied

leaf litter on maize and finger millet than on any other crops. Nyathi and Campbell (1993) found that leaf litter, which cured well with cattle manure, was applied to vegetable crops. This was not in contrast with the results of Mapfumo *et al.* (1997) who found that maize received an average of 49% of the total leaf litter inputs while garden crops received only 11% of the total leaf litter in Murewa Communal area of Zimbabwe.

Farmers were aware of the role that decomposition played in making the nutrients from the leaves available in the soil for plants to use. This is significant because Kayuki and Wortmann (2001) have shown that the process of decomposition is critical for the release of nutrients. According to Schlesinger and Andrews (2000), decomposition is defined as the physical, chemical and biological process converting plant residues into their elemental chemical constituents, controls nutrient availability in natural ecosystems and, ultimately, the amount of carbon released to the atmosphere. The factors that control decomposition of organic biomass have been identified as substrate quality, climate, edaphic and biotic factors (Melin, 1930; Ivarson and Sowden, 1959; Swift *et al.*, 1979). The results of this study suggest that farmers in the study areas were able to relate these factors to the decomposition of leaf litter.

The majority of the farmers indicated that it took between 3 and 6 months for the leaf litter to decompose. Farmers were aware that the decomposition process takes time and implies that in order to synchronize the release of nutrients from the litter with uptake by a crop requires an appropriate timing of its application. The majority of the farmers indicated that they applied water in the form of irrigation in order to enhance decomposition of the leaf litter. Farmers in the study area also mixed leaf litter from different tree species as a means of enhancing its decomposition rate. The fact that farmers identified water as playing role in the decomposition process is significant because moisture enhances the activities of microorganisms that are responsible for the decomposition (Melin, 1930; Witkamp and Van der drift, 1962). This may also explain the reason for the use of leaf litter in summer season when there is plenty water. Temperature and moisture availability regulate many ecosystem functions, including microbial activity and nutrient storage. They are considered as the most critical driving forces in ecosystems, and have the greatest control over decomposition (Anderson, 1973; Swift *et al.*, 1979; Waring and Schlesinger, 1985).

Farmers identified termites and earthworms as the major decomposers of leaf litter. This could be due to the fact that these two organisms can easily be seen with naked eyes while fungi and bacteria are microorganisms that are not seen with naked eyes. Similar results have been reported by Grossman (2003) in Mexico where the biological knowledge of the organic coffee farmers was basically limited to organisms that were visible with the human eye and included earthworms, centipedes, white grubs, ants and crickets. Similarly, in Nepal, Thapa (1994) found that farmers were shown to have an excellent understanding of various above ground tree attributes whereas their understanding of the under ground processes was limited. Earthworms have been shown to act as ecosystem engineers in various ecosystems by ingesting plant residues and producing casts (Fragoso *et al.*, 1997), increasing macroporosity and hydraulic conductivity (Francis and Fraser, 1998) and positively influencing nitrogen mineralization below leguminous surface mulch (Subler *et al.*, 1997).

Farmers in the EDM have favoured certain specific methods of applying leaf litter over others. However, the choice of application method differed from one local municipality to the other. Generally, most of the farmers preferred to incorporate leaf litter into the soil than surface application. The methods of applying leaf litter biomass have been shown to affect its decomposition and nutrient release pattern. Kayuki and Wortmann (2001) reported that if leaves of *Lantana camara, Senna hirsuta and Tithonia diversifolia* were incorporated into the soil, they decomposed faster than when they were applied on the soil surface. This delay in decomposition of surface applied litter could be attributed to variable moisture conditions. They also found that less than 20% of plant N remained after 16 weeks of incorporation of *Senna hirsuta* and *Lantana camara* biomass compared with surface application. This could be due to enhanced microbial activity associated with higher soil moisture and close contact with the soil in the incorporated litter.

It was clear that from their experience or knowledge gained over time, farmers in the study area were aware that the quality of leaf litter, in terms of nutrient content, was relatively low and could be improved by mixing with other materials such as animal manure. It was interesting that farmers used locally available materials such as wood ash, animal manure and bones to supplement nutrient deficiency in the leaf litter. Similarly, Nyathi and Campbell (1993) and Musvoto and Campbell (1995) found that

some farmers in Zimbabwe collected leaf litter from the forest and cured it in cattle pens for period of 1 to 12 months because they believed that leaf litter reduces the wetness of dung in summer and provides a richer source of plant nutrients when applied to crops (Nyathi and Campbell, 1993; Musvoto and Campbell, 1995). The use of manure and wood ash as amendments has been studied widely (Campbell, 1990; Imbeah, 1998; Saarsalmi *et al.*, 2001; Materechera and Salagae, 2002). Chicken manure is favoured since it has relatively higher nutrient content than cattle manure (Table 3.26). Many authors have reported improved crop yield and soil properties after adding farmyard manure (Materechera and Mukwevho, 2007; Materechera and Morutse, 2009). It was therefore not surprising to find in this study that animal manure constituted part of the strategy of utilizing leaf litter for soil fertility management among small scale farmers.

Table 3.26 Chemical composition (%) of different types of manure

Source	Organic matter	Nitrogen	Phosphorus	Potassium
Cattle manure	16	0.3	0.2	0.2
Chicken manure	29	1.5	0.4	0.8
Goat manure	31	0.7	0.4	0.3
Horse manure	22	0.5	0.3	0.3

Source: Mueller-Saemann and Kotschi (1994)

Several factors were found to have a significant influence on the utilization of leaf litter by small scale farmers within the EDM. Education played a major role in the management of soil fertility since it provides a foundation on which farmers can learn and understand new practices particularly in situations where indigenous knowledge is inapplicable or in a situation were indigenous knowledge is merged with scientific or western knowledge (Gowing, 2004). It was found in this study that education had a negative influence on the utilization of leaf litter. This may imply that the higher the level of education of the farmer, the less likelihood that he/she would use leaf litter for replenishing soil fertility. It is common that the utilization of leaf biomass for soil fertility is sometimes considered to be primitive. Sometimes educated people have developed more trust with modern options of managing soil fertility and distance themselves from the use of low external input methods of soil fertility management.

Kolawole and Laogun (2005) found a negative but significant association between level of education and utilization of indigenous knowledge. The surprising finding is that of income being positive as generally the use of locally-available (indigenous knowledge) tends to be negatively related to income (Sseguya *et al.*, 1999). As farmers' income rises the tendency is to rely more on commercially available inorganic fertilizers. The fact that the likelihood of utilizing leaf litter increased with income of the farmers is an indication that there may be a paradigm shift in the farmers' outlook on soil fertility management. This is an indication that farmers are aware of the benefits of incorporating organic resources in the soil to improve its fertility while protecting the environment at the same time.

It was found from this study that the likelihood of using leaf litter decreased as the farm size increased. This could be attributed to the fact that the collection and application of leaf litter for replenishing soil fertility is a labour intensive activity. Apart from being used for maintaining soil fertility, leaf litter has other competing uses such as fuel for cooking, fodder for animals and medicinal value which may limit its utilization for replenishing soil fertility. Other similar studies have yielded similar findings. For example Mkhabela and Materechera (2003) and Mkhabela (2002) found that the utilization of manure for crop production decreased with increasing size of the land cultivated by small-scale farmers in KwaZulu-Natal due to limited access.

3.7 Conclusions

The present study revealed that local farmers across the EDM use leaf litter collected from various fruit trees for soil fertility management. However, this knowledge has to be supplemented with research information on patterns of nutrient demand of different crops and nutrient release from the different tree litter. Although it was not expected in this study, the utilization of leaf litter was positively influenced by the sources of income. This could be a clear demonstration of a paradigm shift in soil fertility management since farmers are now aware of the negative environmental effect of chemical fertilizers. The study also concluded that local farmers applied indigenous knowledge of mixing leaf litter with manure in order to improve its quality. Composting and / or mixing leaf litter with other amendments such as kraal manure by farmers is an assumption that the litter collected by farmers was of poor quality.

CHAPTER FOUR

LITTERFALL AND QUALITY OF LEAF BIOMASS FROM THREE SUB-TROPICAL FRUIT TREES AT NELSPRUIT, MPUMALANGA PROVINCE

4.1 Introduction

Litterfall has received considerable attention in forest ecosystems (Barlow *et al.*, 2007; Zhang *et al.*, 2008). This is because it represents a major biological pathway for nutrient element transfer from vegetation to soils and plays an important role in regulating energy flow and nutrient cycling for maintaining soil fertility in these ecosystems (Yang *et al.*, 2003; Jha and Mohapatra, 2009; Parsakhoo and Jalilvand, 2009). A considerable amount of nutrients in the forest are returned to the soil through litterfall in the form of leaves, twigs, bark, flower and fruits. After decomposition, the nutrients are made available for plant uptake (Switzer and Nelson, 1972). The amount of nutrients that arrive in forest ecosystems through atmospheric deposition or weathering is disproportionately small compared to the amount of nutrients from litterfall (Likens *et al.*, 1977; Odiwe, 2009). The study of litterfall is important for understanding nutrient cycling, plant growth and their interactions with environmental variables in forest ecosystems (Dunham, 1991; Kesseler, 1992). The organic matter that results from leaf litter has the ability to improve the soil's water retention and infiltration capacity (Wood and Raison, 1982), aggregate stability, cation-exchange capacity, and biological activity (Foth, 1984).

Litterfall and the rate at which nutrients are returned to the soil largely depend on factors such as tree species, time of the year, climate, soil fertility, and elevation (Blair, 1988; Stewart and Frank, 2008; Carrera *et al.*, 2008). The quality of leaf litter plays an important role in soil fertility since it is one of the factors that influences the decomposition and quantity of nutrients released into the soil (Swift *et al*, 1979; Cadisch and Giller, 1997). Leaf litter quality is defined in terms of the concentration of nitrogen, lignin, and C:N ratio of the litter (Moorhead *et al.*, 1999). Knowledge of differences in leaf litter quality offers scope for using combinations of plant materials to provide for both a rapid release of nutrients and their slower regular release over a longer period (Cadisch and Giller, 1997; Mapfumo and Giller, 2001). Jha and

Mohapatra (2009) found that *Leucaena leucocephala* and *Acacia nilotica* had litterfall peaks in autumn while *Azadirachta indica* and *Prosopis juliflora* had the maximum shedding of leaves during summer season.

There is a growing body of literature which suggests that sustainability and improved soil fertility under agricultural ecosystems can be achieved if they are operated by mimicking the structure and functioning of natural ecosystems (Lefroy *et al.*, 1995; Van Noordwijk and Ong, 1999; Ewel, 1999). The best possible way of achieving this sustainability is to first develop strategies that can be used to manage litter from the trees since they form the major component of replenishing soil fertility. Litterfall in natural ecosystems is linked very closely to annual rates at which nutrients are recycled (Attiwill and Adams, 1993; O'connell and Sankaran, 1997). However, there is a wide variation in the supply of these nutrients in natural ecosystems because of differences in rates of decomposition and mineralization (Swift *et al.*, 1979). Nutrient inputs via litterfall are of interest because they can help understand nutrient uptake in both forest and agricultural ecosystems (Liao *et al.*, 2006).

The EDM is located in a sub-tropical zone of South Africa and therefore supports growth of many sub-tropical fruit trees. These trees produce leaves that fall to the ground every year and therefore provide biomass that is used for managing soil fertility. The utilization of leaf litter for soil fertility management is a strategy that has received much attention in most smallholder production systems of southern Africa (Nyathi and Campbell, 1993; Jama *et al.*, 2000; Mapfumo and Giller, 2001). Although substantial information is available on nutrient content, litterfall and quality of forest trees (Attwill and Adams, 1993; Dames *et al.*, 1998), little is known about the litter fall, yield and quality of leaf biomass from sub-tropical fruit trees, especially in the EDM. The utilization of this resource can only be maximized if the quantity and quality of the leaves produced are measured. The purpose of the study reported in this chapter was to establish the quantity and quality of the leaf biomass from three fruit trees commonly found within the smallholder farms in the EDM. The specific objectives of the study were to:

1) Quantify litter falling from three sub-tropical fruit trees during the year, and;
2) Determine the quality of leaf litter from the sub-tropical fruit trees and monitor the quality changes with seasons

4.2 Literature review

4.2.1 Introduction

This section gives an overview of the importance of trees in nutrient cycling within natural ecosystems. The careful integration of trees into agricultural systems is thought to enhance the long-term sustainability and productivity of many agroecosystems (Van Noordwijk and Ong, 1999). The sustainability and productivity is generally attributed to the role trees play in maintaining soil organic matter, improving nutrient cycling, controlling erosion and ameliorating microclimates (Walter and Breckle, 1973; Collinson, 1978; Steppler and Nair, 1986). The understanding of the roles that trees play in nutrient cycling is important for designing viable strategies of managing soil fertility using plant litter (Van Noordwijk and Ong, 1999).

4.2.2 Litterfall and nutrient cycling under natural ecosystems

There are six different biomes in the world *viz*: fresh water, marine, desert, forest, grassland, and tundra (Walter and Breckle, 1973; Collinson, 1978). Ecosystem is defined as a functional system of complementary relations between living organisms (biotic) and their environment (abiotic), delimited by arbitrarily chosen boundaries, which in space and time appear to maintain a steady equilibrium (Spurr and Barnes, 1980). Forests are important as they are home to the most diverse biotic communities in the world. Hidden within these biomes are potential medicines and many thousands of unseen and undiscovered species (Perry, 1994). Also, forests have a global climate-buffering capacity, so their destruction may cause large-scale changes in global climate. The flora and fauna within forest and grassland biomes greatly depend on the cycling of nutrients to meet their nutritional demands (Walter and Breckle, 1973). The cycling of nutrients within natural ecosystems mostly involves trees (biotic) and soils (abiotic). Nutrient and organic matter inputs to soil through litterfall in a forest and grasslands ecosystems is an important factor for soil fertility maintenance and carbon sequestration (Walter and Breckle, 1973; Collinson, 1978).

Annual leaf litterfall varies significantly among the forest types and tree species. Bray and Gorhan (1964) reported that conifers have higher litter production compared to deciduous broadleaf forests. However, this was rejected by Yu (1994) who found opposite results in a Mediterranean area and in temperate and sub-tropical China. Jha and Mohapatra (2009) compared litterfall from four different tree species and found that litterfall ranged from 3.3 to 8.5 Mg $ha^{-1}year^{-1}$ and followed the order *Prosopis juliflora* > *Acacia nilotica* > *Azadirachta indica* > *Leucaena leucoceplala*. This variation in litterfall was strongly correlated with the size of canopy of the tree species. Figure 4.1 shows various sources of nutrients and also illustrates the manner in which the nutrients are recycled within plant and soil ecosystems. Nutrients enter the system from various sources including precipitation, dust and air, and through biological nitrogen fixation (Heilman and Norby, 1998). These nutrients are stored in vegetation, litter or soils before they are used by plants. For example, about 80% of the nutrients that were taken up by plant were coming from the topsoil storage while 20% of the nutrients were coming from the subsoil. This implies that litterfall played a major role in the cycling of nutrients.

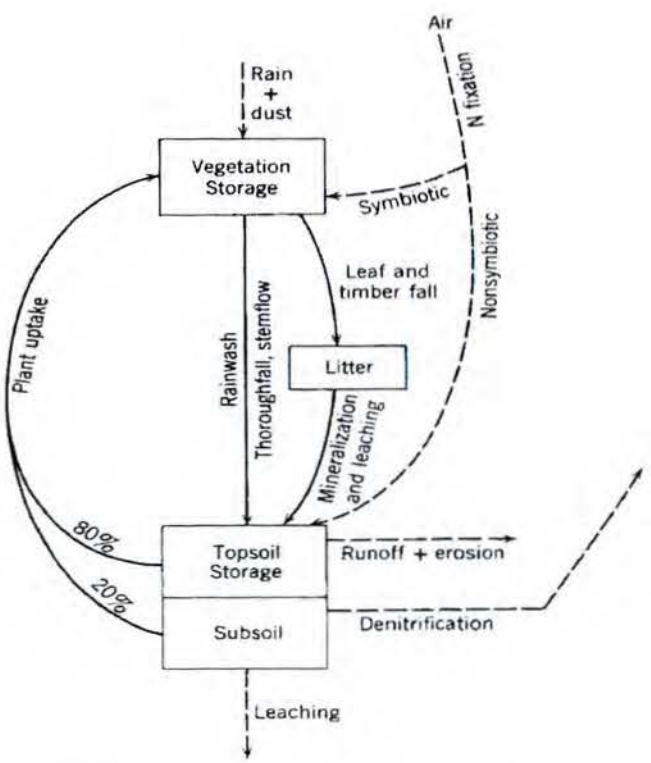


Figure 4.1 A generalized structure of nutrient cycle in natural ecosystems
Source: Heilman and Norby (1998)

Knowledge of the amounts of nutrients that are cycled through litterfall is considered useful because litterfall represents a major process of transferring nutrients from above ground vegetation to soils (Millar, 1974; Vitousek, 1982; Das and Ramakrishnan, 1985; Poschen, 1986). In the dry tropical forests of India, Singh (1992) found that litterfall returned about 51.6–69.6 kg N ha^{-1} $year^{-1}$, 3.1–4.3 kg P ha^{-1} $year^{-1}$ and 14–19 kg K ha^{-1} $year^{-1}$. About 77% of these nutrients were contributed by leaf litter. In the chestnut forests of Portugal, Patricio *et al.* (2009) found that litterfall returned about 57–142 kg N ha^{-1} $year^{-1}$, 5–10 kg P ha^{-1} $year^{-1}$, and 13–45 kg K ha^{-1} $year^{-1}$. In semi-arid environments, litterfall accounts for 90–100% of the external cycles of major nutrients (Attiwill and Adams, 1993).

4.2.3 Factors influencing leaf litterfall

Species composition, basal area, and age structure are the key factors that have been shown to influence litter dynamics and production in natural forests within a climatic region (Gresham, 1982; Stohlgren, 1988; Spain, 1984; Stewart and Frank, 2008). At a regional scale, precipitation and temperature are regarded as the most important climatic factors that control litterfall (Berg and Meentemeyer, 2001). At a local scale, with climatic conditions being relatively similar within a given area, variation in forest litterfall is attributed to differences in tree species and stand age (Bray and Gorham, 1964). Differences in physiology and ecology of tree species have made differences in litterfall of some of the forest trees to be more related to temperature, and in other cases to precipitation (Stohlgren, 1988). Jha and Mohapatra (2009) found that *Leucaena leucocephala* becomes completely devoid of green leaf biomass between April and May when the air temperature reached 48°C. In a tropical forest, Lonsdale (1988) found a significant negative relationship between leaf litterfall and altitude and a positive relationship between leaf litterfall and precipitation. Moore (1986) reported that water stress could initiate the synthesis of abscissic acid, which stimulates senescence of leaves and other plant parts.

Wright and Cornejo (1990) reported that changes in temperature and photoperiod as well as within plant properties such as leaf age were also important triggers of leaf litterfall. The winter season usually brings cold temperatures and water scarcity which force the tree to shed their leaves in autumn and become dormant during winter.

William *et al.* (1981) found that mangrove litterfall appeared to be well correlated with rainfall. Pentry and Proctor (1996) compared the rate of litterfall among trees growing at three different altitudes in Brunei. The amount of litterfall declined from a mean of 10.56 t ha^{-1} $year^{-1}$ in low altitudes to 8.26 t ha^{-1} $year^{-1}$ in the high altitudes. The authors also found a marked peak in leaf litterfall production in April and May. Turnbull and Madden (2006) found that the seasonal pattern of litterfall was most closely related to mean air temperatures. Zhou *et al.* (2007) found that mean air temperature had a significant positive effect on leaf litterfall in different types of forests in China.

McLaughlin *et al.* (1994) monitored the change in nitrogen and phosphorus concentration of live sugar maple (*Acer saccharum*) foliage during the growing season in Michigan, U.S.A and noticed an interesting pattern: an increase in nutrients in early summer as the leaves begun to form, then a constant nutrient concentration during most of the summer, followed by a rapid decline in nutrients over the autumn season. The decline in leaf nutrient during autumn occurred because trees scavenged mineral nutrients (like potassium, sodium, magnesium, iron, nitrogen, phosphorus and sulfur) from their leaves and translocated them to woody tissues of the tree for safe storage during the winter (McLaughlin *et al.*, 1994). The fertility status of the soil has also been reported to influence the rate of litterfall. A study by Vitousek (1982) showed an increase in litterfall with the addition of nitrogen, resulting in increased accumulation of plant organic matter on the forest floor. Similar results have been reported by Smaill *et al.* (2008) in New Zealand. Wienand and Stock (1995) reported a significant increase in the annual litterfall rates and litter accumulation following phosphorus fertilization in a *Pinus elliottii* stand in South Africa.

4.2.4 Leaf litterfall physiology and nutrient re-translocation

A good understanding of the physiological aspects that relate to leaf fall is necessary since it is a path to retrieve knowledge on how, when and why trees loose their leaves. The beginning of leaf drop starts when an abscission layer is formed between the leaf petiole and the stem (Lim *et al.*, 2007). This layer is usually formed during spring when there is active new growth in the leaf. During autumn or when the tree is under stress, the flow of auxins from the leaf decreases or stops, triggering cellular elongation within the abscission layer (Woodhouse, 1978; Addicott, 1982). The elongations of

these cells break the connection between the different cell layers, allowing the leaf to break away from the plant (Woodhouse, 1978).

Prior to senescence, nutrients stored in the leaves and stems are re-translocated back to other parts of the tree and this process is known as "re-translocation" or "re-absorption" (Nambiar and Fife, 1991). Re-translocated nutrients are available for reuse by the plant in the next growth cycle. The amount of re-translocation is dependent on the mobility of the element, the tree species, and the nutrient status of the soil (Dames *et al.*, 2000). Saur *et al.* (2000) found that *Espina corona* re-translocated 39% N, 53% P and 56% K prior to leaf litterfall. In South Africa, Dames *et al.* (2000) found that *Pinus patula* re-translocated a substantial quantity (43%) of phosphorus prior to needle fall, leaving 57% of P to be returned to the forest floor via litterfall. Wang *et al.* (2003) found that during leaf senescence, 77.22% N, 57.53% P, and 44.51% K were translocated out of mangrove senescing leaves. From these results it can be concluded that N, P and K display the greatest re-translocation pattern, possibly because they are the most mobile elements whereas those with lower mobility such as Ca and Mg, did not change much.

4.2.5 Methods of measuring litterfall biomass in forest systems

Evaluation of different tree species in terms of leaf litterfall provides useful information on the development of strategies to be followed for managing soil fertility (Anderson and Ingram, 1993). Litterfall collection is a standard technique of assessing the dynamics of aerial biomass in forests (Newbould, 1967; Lowman, 1988). There is no best method to measure litterfall. The best method will however, depend on the characteristics of the ecosystem, such as turnover time, seasonality, and the objective of the study. Production estimates for leaf litterfall in forests usually involve the use of baskets or litter traps distributed in the forest understory (Whittaker and Marks, 1975). Tree and shrub litter is usually collected in litter traps, which can be constructed with plastic netting, mounted on a wooden or metal frame to avoid contamination with soil and animals. In some cases, a laundry basket of about 40 cm x 54 cm or 0.216 m^2 with drainage holes drilled in the bottom is used to collect litter from forest trees. The holes allow water to drain so that the litter remains dry. The basket is set on the forest floor to catch any litter falling within that area (0.216 m^2). A large rock is placed at the bottom of the basket to prevent wind and animals from tipping it over.

The number of litter traps required in a forest is determined largely by the heterogeneity of the system, with a minimum of ten to twenty traps recommended per plot of 10 000 m^2 (Anderson and Ingram, 1993). Litterfall traps should be located randomly within a defined plot area and care should be taken to avoid edge effects of the plot. Depending on the dynamics of the forest under study, pickups of litter may need to be completed weekly in the case of some tropical forests (Wright and Cornejo, 1990), at a fixed interval (Ogden and Schmidt, 1998), or at the end of the season in temperate deciduous forests (Sala *et al.*, 2000). Once taken from the field, litter is sorted by type or species and dried in an oven at 70°C for 48 hours for the determination of dry mass. To calculate litterfall per plot, the oven dried litter from all plots are added up in order to get the total litter mass (Simmons, 1998). Simmons (1998) has suggested that the following formula can be used to express the litterfall mass in kg $ha^{-1}yr^{-1}$:

Litterfall (kg $ha^{-1}yr^{-1}$) = total litter mass (g) x 1000 (g kg^{-1}) / Area of basket (m^2) x 10, 000 (m^2 ha^{-1}) **(3)**

4.2.6 Mechanisms by which litterfall influence nutrient cycling and soil fertility

Soil enrichment and high crop yields under tree canopies have widely been reported and are attributed to several factors mainly the ability of trees to retrieve nutrients from deep horizon (Van Noordwijk *et al.*, 1996; Gliessmann, 2006; Uphoff *et al.*, 2006), and, the ability of leguminous trees to fix nitrogen from the atmosphere (Van Noordwijk *et al.*, 1996). Nutrients taken up by trees from below the rooting zone of annual crops become an input when transferred to surface soil in the form of leaf litter, root decay and pruned tree leaves and branches (Weil and Mughogho, 1993; Van Noordwijk *et al.*, 1996). When leaves fall to the ground, they become a food source for decomposer soil organisms. Bacteria and fungi feed on the leaves mainly to obtain energy, although they also extract a small amount of the nutrients for their own use. As bacteria break down the carbon compounds into CO_2 and H_2O, the nutrients are released into the soil solution as inorganic ions (e.g., NH_4^+, K^+, PO_4^{-3}). Once these ions are released they can be absorbed by the tree's roots (Blair, 1988).

Numerous studies have reported higher soil organic matter in top soils under trees than in open areas (Weil and Mughogho, 1993; Dancette and Paulain, 1969; Mordelet *et al.*,

1993). Pandey *et al.* (2000) investigated the effect of *Acacia nilotica* on soil properties in traditional agroforestry systems in Central India and found high concentrations of C on soil collected beneath the tree canopy compared to those away from the canopy (Table 4.1). However, there was no significant difference in the concentration of phosphorus between the two treatments. Similarly, Mordelet *et al.* (1993) reported higher soil organic carbon under tree clumps than in open grassland in Cote d' Ivoire. Belsky *et al.* (1993) reported high accumulation of soil organic matter at 0–15 cm depth under *Acacia tortilis* and *Adonsonia digitata* in Kenya.

Table 4.1 Organic C, total N and total P (%) concentration under mid canopy and canopy gap in a traditional agroforestry in central India

Site	Total carbon	Total N	Total P
Mid canopy	0.98a	0.085a	0.065a
Canopy gap	0.61b	0.083a	0.062a

Source: Pandey *et al.* (2000)

Soil enrichment due to the presence of trees has also been reported beneath *Acacia albida* in the African Sahel (Dancette and Paulain, 1969), beneath *Prosopis juliflora* in arid rangelands of South-western United State (Tiedemann and Klemmedson, 1977), and beneath *Acacia sieberana* in a South African savanna (Roos and Allsopp, 1997). The trees were reportedly had a marked effect on increasing soil nitrogen, total carbon and exchangeable cations. Tiedemann and Klemmedson (1977) found high concentration of carbon and nitrogen beneath the canopies of *Prosopis juliflora* (Table 4.2).

Table 4.2 Surface soil nutrient concentrations beneath the canopy of selected trees

Site	pH	C (%)	N (%)	P (ppm)	K (meq/100g^{-1})
Canopy	6.3	0.9	0.05	0.03	2.95
Open	6.4	0.4	0.03	0.03	2.98

Source: Tiedemann and Klemmedson (1977)

The concentrations of nutrient in the leaves of annual crops grown beneath trees serve as an indicator of the contribution of nutrients by trees on nutrient cycling. In Niger, Kho *et al.* (2001) reported significantly higher concentration of N, P, K, Ca and Mg on leaves of millet grown under *Faidherbia albida* compared to millet from outside the tree canopy Nitrogen concencentration was 1.14 % in the leaves of millet grown under *Faidherbia albida* compared to 0.74 % from the leaves of millet grown in the open field (Table 4.3). In Malawi, Weil and Mughogho (1993) found a significantly higher concentration of nitrogen (22.9 g kg^{-1}) and sulphur (1.09 g kg^{-1}) in the leaves of maize (tasseling stage) grown under *Acacia albida* compared to 16.6 g N kg^{-1} and 0.74 g S kg^{-1} in maize away from the trees. Poschen (1986) on the other hand found that the yields of maize in Ethiopia were up to 75% higher and sorghum yields over 50% higher beneath *Acacia albida* canopies than in the open. Higher crop yields beneath the trees have been attributed to the improved soil fertility through greater organic matter content and water holding capacity near the trees (Hassink *et al.*, 1993; Belsky *et al.*, 1989).

Table 4.3 Mean nutrient concentrations of millet in the open field and under *Faidherbia albida* trees at N'Dounga, Niger

	Nutrient concentrations (%)				
Site	N	P	K	Ca	Mg
Open field	0.74	0.14	1.9	0.27	0.23
Under *F. albida*	1.14	0.18	2.0	0.31	0.25
S.E	*0.086*	*0.015*	*0.12*	*0.037*	*0.026*

Source: Kho *et al.* (2001)

4.2.7 The concept of quality of leaf litter and its influence on soil fertility

The success of leaf biomass in improving soil fertility is, among others, related to the amount and quality of the tree litter. Quality refers to the constituents (chemical composition) and the nutrient contents of the organic inputs (Cadisch and Giller, 1997). The quality of organic inputs determines the type of soil organic matter fractions formed after application of the organic inputs. The C, N, P, lignin and polyphenolic

contents along with their interrelations are the most commonly measured (Vanlauwe *et al.*, 1997). The chemical composition of leaf litter differs from one tree species to the other. Kelly and Boerner (2006) and Aerts (1995) reported that deciduous leaf litter had higher nitrogen concentrations in the leaves than evergreen tree species.

The quality of litter biomass is also different from one tree part to the other, within the same tree (Le Roy *et al.*, 2007). Marschner (1995) reported that tree prunings had a higher concentration of mobile nutrients such as N, P, K and Zn than naturally fallen litter from which these elements are re-translocated by the tree prior to abscission. This implies that prunned materials have a better chance of improving soil fertility than naturally fallen litter (Fonte and Schowalter, 2004). The concentration of nutrients in leaf litter differs from one season to the other (Wright and Westoby, 2003). In other words, nutrient concentration in leaf litter tends to show seasonal changes that are consistent with active metabolic functions. The N, P and K tend to increase when the leaves are actively developing and decline afterwards, partly because of the increasing proportion of cell wall structures and partly because there is translocation of nutrients out of the leaves before senescence while nutrients such as Ca and Mg are less mobile and monotonically increase with time (Ralhan and Singh, 1987).

High litter quality (low C/N ratios and low lignin concentrations) would maintain a soil beneath its canopy with low bulk density, low C/N ratios, high available N and P concentrations and high N mineralization rates compared to litter with lower litter quality (Cadisch and Giller, 1997). Palm *et al.* (2001) have proposed a decision guide tree for determining quality parameters of an organic material (Figure 4.2). The decision guide gives a step-by-step characterization of organic resource management based on their nitrogen, lignin and polyphenol contents. The Decision Support System (DSS) also guides the management of the resource with respect to decisions regarding incorporating, mulching and mixing of organic resources. Several attempts have been made to quantify and correlate plant residue quality and the decomposition process (Handayanto *et al.*, 1994; Palm *et al.*, 2001). Organic resources of high quality (high in nitrogen but low in both lignin and polyphenols content) decompose and release nitrogen rapidly. The course of decomposition of organic matter is affected by the presence of carbon and nitrogen. Decomposition takes longer, however, when the initial C:N ratio is much above 30 (Swift *et al.*, 1979).

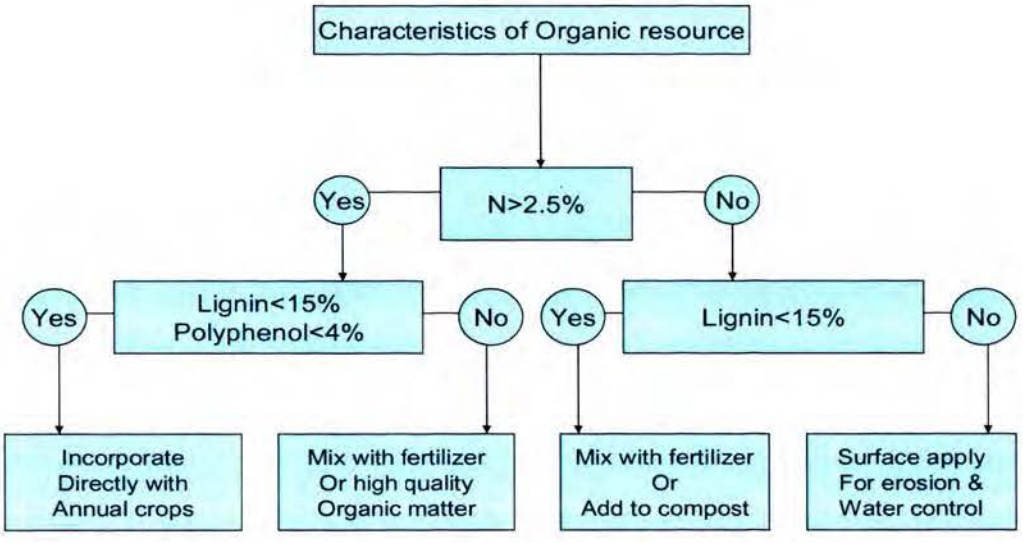


Figure 4.2 Decision Support System (DSS) for organic resource management

Source: Palm *et al.* (2001)

The previous chapter in this thesis has shown that small scale farmers own and use litter biomass from fruit trees to supply food crops with nutrients. The amounts of the litterfall and its quality have however not been well established in the study districts. This information is however crucial if progress is to be made in improving the utilisation of the litter as fertilizer. There is a need to understand the influence of seasons on litterfall and its quality in order to develop optimum management practices. The research reported in this chapter sought to quantify the quantity and quality of litterfall from three selected fruit trees in the EDM. The influence of season on both the litter yield and quality were also quantified.

4.3 Materials and methods

4.3.1 Characteristics of the study site

4.3.1.1 Study location

The study was conducted at the Agricultural Research Councils' Institute for Tropical and Sub-tropical Crops (ARC-ITSC) station located at Nelspruit in Mpumalanga Province (Figure 4.3). The site is located on latitude 25° 27' S and longitude 30° 58' E with an elevation of 650 m above sea level. The station was established in 1926 to conduct research covering a wide range of tropical and subtropical fruits, including avocado, citrus, granadilla, guava, litchi, macadamia nut, and mango. Lesser known exotic crops such as carambola and jaboticaba are also being investigated.



Figure 4.3 A satellite photo showing the ARC-ITSC research station in Nelspruit

The areas on the map marked with an X indicate the location of orchards where litter traps were constructed during the litterfall study.

Source: Maplandia (2005)

4.3.1.2 Climate and vegetation

Nelspruit lies in a summer rainfall zone with rainfall that comes between November and February. The lowest amount of rainfall is expected between May and September (Figure 4.4). The mean monthly maximum and minimum temperature vary from 23.3 °C in June to 29.9 °C in February and 6.5 °C in July to 18.9 °C in January respectively (Figure 4.5). A summary of the long-term (17 years) climatic elements are presented in Table 4.4. The area experiences high evaporation between December and February whereas wind speed is highest between June and September.

Four distinct seasons are experienced namely: summer (December, January, and February), autumn (March, April, May), spring (September, October, November), and, winter (June, July, August). The vegetation in Nelspruit is described as Lowveld sourveld (Acocks, 1975). The most common tree species include *Combretum imberbe*, *Sclerocarya birrea* and *Spirotachys africana* (Palgrave, 1997). However, small patches of evergreen forest also exist in the eastern escarpment with trees such as *Podocarpus*, *Curtisia* and *Trichocladus* (Acocks, 1975; Odendall, 1984).

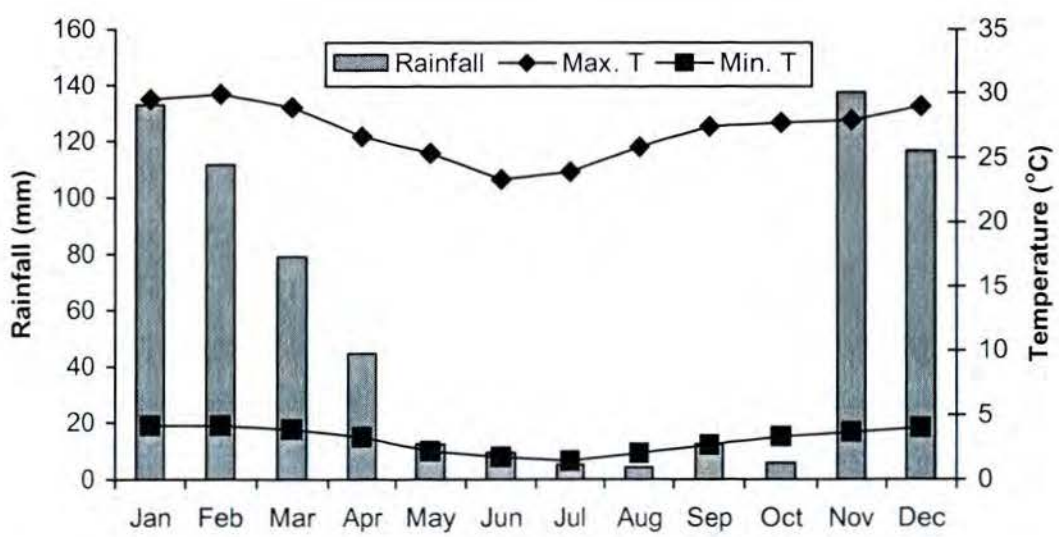


Figure 4.4 Long-term (17 years) mean rainfall and temperature for Nelspruit

Source: ARC-ISCW (1985-2002)

Table 4.4 Mean monthly air humidity, wind speed and evaporation for Nelspruit

Period	Weather element		
	Humidity (%)	Wind speed (km day^{-1})	Evaporation (mm day^{-1})
January	75.6	1947	4.8
February	74	1957.7	4.8
March	73.7	1945.7	4.2
April	74.3	1854	3.1
May	66.7	2347.2	3.0
June	67	2458.9	2.5
July	61.4	2634.5	3.0
August	62.7	2557.4	3.5
September	63.4	2598.4	4.3
October	69.5	2394.7	4.2
November	74.4	2152.7	4.4
December	75.4	2026.7	4.7
Average	*69.8*	*2239.6*	*3.9*

Source: ARC-ISCW (1985–2002)

4.3.1.3 Geological profile and soil characteristics

The underlying geology of Nelspruit consists of granite and magmatite of the Nelspruit granite suite (Geological Survey, 1986). The soils are predominately red to yellow-brown and are classified as Hutton form (Soil Classification Working Group, 1991). The textures of the soils are predominately sandy loam with a typical particle size distribution of 82.4% sand, 9.6% silt and 8% clay (Paterson, 2007). Soils are usually deep and display a rapid drainage. The soil pH ranges from 5.5 to 6.5 which are ideal for growth of most food crops and sub-tropical fruit trees (Paterson, 2007). Soil organic matter is relatively low (average 1.2%) which implies that farmers need to apply large amount of organic materials in order to increase its content.

4.3.1.4 Land use

About 31% of the land in the study area is used for cultivation. Maize, sugarcane, tropical and subtropical fruit and citrus orchards occupy much of the cultivated area (Paterson, 2007). About 6% of the area is used for grazing, particularly cattle and game. The rest of the land is used for residential, business and recreational purposes. During

the period 1988 and 1998 there was a slight increase in the area of land under crops and a decrease in the area of grazing (Thompson, 1996). However, due to high population increase, the land used for agriculture is being reduced.

4.3.2 Measurement of climatic variables during the study period

Climatic variables that could affect litterfall were monitored during the study period. These climatic variables included rainfall, wind speed, maximum and minimum temperature and air humidity. Rainfall was measured daily during the time of the study by using a standard rain gauge located at the centre of the study area. Measurements were taken at the same time (08H00) in the morning. Wind speed was measured daily using a cup anemometer located at the weather station in the research station. Daily minimum and maximum temperatures of the air within the study site were recorded using thermometers in the Stevenson screen. Humidity was calculated from wet and dry bulb hygrometer at the Stevenson screen.

4.3.3 Experimental treatments and design

In August 2006 three plots each measuring 100 x 100 m and containing avocado (*Persia americana*), mango (*Mangifera indica*) and litchi (*Litchi chinensis*) trees were selected for the study. The tree species (avocado, mango and litchi) were chosen because they represent the most commonly grown fruit trees within the EDM (Mpumalanga Provincial Government, 2003b). These tree species form an important source of food and income for the majority of the people who lived within the EDM (Mpumalanga Provincial Government, 2003b). In each plot, five individual trees were randomly selected and used for collecting leaf litter. A nylon mesh litter trap measuring 3.5 x 4 x 3 m was constructed around the five randomly selected individual trees (Figure 4.5). A nylon net was placed at the base of each tree to avoid soil contamination and to make litter collection easier. The characteristics of the trees that were used in the study are presented in Table 4.5. The height of each tree was measured using a 15 m calibrated pole. Canopy and stem diameters were measured using a measuring tape. Stem diameter of each tree was measured at 60 cm above the soil surface. A distance from the tree trunk to the end of the canopy was measured using a measuring tape and multiplied by two in order to get a canopy diameter. For

purposes of statistical analysis, the experiment was designed as a completely randomised design with five replicates and three factors (year, species and season).

A. Avocado **B. Mango**



C. Litchi



Figure 4.5 A nylon mesh leaf trap erected around individual trees for litterfall collection

Table 4.5 Characteristics of the tree species used for the study in Nelspruit

Tree species diameter	Age (year)	Height (cm)	Stem diameter (cm)	Canopy (cm)
Avocado	13	232±13.0	9.3±2.0	288±22.8
Mango	08	242±21.7	12.5±1.4	262±26.8
Litchi	13	298±4.5	11.7±0.5	354±45.1

Values are mean ± SD, n=5

4.3.4 Determination of leaf litterfall yield

Leaf litterfall from the selected trees in each plot was monitored for two growing seasons. All the leaves falling into the litter trap were collected monthly for two years (2007 and 2008). Immediately after collection, leaves were weighed on a scale to determine the wet mass and thereafter, were dried in the oven at 65°C for 48 hours and weighed again to obtain their dry mass. Leaf litter yield for the season was obtained by adding the yields of leaves collected for September–November (spring), December–February (summer), March–May (autumn) and June–August (winter). To calculate litterfall per plot, the oven dried litter from all plots were added up in order to get the total litter mass in grams. Equation (3) was used to express the litterfall mass in kg $ha^{-1}yr^{-1}$.

4.3.5 Determination of quality of leaf litter

The quality of litter was determined for each species on samples collected at the end of each month. The leaves from each species were bulked and a sample was collected from the bulk and ground to pass 1.0 mm in a Willey mill (MF 10 basic IKA® WERKE). The ground material was analysed for polyphenols, lignin, cellulose, ash and mineral elements. Polyphenol, lignin, cellulose and ash were analysed at the Agricultural Research Council- Animal Nutrition and Production Institute (ARC-ANPI) in Pretoria while mineral elements were analysed at the ARC-ITSC in Nelspruit.

4.3.5.1 Total nitrogen

Total nitrogen was determined by the micro-Kjeldahl procedure which was established by Johan Kjeldahl in 1883 (Christensen and Fulmer, 1927; AOAC, 1995). This procedure involved digesting the ground leaf samples with concentrated sulfuric acid (H_2SO_4). Ammonium-N from the digest was obtained by steam distillation, using excess Sodium hydroxide (NaOH) to raise the pH. The distillate was collected in saturated Boric acid (H_3BO_3) and then titrated with dilute H_2SO_4 until the colour changed from green through grey to a definite pink.

4.3.5.2 Total P and extractable cations (K, Ca, Mg, Zn, and Mn)

The total phosphorus, extractable calcium, magnesium, zinc, and manganese in the leaf litter were determined by the perchloric acid digestion procedure of Karla and Maynard (1991). Samples were heated by the oscillating electromagnetic field and digested by acid oxidation (Nitric acid, concentrated 70% HNO_3, Hydrogen peroxide, 30% H_2O, Hydrochloric acid: concentrated, 37%). Total phosphorus was determined using a spectrophotometer at a wavelength of 660 nm whereas extractable K, Ca, Mg, Zn, and Mn were determined on the Atomic Absorption Spectrometer.

4.3.5.3 Total carbon

The carbon content of the leaves was determined by using the method recommended by Okalebo *et al.* (1993). About 5g of sample was oxidised by heating with sulphuric acid and aqueous potassium dichromate (K_2CrO_7) mixture. The carbon was determined by titrating using 0.5 M ferrous ammonium sulphate ($FeSO_4$).

4.3.5.4 Lignin and cellulose content

Cellulose and lignin contents were analyzed via neutral detergent fiber (NDF) and acid detergent fiber (ADF) using the Van Soest detergent procedure (Van Soest and Wine, 1967). NDF content was determined by extracting a 0.5g of leaf samples in boiling neutral detergent solution (3% (w/v) sodium dodecyl sulphate, sodium lauryl sulphate, 18mM sodium tetraborate deccahydrate ($Na_2B_4O_7$. $10H_2O$), 32 mM sodium phosphate (dibasic, $NaHPO_4$), 50 mM Na_2-EDTA, and 1% (v/v) ethylene glycol (2-ethoxyethanol) for 1 hour. The suspension was filtered, and the cell wall residues on the filter were washed in hot water and acetone. After drying overnight at 100°C, the sample was weighed and NDF was calculated as percentage of the original leaf sample. ADF was determined on the dried NDF sample, by boiling for 1 hour in 200 mL acid detergent solution (0.5 M sulfiric acid, 2% (w/v) CTAB). ADL was measured by further treating ADF with strong acid, which dissolved the cellulose. Cellulose was estimated by subtracting ADF from NDF (Rinne *et al.*, 1997).

4.3.5.5 Polyphenols

Total soluble polyphenol was analysed by a revised Folin–Denis method (King and Heath, 1967; Constantinides and Fownes, 1994). Soluble polyphenols were extracted in 50% (v/v) aqueous methanol for 1 hour in a water bath (80°C) with a plant extract ratio of 0.1 g per 50 mL (Constantinides and Fownes, 1994). Total soluble polyphenol concentration was analyzed colorimetrically against a tannic acid standard and expressed as tannic acid equivalent.

4.3.6 Analysis of data

Analysis of variance (ANOVA) was conducted for data on each parameter to test the effect of year, season and species using General Linear Model (GLM) procedure of SAS (SAS Institute Inc. 1999) on the yield and quality of litter. Differences between means for years, season and species were tested for significance using Tukey's multiple comparison in SAS (SAS Institute Inc, 1999). Correlations between litter yield, litter quality and climatic variables were calculated using Pearson Correlation Coefficients (r).

The model used for ANOVA was:

$$Yijkl = \mu + Yi + Sj + Tk + (YS)ij + (LT)jk + (YST)ijk + Eijkl \quad \textbf{(4)}$$

Where:

μ = overall mean

Yi = effects of the i^{th} year

Sj = effects of the j^{th} season

Tk = effects of the k^{th} species

$(YS)ij$ = interaction of the i^{th} year and j^{th} season

$(YT)jk$ = interaction of the i^{th} year and k^{th} species

$(ST)jk$ = effects of the j^{th} season and k^{th} species

$(YST)ijk$ = interaction of i^{th} year, j^{th} season and k^{th} species

$Eijkl$ = residual

4.4 Results

4.4.1 Climatic variables during the study period

The total annual rainfall for the two years was 763.9 and 728.8 mm respectively. The pattern in the monthly distribution of the rainfall was similar in both years. Rainfall was at a maximum in November and December after which it dropped and was lowest between June and July. The only month which showed a wide variation in rainfall was January where the rainfall in 2008 was three times that of 2007 during the month. In all the months, 2007 had higher rainfall than 2008 (Figure 4.6). The air humidity at the site increased steadily from September reaching a maximum in January and steadily decreasing thereafter. The humidity for both growing seasons was generally lower than the long-term average (Figure 4.6).

The patterns for maximum and minimum monthly temperatures were similar in the two years. Highest temperatures of around 30°C in both growing seasons were recorded in February while lowest temperatures were recorded in July. In both growing seasons, the distribution of both maximum and minimum temperatures mirrored the long-term averages for the site. It was observed however that the maximum temperatures for 2007 were higher than both the long-term average and 2008 for the months of February and March (Figure 4.6). The wind speeds showed a consistent pattern where the speed was highest between May and September and also between February and March. November and April had the lowest wind speed in both years. The pattern of wind speed for both years mirrored the long-term average. However, the wind speed for the months of December, February and March in 2007 were higher than the long-term average (Figure 4.6).

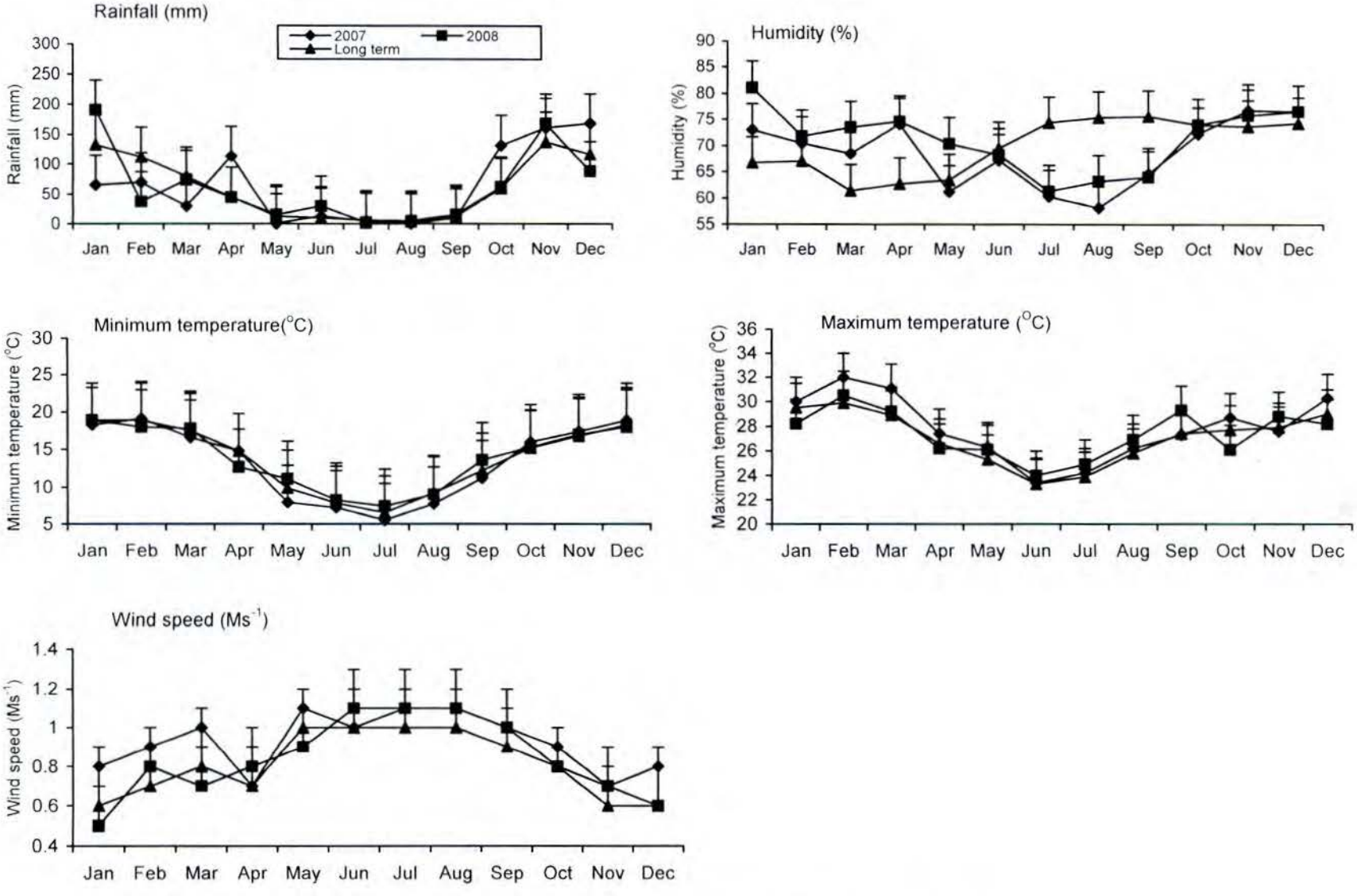


Figure 4.6 Climatic elements recorded at the site during the study period. Vertical bars indicate standard errors

4.4.2 Quantity and pattern of litterfall from the three tree species

4.4.2.1 Leaf litter quantity

A summary of the analysis of variance (ANOVA) for the leaf litter yield from the three tree species during the two growing seasons of the study is presented in Table 4.6. The results show that all the three variables (year, seasons and species) had highly significant ($P<0.001$) influence on the yield of leaf litter. There were also significant ($P<0.05$) interactions among the factors implying that they were influencing the yield differently.

Table 4.6 A summary of ANOVA for leaf litter yield

Source of variation	d.f	Sum of squares	F – ratio	P > F
Year (Y)	1	124146.63	18.15	0.0001
Season (S)	3	290824.96	14.17	0.0001
Specie (T)	2	91082.68	6.66	0.0028
Y x S	3	68378.86	3.33	0.0271
Y x T	2	51954.55	3.80	0.0294
S x T	6	100529.01	2.45	0.0380
Y x S x T	6	52363.82	1.28	0.2862

The annual leaf litter yield from the three tree species during the two years of the study are presented in Table 4.7. In 2007, the average leaf litter yield was in the order: litchi (2252.2 g $tree^{-1}$) > mango (1180.4 g $tree^{-1}$) > avocado (480.2 g $tree^{-1}$). In 2008 there were no significant differences between the leaf litter yields of mango and litchi trees. In 2008, the total leaf litter of avocado trees was four times higher than that in 2007. The estimated mean annual leaf litter yields (in terms of t ha^{-1}) from the three tree species during the two years of the study are presented in Table 4.8. The litter yields for all three species were significantly higher in 2008 than in 2007. In both years, the mean leaf litter yields produced was 8.3 t ha^{-1}, 6.3 t ha^{-1} and 4.7 t ha^{-1} for litchi, mango and avocado, respectively. It was also generally observed that the litchi trees enclosed in the net grew larger than those which were not enclosed.

4.4.2.2 Seasonal pattern in litterfall yield

The mean leaf litter yields for the trees (combined) for spring, summer, autumn and winter is presented in Table 4.9. The seasonal total litter yield was in order autumn (4397.6 g tree^{-1}) > spring (2568.8 g tree^{-1}) = summer (2504.3 g tree^{-1}) > winter (1303.2 g tree^{-1}). This implies that farmers can collect large amounts of leaf litter biomass for maintaining soil fertility during autumn. The patterns of litterfall for each tree species during the four seasons of each of the two years is presented in Figure 4.7. In both years, the trees produced the least amount of litter during winter and the yields began to rise in spring and were highest in autumn. There was not much difference in the litterfall yield between spring and summer among all the species while the litter yield for autumn was higher for all the species. In 2008 however, mango and avocado produced the largest amount of leaf litter in spring.

Table 4.7 Total annual yield of leaf litter biomass from three sub-tropical fruit trees

	Leaf litter yields (g tree^{-1} year^{-1})					
	Avocado		Mango		Litchi	
Tree No.	2007	2008	2007	2008	2007	2008
T1	389.7	2299.1	1245.2	2613.4	1793.2	2784.9
T2	638.9	2385.6	747.5	1871.2	2123.3	1482.5
T3	507.9	2362.3	1427.7	1680.5	2273.8	2425.3
T4	470.8	1738.7	1405.1	1751.7	2369.8	2512.3
T5	393.8	1874.2	1076.5	3884.5	2701	2638.8
Total	*2401*	*10659.9*	*5902*	*11801.2*	*11261.1*	*11843.8*
Mean	*480.2*	*2132*	*1180.4*	*2360.2*	*2252.2*	*2368.8*

Table 4.8 Total dry mass yield of leaf litter from three tree species during 2007 and 2008

Year	Leaf litter yield (t $ha^{-1}year^{-1}$)				
	Avocado	Mango	Litchi	*Total*	*Mean*
2007	1.715a	4.216b	8.044c	*13.975*	*4.658*
2008	7.614a	8.429b	8.460b	*24.503*	*8.168*
Total	*9.329*	*12.645*	*16.504*		
Mean	*4.665*	*6.323*	*8.252*		

Values within a row with similar letter are not significantly different P<0.05 by the LSD test

Table 4.9 Seasonal mean litter yields for the three tree species during 2007 and 2008

Year	Leaf litter yields (g $tree^{-1}$)					
	Spring	Summer	Autumn	Winter	*Total*	*Mean*
2007	645.3b	642.2b	2235.8c	389.4a	*3912.8*	*978.2*
2008	1923.5b	1862.0b	2161.8c	913.8a	*6861.1*	*1715.3*
Total	*2568.8*	*2504.3*	*4397.6*	*1303.2*		
Mean	*1284.4*	*1252.2*	*2198.8*	*651.6*		

Values within a row with similar letter are not significantly different P<0.05 by the LSD test

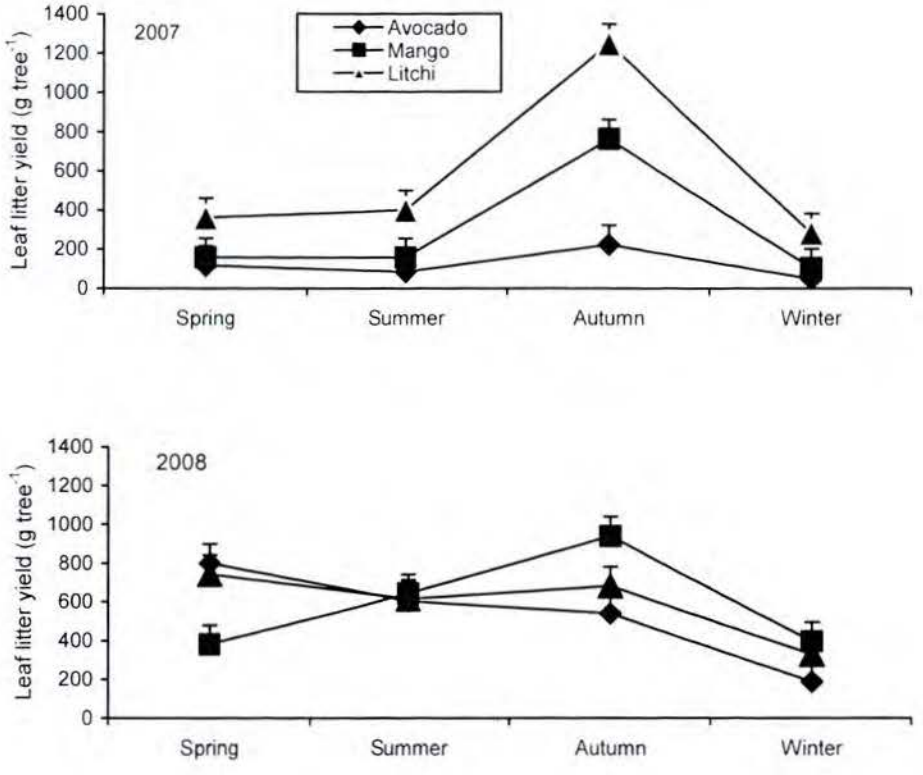


Figure 4.7 Seasonal patterns in leaf litterfall yield from the three sub-tropical fruit tree species in Nelspruit. Vertical bars indicate standard errors.

4.4.3 Quality of leaf litter from the three tree species

A summary of the ANOVA for litter quality variables investigated in the study is presented in Table 4.10. The years showed significant effect on polyphenols but not lignin and cellulose. Species and seasons had significant effect on polyphenols, cellulose, lignin, carbon, C:N ratio and mineral elements. Interaction of year by season was significant on the concentration of polyphenol, ash, lignin, cellulose, C:N ratio, N, P, K, S, Ca, and Mn. There was also significant interaction of year by species on almost all variables except for C:N ratio, C, N, and Zn. The interactions among the three variables (Year x Season x Species) were also significant for lignin, cellulose, P, S, Ca, Mg, Zn, and Mn.

Table 4.10 A summary of ANOVA showing the effects of factors on the mean squares of leaf litter quality variables

Source of variation	df	PP	Ash	Li	Cell	N	C	P	K	S	Ca	Mg	Zn	Mn	C:N
Year (Y)	1	***	***	*	ns	ns	ns	ns	***	ns	***	***	*	***	ns
Season (S)	3	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Specie (T)	2	***	***	***	***	***	***	***	***	***	*	***	***	***	***
Y x S	3	***	*	***	***	***	ns	***	***	***	*	ns	ns	***	***
Y x T	2	ns	***	ns	***	ns	ns	***	***	***	*	***	ns	***	ns
S x T	6	ns	***	***	***	ns	***	***	***	***	***	***	***	***	ns
Y x S x T	6	ns	ns	***	***	ns	ns	***	ns	*	***	***	***	***	*

Polyphenol (PP), Lignin (Li), Cellulose (Cell),
* = $P < 0.05$
*** = $P < 0.001$
ns = not significant

4.4.3.1 Polyphenol, ash, lignin and cellulose content

A difference in the trend in the concentration of polyphenol between the two years was observed (Figure 4.8). In 2007 the polyphenol content of leaves was lowest in spring but increased during summer and reached maximum in winter (Figure 4.8). In both years, avocado trees had the lowest content of polyphenol compared to the other two species. Leaf ash was highest in autumn (Figure 4.8). The highest lignin content for the leaves was in summer and autumn while winter had the lowest concentration. The winter leaf lignin of 2008 was higher than in 2007 (Figure 4.8). There was a different pattern for cellulose concentration in the two years. In 2007, the highest concentration of cellulose was observed during summer and autumn while in 2008, the concentration was higher during winter for mango tree (Figure 4.8). These results clearly indicated that there was a seasonal variation in the quality of leaf litter from the three tree species. Generally, there was higher concentration of polyphenols, lignin and cellulose in autumn. There were also differences in the concentration of polyphenol, ash, lignin and cellulose among the three tree species. Mango leaves had higher concentration of polyphenol and ash whereas litchi had higher concentration of lignin. In 2008, mango leaves had higher concentration of cellulose.

4.4.3.2 N, P, K and carbon content of leaf litter biomass

The result indicated that in 2007, nitrogen content in leaves was lowest in the autumn but increased in winter and reached its maximum in spring (Figure 4.9). In 2008, nitrogen was high during the spring but decreased thereafter to reach its lowest during winter (Figure 4.9). The pattern of phosphorus concentration mirrored that of nitrogen in both years. In 2007, the phosphorus concentration was highest during the spring and winter but decreased to the lowest in summer and autumn (Figure 4.9). In 2008, phosphorus was higher in spring and progressed to its lowest level in winter (Figure 4.9). The concentration of potassium in leaves of all species showed a similar pattern in both years (Figure 4.9). The concentration was high during spring, dropped thereafter and reached its lowest level in summer. The content of carbon in the leaves showed a similar pattern to that of nitrogen and phosphorus. There were very few differences among species in all the seasons of the study period (Figure 4.9). Avocado leaves had higher nitrogen and phosphorus concentration while litchi had high carbon content. In 2007, mango leaves had higher potassium concentration.

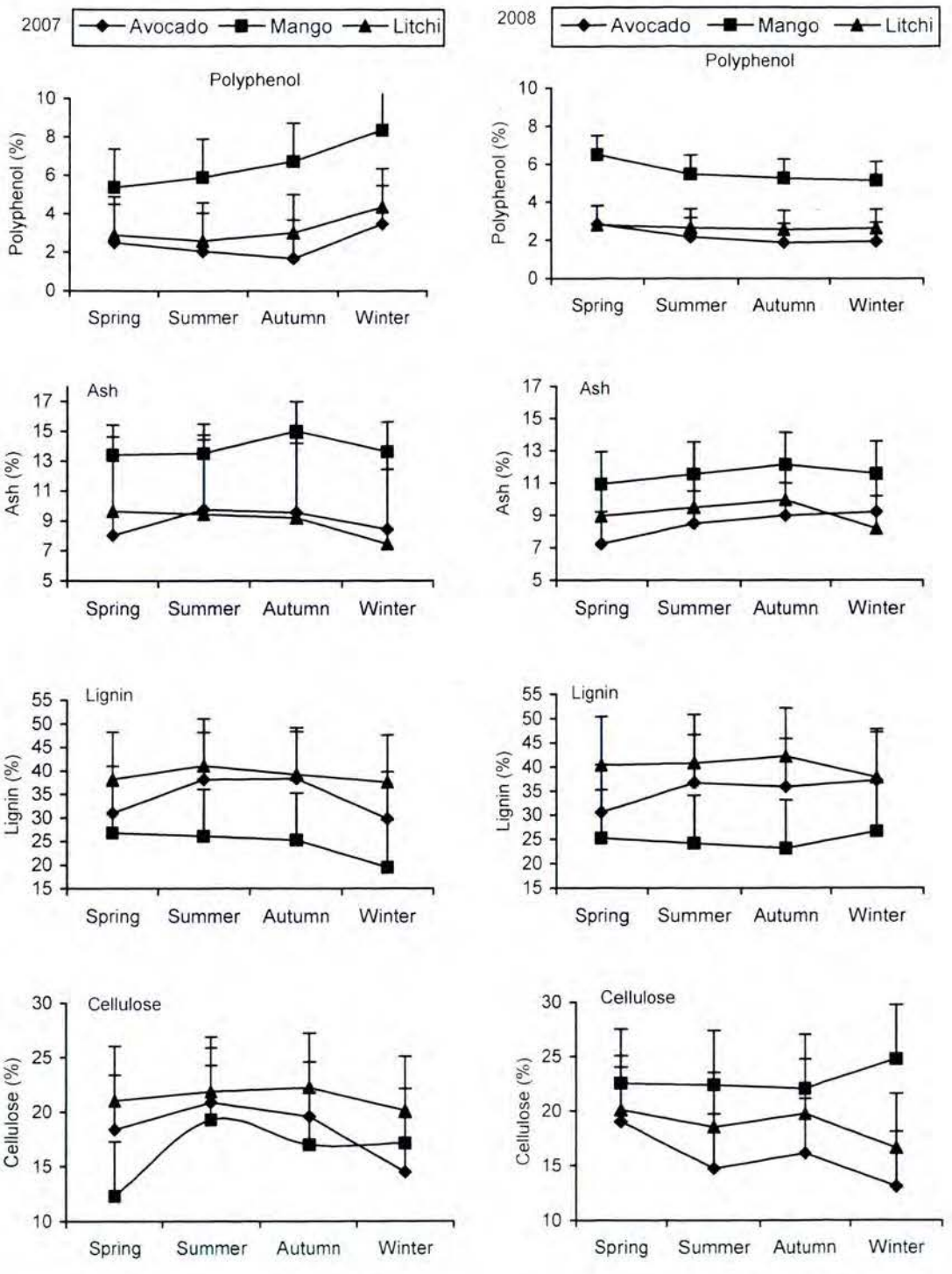


Figure 4.8 Seasonal variations in the concentration (%) of polyphenols, ash, lignin and cellulose in leaf litter biomass from sub-tropical fruit trees during 2007 and 2008. Vertical bars indicate standard errors.

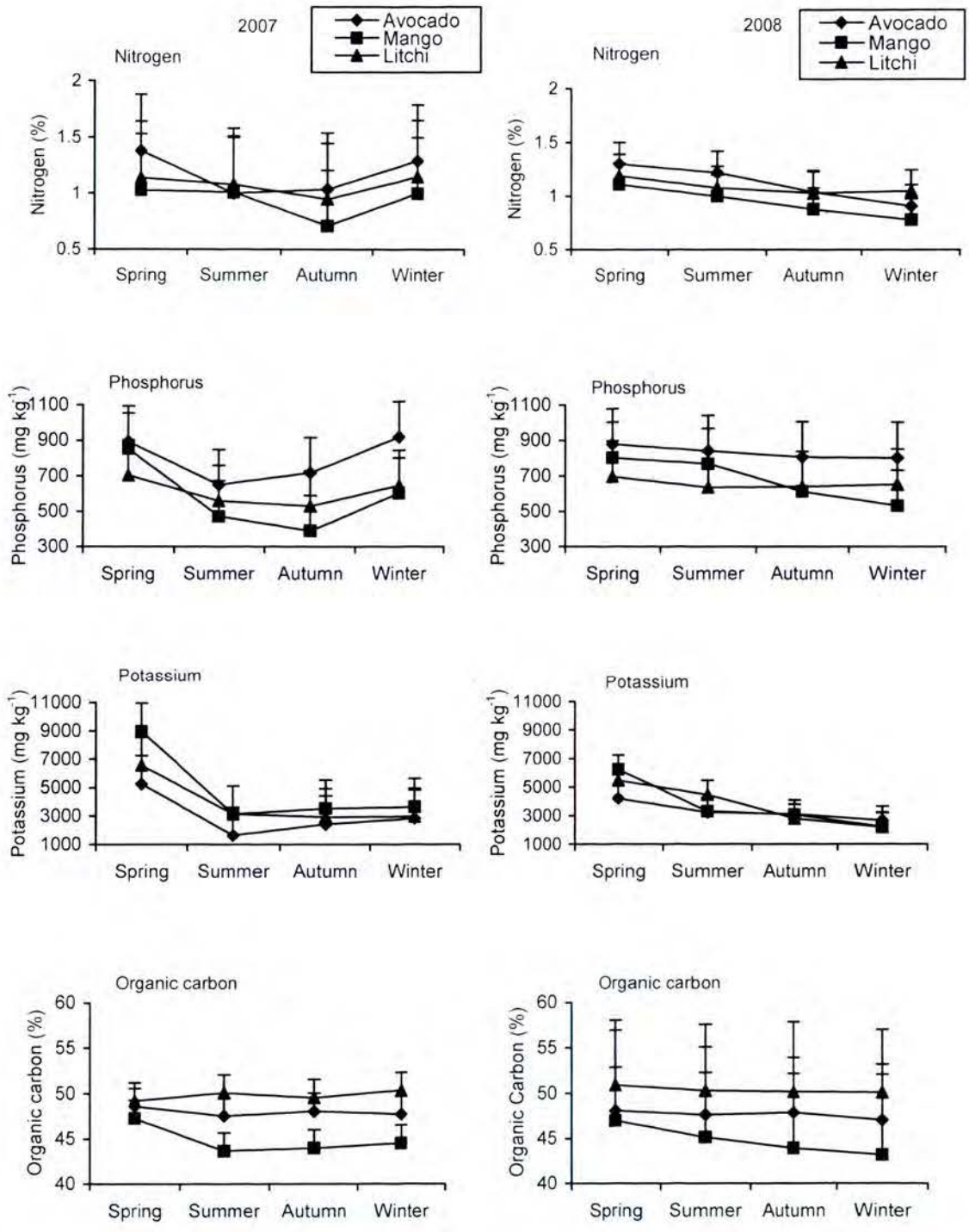


Figure 4.9 Seasonal variations in the concentration of nitrogen, phosphorus, potassium and organic carbon in leaf litter from sub-tropical fruit trees during 2007 and 2008. Vertical bars indicate standard errors.

4.4.3.3 Ca, Mg, S and C:N ratio of leaf litter biomass

The patterns of calcium concentration in the leaves of tree species were similar in both years (Figure 4.10). In 2008, the calcium concentration for all species rose steadily from spring to winter. There were no significant differences in the concentration of leaf calcium among the species except in the spring of 2007, when litchi leaves had higher calcium concentrations than mango leaves and avocado leaves. In spring of 2007 mango leaves had much lower concentrations of calcium than the spring of 2008. In both years, the trend in the concentration of magnesium in the leaves was consistently in the order avocado > litchi > mango. In avocado leaves, the highest magnesium concentrations were observed in winter. In general, the concentrations of magnesium in all three tree species followed a similar trend in both years. Highest concentrations of sulphur in the leaf litter biomass were recorded during spring and winter seasons. Mango leaves had the least sulphur concentration in all the seasons while avocado had the highest sulphur concentration (Figure 4.10). The patterns of C:N ratios in the leaves of three tree species were similar in both years and showed an increasing trend from spring to winter (Figure 4.10).

4.4.3.4 Zn and Mn content in leaf litter biomass

The concentration of zinc in the leaf litter displayed a similar pattern in 2007 and 2008. The general pattern was that the leaves had a higher zinc concentration in summer than spring, autumn and winter. In both years, mango leaves had the lowest zinc concentration during spring while in subsequent seasons the concentrations were not different (Figure 4.11). Litchi had much higher concentration of zinc compared to avocado and mango leaves. Manganese showed a similar trend in both years with the highest concentration in mango leaf litter compared to avocado and litchi leaf litter (Figure 4.11).

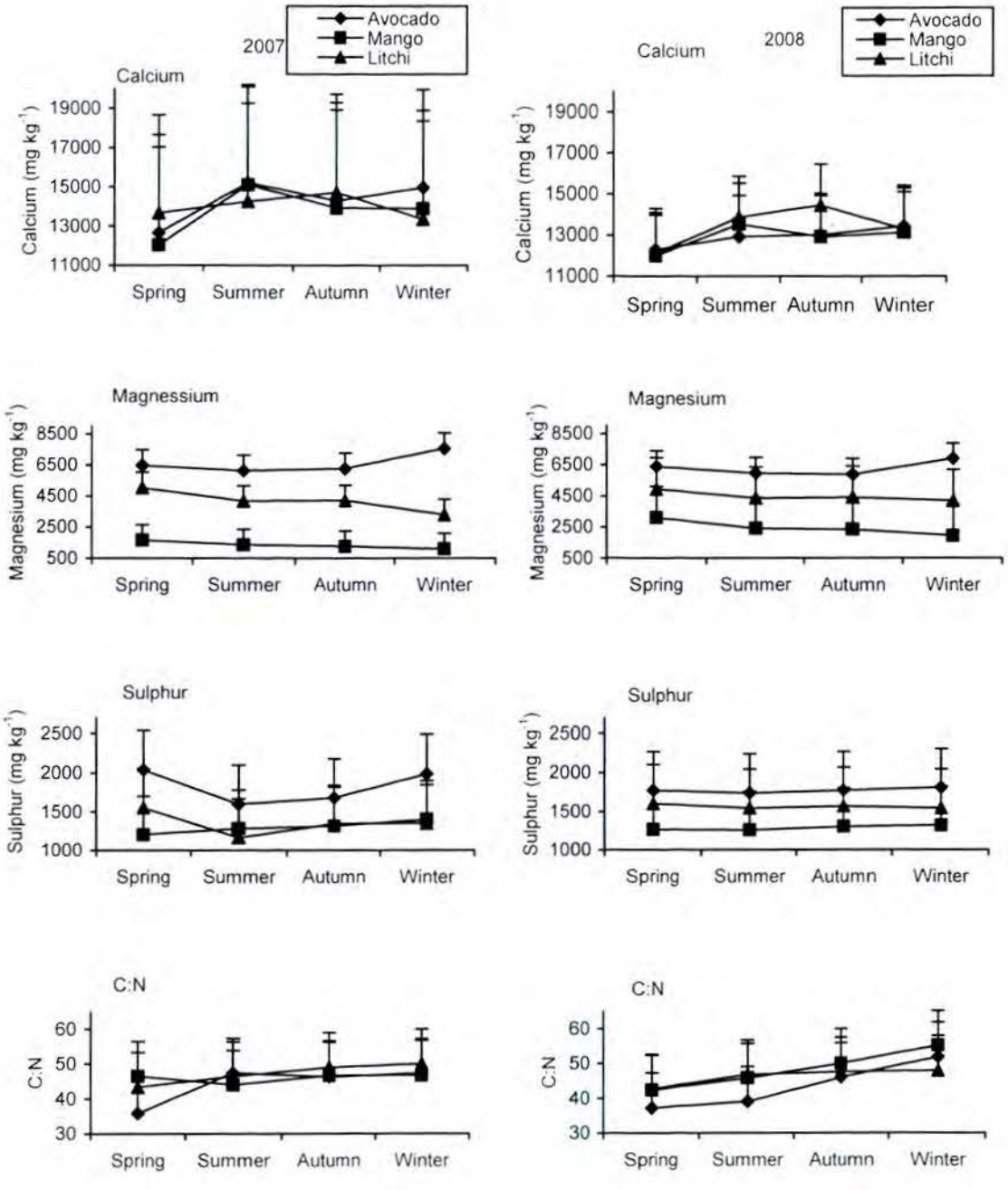


Figure 4.10 Seasonal variations in the concentration of calcium, magnesium, sulphur and C:N ratio in leaf litter biomass from sub-tropical fruit trees during 2007 and 2008. Vertical bars indicate standard errors.

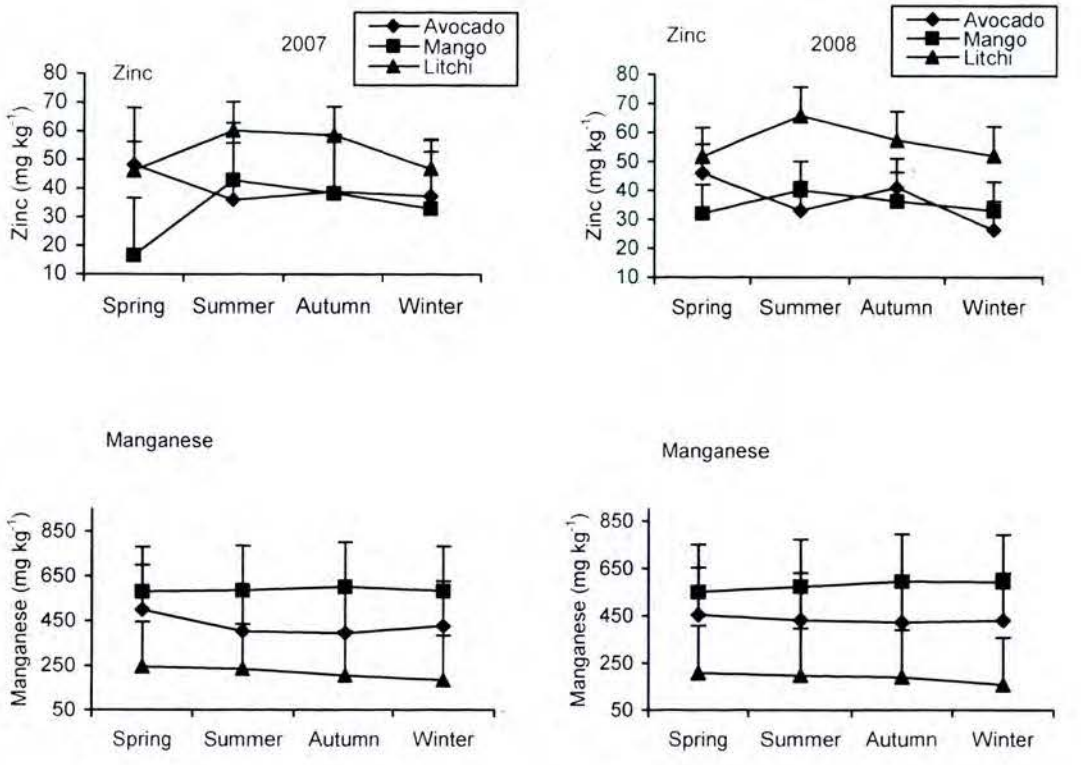


Figure 4.11 Seasonal variations in the concentration of zinc and manganese in leaf litter biomass from sub-tropical fruit trees during 2007 and 2008. Vertical bars indicate standard errors.

4.4.4 Relationships between litter quality, climatic elements, litter yield and seasons of the year

Correlation coefficients were calculated on pooled data for both two growing seasons and all tree species (Table 4.11). Most of the correlations between climate and quality variables were very weak. There were however some high correlations among the leaf quality variables which were significant. For example, there was a positive correlation between: nitrogen and carbon (r=0.57*). Negative correlation was observed between polyphenols and lignin (r=-0.86*), nitrogen and C:N (r=-0.95*), ash and magnesium (r=-0.80*), and polyphenols and magnesium (r=-0.85*). Polyphenols also showed a negative relationship with nitrogen (r=-0.41ns) and sulphur (r=-0.57*). Leaf litter yield was

negatively correlated with wind speed (r=-0.44) and positively correlated with air humidity (r=0.34). However, the negative relationship between wind speed and leaf litter yield was not expected in this study.

Due to possible masking of relationship in the pooled data, the species were isolated and the results were expressed as linear regressions and are summarized in Table 4.12. There are many relationships that could influence the litter quality. In avocado tree leaves, strong relationships were found between: lignin and phosphorus (r=0.73*); polyphenol and lignin (r=0.80*), nitrogen and C:N ratio (r=0.98*) In mango trees, strong relationships were found between: nitrogen and C:N (r=0.93*); potassium and carbon (r=0.82*). There was also a positive correlation between rainfall and mass (litterfall) from avocado (r=0.85*) and litchi (r=0.63*) tree species. Generally, polyphenols and lignin have strong relationships with other mineral elements which could have an influence on the quality of leaf litter biomass (Coldwell and Delong, 1950; Falconer *et al.*, 1932; Anderson, 1973; Suberkropp *et al.*, 1976; Cadisch and Giller, 1997).

Table 4.11 Pearson's correlation coefficients (r) between climatic elements, litter biomass yield, seasons and quality variables of leaf litter

	PP	Ash	N	C	C:N	Li	Cell	P	K	S	Ca	Mg	Zn	Mn	Mass
PP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ash	0.771*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N	-0.407	-0.718*	-	-	-	-	-	-	-	-	-	-	-	-	-
C	-0.686*	0.708*	0.567*	-	-	-	-	-	-	-	-	-	-	-	-
C:N	0.275	0.598*	-0.948*	-0.359	-	-	-	-	-	-	-	-	-	-	-
Li	-0.855*	-0.638*	0.266	0.849*	-0.082	-	-	-	-	-	-	-	-	-	-
Cell	0.243	0.215	-0.192	-0.100	0.135	-0.124	-	-	-	-	-	-	-	-	-
P	-0.400	-0.490*	0.618*	0.364	-0.599*	0.137	-0.198	-	-	-	-	-	-	-	-
K	0.314	0.220	0.280	0.089	-0.282	-0.251	0.069	0.256	-	-	-	-	-	-	-
S	-0.574*	-0.634*	0.597*	0.283	-0.528*	0.265	-0.581*	0.546*	-0.165	-	-	-	-	-	-
Ca	-0.163	0.111	-0.212	-0.109	0.179	0.180	-0.027	-0.278	-0.629*	0.167	-	-	-	-	-
Mg	-0.853*	-0.803*	0.590*	0.542*	-0.494	0.601*	-0.387	0.602*	-0.247	0.843*	0.185	-	-	-	-
Zn	-0.393	-0.369	0.211	0.616*	-0.046	0.596*	0.088	-0.094	-0.215	0.040	0.295	0.170	-	-	-
Mn	0.743*	0.762*	-0.417	-0.775*	0.298	-0.723*	-0.150	-0.509*	0.070	-0.271	0.187	-0.594*	-0.375	-	-
Mass	-0.069	0.096	0.225	0.101	0.295	0.142	0.261	0.043	-0.110	-0.249	0.014	-0.122	0.434	-0.167	-
Rain	-0.151	0.022	0.307	0.128	-0.342	0.107	0.229	0.098	0.410	-0.155	-0.068	0.024	0.064	-0.048	0.095
MaxT	-0.169	0.154	0.035	0.037	-0.070	0.178	0.277	-0.142	0.053	-0.274	0.256	-0.011	0.133	0.081	0.193
MinT	-0.190	0.070	0.142	0.076	-0.196	0.160	0.249	-0.229	0.168	-0.219	0.104	0.009	0.137	-0.022	0.252
Ws	0.165	-0.012	-0.146	-0.083	0.205	-0.130	-0.163	-0.058	-0.111	0.152	-0.042	-0.020	-0.189	0.090	-0.438
Hn	-0.221	-0.018	0.134	0.077	-0.202	0.154	0.192	0.030	0.163	-0.164	0.020	0.019	0.150	-0.113	0.343

* ($P<0.05$), ** ($P<0.01$)

Li (Lignin), Cell (Cellulose), PP (Polyphenol), MinT (Minimum temperature), MaxT (Maximum temperature), Hn (Air humidity), Ws (Wind speed), Mass (leaf litter yield).

Table 4.12 Linear regression relationships between leaf litter yield, litter quality and climatic elements

Tree specie	Variable	Regression	r^2	P>f
(a) Avocado	Ash vs Li	y = 3.6271x + 3.0697	0.7043	*
	Li vs P	y = 21.618x + 1564	0.725	*
	PP vs Li	y = -5.4854x + 47.375	0.8029	*
	N vs C:N	y = -35.283x + 83.103	0.9835	*
	K vs Mn	y = 0.0272x + 346.92	0.8849	*
	Rain vs mass	y = 0.024x – 42.458	0.8452	*
(b) Mango	Ash vs Cell	y = -1.8328x + 43.871	0.8175	*
	N vs C:N	y = -48.939x + 94.853	0.928	*
	C vs K	y = 1318.1x – 54650	0.8154	*
	Hn vs S	y = -8.7314x + 1903.7	0.5584	*
	AveT vs S	y = -13.027x + 15623	0.4931	*
	Rain vs S	y = -1.2031x + 1368.2	0.7206	*
(c) Litchi	Ash vs Mass	y = 78.996x – 540.45	0.7112	*
	N vs C:N	y = -37.471x + 87.134	0.9313	*
	Rain vs Mn	y = 0.541x + 169.68	0.6142	*
	Hn vs Li	y = 0.2817x + 19.966	0.6539	*
	AveT vs Li	y = 0.3923x + 31.559	0.5032	*
	Rain vs mass	y = 23.127x + 325.3	0.6315	*

* ($P<0.05$); Li (Lignin), Cell (Cellulose), PP (Polyphenol), Hn (Air humidity), AveT (Average temperature), Mass (leaf litter yield).

4.5 Discussion and conclusions

This study has revealed that the amount of leaf litterfall from the three tree species varied from one season to the other. In both years, litchi trees tended to produce higher litter biomass than the other two species. This difference could be attributed to the characteristics of the species such as age, height and the canopy size (Hudds, 1971; Vogt *et al.*, 1985). As trees grow older, they increase in size, produce more branches and more leaves (Osada and Takeda, 2003). Consequently, large and old trees produce more leaf litter compared to younger trees which may be smaller. The canopy of the litchi trees were larger (3.4 m) compared to those of the avocado (2.88 m) and the mango (2.62 m) trees. The size of the canopy determines the amount of leaf litter produced (Jung, 1970; Weil and Mughogho, 1993; Prescott, 2002). This has an influence on the amount of nutrients that can be recycled, the composition of the soil microbial and faunal

communities and the resulting availability of nutrients. Nyathi and Campbell (1993) found that a mango tree of 24 years produced more leaf litter compared to an 11 year old tree.

This study has found that the leaf litter yield varied between the two years of study except for litchi trees. High leaf litter produced by avocado and mango trees in 2008 is attributed to variation in climatic elements between the two years. In 2008, the total leaf litter of avocado trees was four times higher than that in 2007. This could be due to changes in orchard management practices such as irrigation and application of fertilizers. Before the start of the trial, the avocado orchard was neglected and the irrigation system was not working properly while mango and litchi orchards were under a proper management. This is in agreement with O'Connell and Grove (1993) who found lower litterfall in eucalypt trees deprived of nitrogen and phosphorus fertilizer in Australia. Although there was a variation in climatic conditions between the two years of the study, the relationship with leaf litter yield were weak. Several studies have found that at a local scale, with climatic conditions being relatively similar within a given area, the variation in litterfall is mainly due to species and age of the trees (Bray and Gorham, 1964; Stohlgren, 1988; Lu and Liu, 1988). However, there was a positive relationship between leaf litter yields and air humidity ($r=0.343$) while its relationship with wind speeds ($r=-0.438$) was negative. The negative relationship between leaf litter yield and wind speed was not expected in this study. There was also a significant positive correlation between rainfall and mass (litterfall) from avocado ($r=0.85^*$) and litchi ($r=0.63^*$) tree species. Several authors have implicated rainfall to litterfall (Gresham, 1982; Spain, 1984; Berg and Meentemeyer, 2001).

In terms of improving soil fertility, these results imply that farmers who have more litchi trees could collect more leaf litter throughout the year. The lower yield of leaf litter from avocado trees could be due to the structure and composition of its leaves. Avocado trees generally have larger but fewer leaves compared to litchi and mango leaves. Avocado leaves are very thin and can therefore withstand water stress which triggers leaf litterfall (Whiley *et al.*, 1988; Blanke and Lovatt, 1993). These reasons could explain why avocado trees produced lower litterfall biomass compared to mango and litchi trees.

In all the tree species, leaf litterfall showed a seasonal peak during the autumn but fell to its lowest value during the winter season. This is a common phenomenon for most tropical and sub-tropical trees (Weng *et al.*, 1993; Zheng *et al.*, 1995). Similar patterns in leaf litterfall have been reported by Jha and Mohapatra (2009) who found that *Leucaena leucocephala* and *Acaci nilotica* had maximum leaf litterfall in autumn. Liao *et al.* (2006) recorded low amount of litterfall during spring and higher amount in autumn. They attributed the high amount of litterfall in autumn to strong winds and typhoons that occurred during the study period. Similar studies from evergreen broadleaved forests have also demonstrated the same litterfall pattern (Lu and Liu, 1988; Tu *et al.*, 1993; Weng *et al.*, 1993; Zheng *et al.*, 1995). In this study, the wind speed during autumn was highest compared to the other seasons and could therefore have influenced litterfall. The seasonal variation in leaf litterfall could also be attributed to differences in climatic conditions among the seasons, particularly higher temperatures which stimulated abscisic acid synthesis in plant foliage and which in turn stimulates leaf senescence (Woodhouse, 1978; Addicott, 1982). In the Nelspruit area, autumn is a transition between summer and winter and is characterised by declining rainfall, temperature and air humidity. According to Perry (1971), these changes in climatic features serve as a warning to the tree to prepare itself for the drier period. In response, most trees shed their leaves and go into a dormant state.

The results of this study revealed a wide variation in the concentration of nutrients and other organic compounds in the leaf litter from different tree species that were studied. Polyphenol and lignin content were mentioned by many authors as the major variables that influence the quality of leaf litter since they plays a vital role in the decomposition and nutrient release from decomposing materials. Avocado tree leaf litter showed a higher quality (low polyphenols, low lignin, low C:N and high nitrogen) than mango and litchi trees. However, the content of these quality factors were lower than those suggested by Palm *et al.* (2001) in the Decision Tree Support System (Table 4.13). The variation in leaf litter quality among the three tree species was attributed to tree phenological factors such as the nutrient uptake ability of the tree and nutrient re-translocation efficiency (Nambiar and Fife, 1991; Wang *et al.*, 2003). Since the trees used in this study received almost similar amounts of fertilizers and water and thus could not affect the quality. The metabolism of the three tree species could be completely different and thus affect the quality. Based on the DSS, the litter type from the three tree

species that were studied here, it can be suggested that that the leaf litter must be mixed with fertilizer or compost before it is applied or incorporated into the soil. Another option is to apply the leaf litter on the soil surface for erosion and water control.

Table 4.13 A comparison of the leaf litter quality of three fruit tree species to the limit for high quality litter according to the DSS*

Species	Parameters (%)				
	Polyphenol	Lignin	Nitrogen	Carbon	C:N
Persea americana	2.31a	34.7a	1.15a	42.6a	47.8a
Mangifera indica	6.09b	24.6b	0.94b	49.0b	44.8b
Litchi chinensis	2.94c	39.7c	1.08a	46.5b	50.1c
*DSS**	**> 4**	**> 15**	**< 2.5**	**N/A**	**> 25**

* = Decision Support System for managing organic resources (Palm *et al.*, 2001)

As was the case with the yields, the quality of the leaf litter showed seasonal variability. A marked seasonal variability was observed in the leaf concentrations of polyphenols, N, P, and K but not for S, Ca and Mg. The lack of changes in the concentration of Ca and Mg could be because they are less mobile within the tree compared to nutrients such as nitrogen, phosphorus and potassium (Shelp, 1987). Palm *et al.* (2000) recorded high concentrations of nitrogen and potassium in leaves during spring and lowest amounts in winter season. Similar results have been reported for avocado trees in California by Bingham (1961). Fernandez-Escobar *et al.* (1999) found high leaf concentration of nitrogen in olive trees during the autumn.

The seasonal changes in the concentration of N, P, K and Zn observed in this study could be attributed to differences in the re-translocation of these nutrients before abscission. In Australia, Menzel and Simpson (1990) reported that the concentration of N, P and K in litchi tree leaves decreased after harvest and during the autumn flush. Other authors have found that mineral nutrients such as N, P, and K increased when the leaf was in developing stage and declined thereafter (Whitney *et al.*, 1990; Singh *et al.*, 1999). They explained this to be partly because of the increasing proportion of cell wall structures and partly because there is translocation of nutrients out of the leaves before senescence

(Chapin and Kedrowssky, 1983; Pugnaire and Chapin, 1993). The re-translocated nutrients are mobilized again in the spring to help build new tissues (Saur *et al.*, 2000). The observed seasonal variation of leaf litterfall and quality implies that different amounts of nutrients will be added into the soil at different times and at different rates and suggests that soil fertility improvement through leaf litterfall can be expected to be at its maximum during the autumn season.

The study has revealed that high yield of leaf litter compromises its quality. Large amounts of leaf litter were collected in autumn. The leaf litter that was collected in autumn was of poor quality in the sense that it had high polyphenols, high lignin, high cellulose and low nitrogen content. The quality and quantity of leaf litter biomass will influence its contribution to soil nutrients. Several studies have shown the effects of litter quality on decomposition and nutrient release (Cadisch and Giller, 1997; Mapfumo and Giller, 2001). Poor litter quality decomposes and releases nutrients slowly which can have a negative impact on crop productivity. It was found in this study that variables such as polyphenols, lignin, cellulose, C:N have an influence on the quality of leaf litter. For example, there was a negative significant relationship between nitrogen in leaf litter and C:N ratio meaning that when nitrogen increased, the C:N ratio decreased which symbolised good quality in terms of decomposition. According to the DSS, materials with low nitrogen (<2.5%), high polyphenols (>4%) and high lignin (>15%) can be mixed with fertilizers or applied on the soil surface for controlling erosion and reducing soil moisture loss (Palm *et al.*, 2001). In terms of contributing to soil nutrients, litterfall studies can assist in estimating the amounts of nutrients that can be added to the soil from the litterfall. Due to the litter quality variations, small scale farmers can mix leaf litter from these three tree species in order to synchronize the nutrient release and nutrient crop demand. Farmers can also make separate heaps of leaf litter manure from different seasons.

The study concluded that litterfall differed significantly among the three sub-tropical fruit tree species studied and varied with seasons within the year. This variation is attributed to both the genetic and physiological make up of the trees and climatic elements. High wind speed in autumn contributed to a larger litterfall biomass compared to the other seasons. The quality characteristics of the litterfall also changed with seasons within a year. Avocado leaves had better chemical qualities compared to litchi and mango leaves

implying that avocado leaf litter can be decomposed and release available nutrients faster than that from the other tree species. It is recommended that further studies concerning leaf litter decomposition, nutrient release pattern and nutrient uptake by vegetables and field crops need to be investigated. This information will help in making good decisions on the utilization of leaf litter collected from sub-tropical fruit trees for soil fertility management particularly by small scale farmers.

CHAPTER FIVE

DECOMPOSITION AND NUTRIENT RELEASE FROM LEAF LITTER BIOMASS OF THREE SUB-TROPICAL FRUIT TREES AT NELSPRUIT, MPUMALANGA PROVINCE

5.1 Introduction

The decomposition of leaf litter biomass is the main process by which nutrients are recycled in the major ecosystems of the world such as forest and savannas. Decomposition is a process whereby organic residues are physically broken down and the constituent nutrients released into the soil (Swift *et al.*, 1979). As organic materials get broken down by insects and microbiological decomposers, organically-bound nutrients are released as free ions to the soil solution which are then made available for uptake by plant roots (Lynch, 1984). The recycling of nutrients by decomposition has received much attention because of its significance as a sustainable way of managing soil fertility (Woomer and Swift, 1984; Palm, 1995; Mapfumo and Giller, 2001), and improving productivity in forest ecosystems (Van Noordwijk and Ong, 1999). However, management strategies of maintaining soil fertility using organic resources in agroecosystems is still lacking for the vast majority of small scale farmers in South Africa. This can be attributed to poor understanding of the manner in which organic materials decompose and release nutrients into the soil.

The release of nutrients from decomposing leaf litter biomass is influenced by many factors including temperature, soil moisture, and decomposer community and leaf litter quality (Swift *et al.*, 1979; Cadisch and Giller, 1997). The influence of litter quality on decomposition has received much attention because it serves as substrate for microorganisms which are involved with the decomposition (Mapfumo and Giller, 2001). Litter quality has been defined as the concentration of nitrogen, lignin, polyphenols, and C:N ratio of the organic biomass (Moorhead *et al.* 1999). If properly managed, the release of nutrients from plant litter can be manipulated in such a manner that it supplies nutrient to the growing crops at the right time. Several management practices to manipulate litter decomposition and nutrient release have been proposed and include: mixing litter of different qualities, a proper timing of litter application so that nutrient release coincide with crop demand (synchronization), mixing leaf litter with high quality

amendments such as animal manure, and choice of leaf litter application methods. The timing of leaf litter application can be synchronized with nutrient release and crop demand. Leaf litter quality has been reported by many authors as the most important factor that controls the decomposition and release of nutrients from plant litter (Swift *et al.*, 1979; Cadisch and Giller, 1997; Mafongoya *et al.*, 1998; Mapfumo and Giller, 2001). There are several methods or indices that have been suggested to predict the rate at which organic materials decompose and release nutrients (Cadisch and Giller, 1997). Consequently, parameters such as carbon, nitrogen, polyphenols, lignin and their ratios have been suggested as the best predictors of litter decomposition (Taylor *et al.*, 1989; Meentemeyer, 1978; Melillo *et al.*, 1982).

As has been indicated in Chapter Four of this thesis, the climate of the Ehlanzeni District Municipality encourages growth of sub-tropical fruit trees which shed their leaves during autumn every year. The mean annual amount of leaf litter that is produced by the three trees species investigated has been estimated in Chapter Four to be about 6433 kg ha^{-1} $year^{-1}$. This litter biomass has a potential to be utilized by small scale farmers in providing nutrients for their field grown food crops. In order to maximize the utilization of this resource, however, there is need to understand their decomposition and nutrient release patterns. This knowledge is important in order to enable farmers to make decisions regarding the time at which the biomass should be incorporated for optimum nutrient uptake by plants. There is therefore the need for the decomposition and nutrient release from this litter to be quantified. Another reason for understanding decomposition is that farmers can synchronize decomposition with the peak period of crop demand as suggested by Nair (1993) and Palm and Sanchez (1991). The objectives of the study reported in this chapter were to:

1) Determine the decomposition rate of leaf litter from three sub-tropical tree species found in the EDM;

2) Determine the nutrient release (mineralization) patterns during decomposition of the leaves of the tree species.

5.2 Literature review

5.2.1 Decomposition of leaf litter biomass

Decomposition is a process whereby organic residues are physically broken down and the component nutrients are released (Swift *et al.*, 1979). Plant litter decomposition plays an important role in determining carbon and nutrient accumulation, as well as the rate and timing of nutrient release in forms available for uptake by plants. Litter decomposition and nutrient dynamics are determined to varying degrees by litter quality, temperature, moisture, soil texture, microbial and faunal activity (Buckman and Brady, 1969). Decomposition involves not only mass loss but also changes in the nutrient content of plant litter and the eventual release of nutrients thereafter. Decomposition involves leaching of soluble organic and inorganic components, catabolic breakdown of organic matter, and communition or physical fragmentation of the litter (Swift *et al.*, 1979). These processes ultimately transform senescent organic plant materials into both labile and stable organic matter (Swift *et al.*, 1979).

5.2.2 Factors influencing litter biomass decomposition

The factors that regulate litter decomposition have been identified as (i) climatic factors such as mean annual temperature, mean annual precipitation and annual actual evapotranspiration (Moore, 1986; Meentemeyer and Berg 1986; Dyer *et al.*, 1990; Aerts, 1997; O'Neill *et al.*, 2003); (ii) litter quality, such as nitrogen content (Yavitt and Fahey, 1986), carbon:nitrogen ratio (Edmonds 1980; Berg and Ekbohm 1991), lignin content (Gholz *et al.*, 1985) and lignin:nitrogen ratio (Aerts, 1997; Waring and Schlesinger, 1985); (iii) vegetation and litter types (Gholz *et al.*, 1985; Prescott *et al.*, 2000) and (iv) geographical variables such as site latitude and altitude (Aerts, 1997; Silver and Miya, 2001).

The quality and quantity of carbon in leaf litter plays an important role in the decomposition process since it is the source of energy for microbial organisms that are responsible for the decomposition of organic materials (Swift *et al.*, 1979; Cadisch and Giller, 1997; Mafongoya *et al.*, 1998). The quality of carbon of organic materials depends on the proportions of soluble carbon, cellulose and lignin. The amount of

soluble carbon compounds also determines the immediate nutrient mineralization or immobilization pattern. If there is a large amount of soluble carbon but little soluble nitrogen, net immobilization will occur, which in turn renders nitrogen unavailable for plant use (Aber and Melillo, 1991).

In agroecosystems, decomposition of leaf litter biomass differs from that in natural ecosystems because of differences in the types and quality of organic inputs. For example, litter differs from green foliage or leaves in that much of the soluble carbon compounds and nutrients are translocated from leaves during senescence, prior to abscission and leaf fall (Constantinides and Fownes, 1994). According to Mafongoya *et al.* (1998) tree foliage and litter contain about 60-67% cellulose, 10-25% lignin, 15-25% soluble carbon, 1.5-3.5% nitrogen and 0.002-0.05% phosphorus.

Lignin is considered by many to be the most important component of leaf litter that determines the rate of decomposition (Meentemeyer, 1978; Mafongoya *et al.*, 1998). It has been suggested that 15% lignin is a critical level above which decomposition is impaired because lignin protects the cellulose in the cell wall from attack (Chesson, 1997; Palm and Rowland, 1997). The percentage of lignin in leaves of agroforestry species varies widely, ranging from 5% to 20% of dry weight in green foliage and from 10% to 40% in leaf litter. Polyphenols comprise a relatively small percentage of the organic material but have a disproportionate effect on decomposition (Vallis and Jones, 1973). Many studies have shown negative relationships between polyphenolic content and nitrogen release (Martin and Haider, 1980; Palm and Sanchez, 1991; Constantinides and Fownes, 1994; Handayanto *et al.*, 1994). Furthermore, the soluble condensed tannins can react with nitrogen and amino groups in the plant or soil solution, reducing nitrogen release (Mafongoya *et al.*, 1998). Handayanto *et al.* (1994) found that condensed tannins can react with nitrogen to form very strong bonds which in some cases render nitrogen indefinitely unavailable. The bound condensed tannin may slow down decomposition by binding to the cell wall and protein, making them physically or chemically inaccessible to the decomposer organisms.

5.2.3 Indices for predicting nutrient release pattern

Several methods have been proposed by researchers to predict litter decomposition and nutrient release (Palm and Sanchez, 1991; Tian *et al.*, 1992a; Mtambanengwe and Kirchman, 1995). According to Mafongoya *et al.* (1998), the main objective of developing the indices was to identify parameters that predict decomposition and nutrient release, and to avoid the need for detailed studies of decomposition of various plant materials in every location. The indices could also facilitate the screening of agroforestry trees for their nutrient-supplying capacity, and improve understanding of controls needed in nutrient cycling. The indices could also be used to model soil fertility changes, including soil organic matter dynamics in systems where plant litter is applied as a source of nutrients for a long time.

The indices that are used to predict litter decomposition include ratios of carbon to nitrogen (C:N), polyphenols to nitrogen (PP:N), lignin to nitrogen, and polyphenols + lignin to nitrogen (PP+Li):N. These indices depend on the time under consideration and the type of materials. For example, over a short-term, Palm and Sanchez (1991) found that nitrogen mineralization was negatively correlated with PP:N for foliage with high nitrogen content. Contantinides and Fownes (1994) suggested that over a long-term, (PP+Li):N was a better predictor of nitrogen release. Moreover, the (PP+Li):N ratio has been found to be the most robust index to predict mass loss and nitrogen release pattern in most agricultural systems. Materials with a (PP+LI):N ratio of less than 10 release nitrogen quicker (Mafongoya *et al.*, 1998). Melillo *et al.* (1989) recommended Li:N as a better decomposition predictor for litter biomass which have lower nitrogen and higher lignin content. With the exception of studies done by Sandhu *et al.* (1990), Tian *et al.* (1992b) and Mtambanengwe and Kirchman (1995), C:N ratio was found to be a poor predictor of decomposition and nutrient release in most agroforestry systems (Mafongoya *et al.*, 1998).

5.2.4 Management of decomposition and nutrient release processes

Nutrient release from litter biomass and its synchrony with crop uptake can be influenced by management. There are several management options for manipulating decomposition and nutrient release patterns (Mafongoya *et al.*, 1998). These include the timing of biomass application and the incorporation of biomass into the soil, which accelerates decomposition while surface application provides protection of the soil surface from erosion. Of interest is also the possibility of mixing different litter types, such as recalcitrant materials, which provide long-lasting surface mulch, with high quality materials, which decompose and release nutrients rapidly (Palm *et al.*, 2001). Biomass may also be applied together with mineral nutrient sources to overcome nutrient imbalances (Palm *et al.*, 2001).

The degree to which leaves are chopped and mixed will determine the immediate accessibility of their components to microbial attack, and may reduce the amounts of nutrients that are readily lost through leaching or for plant uptake. Fine grinding of plant residues has been shown to enhance decomposition of materials with high C:N ratio (Jensen, 1994). Application of fresh leaf litter directly into soil without drying them results in faster decomposition and can result in greater nitrogen recovery by crops (Wilson *et al.*, 1986). Mafongoya *et al.* (1998) found greater maize yields when fresh, rather than sun-dried prunings of *Flemingia macrophylla* were applied in the field.

Incorporation of leaf litter into the soil results in faster decomposition because there is more intimate contact between leaf litter and the soil particles, and the litter is maintained in a moist environment that is more favourable for decomposition (Wilson *et al.*, 1986). Incorporation of leaf litter into the soil results in a higher bacteria dominated microbial community, while fungi dominate with surface placement (Holland and Coleman, 1987). Such differences in the composition of the microbial community can influence nutrient dynamics and soil organic matter formation because of differences in the efficiency of carbon assimilation and carbon-to-nutrient ratios of bacteria and fungi (Mafongoya *et al.*, 1998). Wilson *et al.* (1986) reported more rapid decomposition and greater nitrogen recovery of *Leucaena leucocephala* and *Gliricidia sepium* pruning when they were incorporated into the soil. The timing of leaf litter application can be varied to help synchronize nutrient release and crop demand. Mulongoy *et al.* (1993) showed the

advantages of applying low-quality leaf litter two to four weeks before planting to allow sufficient time for decomposition.

5.2.5 Methods of determining litter decomposition and nutrient release

Many methods have been developed to determine plant litter decomposition and nutrient release rates (Swift *et al.*, 1979; Zaharah and Bah, 1999). However, the methods used to determine decomposition and nutrient dynamics vary for different types of plant litter. Although several studies have recommended the litterbag method for studying decomposition, it is significant to briefly highlight other potential methods. In general, the litterbag method is used as the standard protocol for determining the rate at which litter decomposes and accumulates or releases nutrients (Swift *et al.*, 1979). In the litterbag method, pre-weighed material is confined within the mesh bags and changes in mass, nutrient content and carbon chemistry are measured overtime (Bocock *et al.*, 1960; Swift *et al.*, 1979). This method excludes macro invertebrates, which are important elements of the decomposer community in many ecosystems. The litterbag can alter the microclimate within the bag by slowing drying rates (Witkamp and Olson, 1963) and can reduce the rates of fungal hyphal colonization and growth (St. John, 1980).

Although the litterbag method has limitations, it is highly repeatable, relatively inexpensive, and widely used (Zaharah and Bah, 1999). Several types of litterbag systems have been used in the past, most differing in the size of the mesh used to contain the litter (Lousier and Parkinson, 1978; Edmonds, 1980; Berg *et al.*, 1984; Aber *et al.*, 1990). The litterbag method can be used for fine roots, leaves, twigs, reproductive parts and small bark fragments. Data generated from litterbag studies, can be presented as the percentage of initial mass remaining overtime. Decomposition curves can also be mathematically described (Jenny *et al.*, 1949; Olson, 1963). Percent mass remaining from individual litterbags can be averaged, and mean percent remaining overtime can be plotted, by treatment or litter type, and used to calculate decomposition rate constants.

Litter baskets are another method used to determine litter decomposition in forest ecosystems. In this method, litter materials are confined between a fine mesh bottom and a coarse mesh hardware-cloth to allow access by macro invertebrates (Blair *et al.*, 1991). The shortfall with this method is that the potential input addition may restrict the

interpretation to areas with relatively large leaves (e.g. broadleaf forest). A tether is another method which leaves materials completely exposed (Witkamp and Olson, 1963). The problem with this method is the fact that while exposed to invertebrates and natural microclimatological conditions, it is subject to high rates of fragmentation, which can overestimate decomposition. A chronosequence approach, in which annual accumulation of layers are separated and analyzed for change in mass, nutrient content, particle size and type has been used (Kendrick, 1959). This approach can yield extremely interesting information. However, there must be clear indicators to mark the annual layers, and one must assume that annual rates of litterfall are constant and that mixing of the layers is minimal.

There are several other available models to which mass loss and nutrient release data can fit (Olson, 1963; Minderman, 1968; Wieder and Lang, 1982; Andren and Paustain, 1987). The most common and simplest of these is the single negative exponential model (Jenny *et al.*, 1949; Olson, 1963) of the form:

$$Xt/Xo=e^{-kt} \quad \textbf{(5)}$$

Where: Xo and Xt are the mass or quantity of nutrient at the beginning of the experiment and after time t, respectively, and k is the decomposition constant. The time after which the material loss halves its initial mass is obtained as:

$$t_{½} = \text{In } 2/k. \quad \textbf{(6)}$$

where:

t is the time and, k is the decomposition constant

In cases where biomass consists of fractions that decompose and release their nutrients rapidly, and other most recalcitrant ones, double or higher exponential models have also been used that have coefficients for the proportion of material in each fraction and their respective decay constants (Wieder and Lang, 1982). Nutrient release from decomposing litter is usually measured by collecting litter samples from litterbags or tether at intervals and then measuring their weight and nutrient concentrations and expressing it relative to the initial values. Alternatively, nutrient release from undisturbed litter can be monitored by collecting the leachate beneath the litter with trays or funnels and subtracting the nutrient input in rainfall or throughfall (Wood and Raison, 1982).

5.3 Materials and methods

5.3.1 Location of the study site and soil type

The study was conducted at the ARC-ITSC experimental station in Nelspruit. The station was established in 1926 and has conducted research on tropical and sub-tropical fruit trees ever since. The site selected for the decomposition study has, however, not been cultivated for the past twenty years. The surface was covered with a layer of grass and a few shrubs. The dominating grasses were *Panicum maximum*, *Urochloa mozambicencis and Cynodon dactylon*. The site is characterized by a deep red yellow brown soil classified as Hutton series (Soil classification working group, 1991). The soil profile showed two distinct A and B horizons. The A horizon extended from 0 to 300 mm while the B horizon extended from 300 mm to 1000 mm. The structure of the soil is weak while the texture consisted of 78% sand, 12% silt and 10% clay (ARC-ITSC, 2007).

5.3.2 Land preparation and soil sampling

In September 2006, the site was ploughed using a disc plough to a depth of about 300 mm. This was followed by disc harrowing in order to level the soil surface and to remove coarse roots, grasses, leaves and twigs. About three months later (January 2007) soil samples were collected randomly across the field using a bucket auger 6.5 cm in diameter. Ten sub-samples were collected at 100 mm depth. The sub-samples were thoroughly mixed to form a composite sample of about 5 kg soil. The bulk soil was air dried and sieved through a 2.0 mm sieve and stored in plastic bags for analysis.

5.3.3 Collection of leaf litter

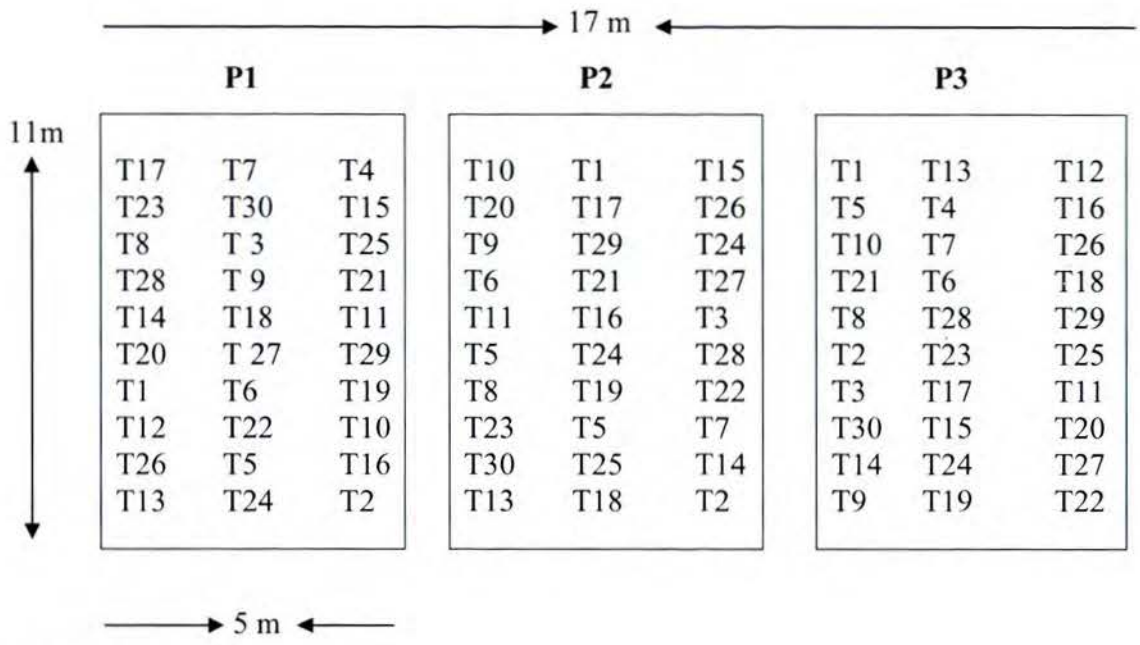
Leaf litter biomass used in the study was collected during spring and summer 2007 from the same trees that were used in the litterfall study reported in Chapter Four (section 4.3.5). In the laboratory, the leaves were gently rinsed with distilled water to remove soil particles and debris, and were oven-dried at 65°C for 72 hours. A sample of the leaf litter was drawn from the composite sample and ground to pass through 1.0 mm sieve. This sample was analyzed to establish initial quality of the litter using the same procedures reported in Chapter Four (Section 4.3.5).

5.3.4 Construction and filling of litterbag

Decomposition of litter biomass was determined by using the litterbag technique similar to that of Swift *et al.* (1979). Litterbags measuring 20 x 20 cm were made from black polythene net with 1.0 mm screen openings. The mesh size allows easy movements of microorganisms in and out of the net. For each of the three sub-tropical tree species, ten grams of leaf materials were placed into each bag. A total of 90 bags were filled with dried leaf litter from the three species.

5.3.5 Incorporation of litterbags into the soil

On the 10th February 2007, the study site was ploughed again using a disc harrow in order to loosen the soil and to remove weeds which had started to grow. After ploughing, the land was divided into three plots measuring 5 x 11 m each (Figure 5.1) with 1.0 m between the plots. Litterbags were buried on the 14th of February 2007. Within each plot, ten litterbags from each of the three tree species were randomly buried in rows to 10 cm depth at a distance of 0.5 m apart. A plastic tag of about 45 cm height containing the name of the treatment, retrieval date of each litterbag and plot number was installed next to each litterbag (Figure 5.2). The soil was kept free of weeds during the period of incubation. A rain gauge was mounted on a pole and was installed in the middle of the decomposition plots. Three soil thermometers were also installed to 10 cm depth in the middle of each of the three plots in order to measure soil temperature. Rainfall, maximum and minimum soil temperatures were recorded daily for two years during the period of study (February 2007/8–January 2008/9). The daily readings for each growing seasons were aggregated to obtain monthly means.



P = plot number

Figure 5.1 Field lay-out of the litterbag study



Figure 5.2 Field lay-out of the decomposition trial at Nelspruit

5.3.6 Treatment and experimental design

The treatments consisted of combination of three tree species namely avocado (*Persea americana*), mango (*Mangifera indica*) and litchi (*Litchi chinensis*) with 10 retrieval days (14, 28, 42, 88, 134, 180, 226, 272, 318 and 364) as shown in Table 5.1. The retrieval days were structured in such a way that it covers one year period. Each treatment was replicated three times and laid in a completely randomized design.

5.3.7 Retrieval of litterbags

Litterbags were retrieved from the plots at 14, 28, 42, 88, 134, 180, 226, 272, 318 and 364 days after incorporation. Three litterbags of each tree species were retrieved on each retrieval day. After recovery of the litterbags, the leaves were gently rinsed with de-ionized water to remove any adhering soil particles, dried in the oven at 65°C for 72 hours and weighed. Leaves which were retrieved from each sampling date were ground in a Wiley mill to pass through 1.0 mm mesh and analyzed for polyphenols, lignin, cellulose, ash, carbon and nutrient elements using the methods outlined in Chapter Four (section 4.3.5)

5.3.8 Determination of decomposition and nutrient release from the litter

Decomposition of leaf litter was determined by calculating the loss in mass of the leaves during the time of incorporation. This was done by using a single exponential decay function defined by Jenny *et al.* (1949) as:

$$[((W0 - W1)/W0)] \times 100 \quad \textbf{(7)}$$

where:

W0 = weight of leaf litter in the bag before burial,

W1 = weight of leaf litter after a certain period of time.

The decomposition constant (k) for the litter biomass of each species during the time of decomposition was calculated as:

$$Xt/Xo = e^{-kt} \quad \textbf{(8)}$$

Where:

Xo = Original dry mass of leaf litter

Xt = Leaf litter dry mass remaining after time t

t = Time interval of sampling Xt

k = Decay coefficient (Olson, 1963)

Release of nutrients from litter biomass was determined by measuring the amount of nutrient in the decomposing leaf litter in the litterbag.

Table 5.1 Treatment combinations used in the study

Treatment	Combination	Description
T1	S1 T1	Avocado, 14 days
T2	S2 T1	Mango, 14 days
T3	S3 T1	Litchi, 14 days
T4	S1 T2	Avocado, 28 days
T5	S2 T2	Mango, 28 days
T6	S3 T2	Litchi, 28 days
T7	S1 T3	Avocado, 42 days
T8	S2 T3	Mango, 42 days
T9	S3 T3	Litchi, 42days
T10	S1 T4	Avocado, 88 days
T11	S2 T4	Mango, 88 days
T12	S3 T4	Litchi, 88 days
T13	S1 T5	Avocado, 134 days
T14	S2 T5	Mango, 134 days
T15	S3 T5	Litchi, 134 days
T16	S1 T6	Avocado, 180 days
T17	S2 T6	Mango, 180 days
T18	S3 T6	Litchi, 180 days
T19	S1 T7	Avocado, 226 days
T20	S2 T7	Mango, 226 days
T21	S3 T7	Litchi, 226 days
T22	S1 T8	Avocado, 272 days
T23	S2 T8	Mango, 272 days
T24	S3 T8	Litchi, 272 days
T25	S1 T9	Avocado, 318 days
T26	S2 T9	Mango, 318 days
T27	S3 T9	Litchi, 318 days
T28	S1 T10	Avocado, 364days
T29	S2 T10	Mango, 364 days
T30	S3 T10	Litchi, 364 days

T = Retrieval time; S1 = Avocado; S2 = Mango; S3 = Litchi

5.4 Data analysis

The data were subjected to analysis of variance (ANOVA) performed using a General Linear Model (GLM) of SAS (SAS Institute Inc, 1990). The means were compared using the Tukeys' multiple comparison tests where significant differences were found. Linear regressions were calculated in order to determine the relationships between leaf litter quality, time of litter incorporation and climatic elements.

The model used for the ANOVA was:

$$Yijkl = \mu + Gi + Sj + Tk + (GS)ij + (LT)jk + (GST)ijk + Eijkl \quad (9)$$

Where:

μ = overall mean

Gi = effects of the i^{th} growing season

Sj = effects of the j^{th} specie

Tk = effects of the k^{th} time

(GS)ij = interaction of the i^{th} growing season and j^{th} specie

(GT)jk = interaction of the i^{th} growing season and k^{th} time

(ST)jk = effects of the j^{th} specie and k^{th} time

(GST)ijk = interaction of i^{th} growing season, j^{th} specie and k^{th} time

Eijkl = residual

5.5 Results

5.5.1 Initial chemical composition of leaf litter

The initial chemical composition of the litter biomass from three sub-tropical fruit tree investigated is presented in Table 5.2. There were no clear differences in phosphorus, sulphur, and carbon contents of the litter from the three species but there were differences in nitrogen, polyphenols, lignin and ash contents. Avocado leaf litter had higher nitrogen, sulphur and magnesium content than mango and litchi. Litchi leaf litter had relatively high lignin and polyphenols contents. In terms of calcium and magnesium, only litchi leaf litter had lower values than mango and avocado leaf litter. Avocado leaves had low C:N ratio largely due to their high nitrogen contents. This may suggests

that avocado leaf litter may decompose faster and release nutrients rapidly during decomposition compared to that of litchi and mango. Leaf litter biomass from litchi had very low Li:N and higher PP:N ratio.

Table 5.2 Composition of leaf litter biomass for fruit trees for the 2 growing seasons

		Tree species*		
Property	Unit	Avocado	Mango	Litchi
C	(%)	48±0.4	45 ±1.4	50±0.4
N	(%)	1.15±0.16	0.9±0.12	1.1±0.06
P	(mg kg^{-1})	814±114.5	630±111	683±23.9
K	(mg kg^{-1})	3171±1355.3	4446±1510.8	3817±1300.4
S	(mg kg^{-1})	1829± 254	1294±25.4	1458±23.2
Ca	(mg kg^{-1})	13604±990.1	13071±262.7	13471±873.4
Mg	(mg kg^{-1})	6534±540.4	1897±419.4	4324±284
Zn	(mg kg^{-1})	39±7.9	34±3.2	55±5.7
Mn	(mg kg^{-1})	434±40.9	477±37.5	218±24.1
PP	(%)	2±0.7	2±0.5	3±0.1
Ash	(%)	9±0.7	13±0.4	10±0.66
Cell	(%)	18±1.6	21±1.1	20±1.4
Li	(%)	35±7.1	38±1.3	40±1.6
C:N		43	49	47
PP:N		1.04	1.22	2.7
Li:N		31	27	37
PP+Li:N		33	34	40

* Values are means for the 2 growing seasons ± SD; n=5; PP (polyphenols); Li (lignin); Cell (cellulose)

5.5.2 Decomposition of leaf litter biomass

A summary of ANOVA presented in Table 5.3 shows that the mass loss during decomposition of leaf litter was significantly influenced by both species and time (retrieval date). There was a significant interaction between growing season and species and growing season and retrieval date. The interactions between these variables suggest that the loss of mass from decomposing leaf litter was not only influenced by the main factors (growing season, species and time) alone. Three way interactions (G x S x T) were not included in the ANOVA table because in most cases they were not significant.

Table 5.3 A summary of ANOVA for mass loss from leaf litter from three tree species

Source of variation	df	Sum of square	F Value	Pr > F
Growing season (G)	1	30.95	3.54	0.0762 ns
Species (S)	2	1539.85	176.12	0.0001 ***
Time (T)	9	1290.10	147.56	0.0001 ***
G x S	2	60.81	6.96	0.0058 **
G x T	9	23.65	2.71	0.0346 *
S x T	18	14.37	1.64	0.1504 ns

* (P<0.05); ** (P<0.01); *** (P<0.001); ns (not significant)

The loss in mass of the litter biomass during the two growing seasons of study is shown in Figure 5.3. The decomposition pattern of the three tree species was similar in the two growing seasons of study. Decomposition of all leaf litter biomass followed a two-phase pattern: early rapid mass loss followed by a long period of low mass loss. There was a rapid loss of mass during the first 14 days after incorporation which could be attributed to the loss of water soluble substances (e.g. sugars, acids, carbon and phenolics). The predicted decomposition constants (k) for the leaf litter biomass of the three tree species are presented in Table 5.4. The results showed that mango and avocado leaf litter biomasses were decomposing faster compared to litchi leaf litter biomass. Litchi leaf litter biomass was predicted to have been lost about 0.014 g day^{-1} while avocado and mango leaf litter was predicted to have lost about 0.019 and 0.018 g day^{-1}, respectively.

The times taken for 50% of litter mass for the different tree species to disappear are presented in Table 5.5. In the 2007/8 growing season, about 318 days after incorporating leaf litter biomass into the soil, 50% of the avocado and mango leaf litter had disappeared while those of litchi leaf litter disappeared 364 days after incorporation. In the following growing season (2008/9) 50% of leaf litter mass from avocado and mango trees disappeared at 226 and 318 days after incorporation, respectively while litchi leaf litter did not reach 50% even at the end of the trial. This implies that the incorporation of leaf litter for determining decomposition from these tree species need to be done for more than 365 days for decomposition to be complete.

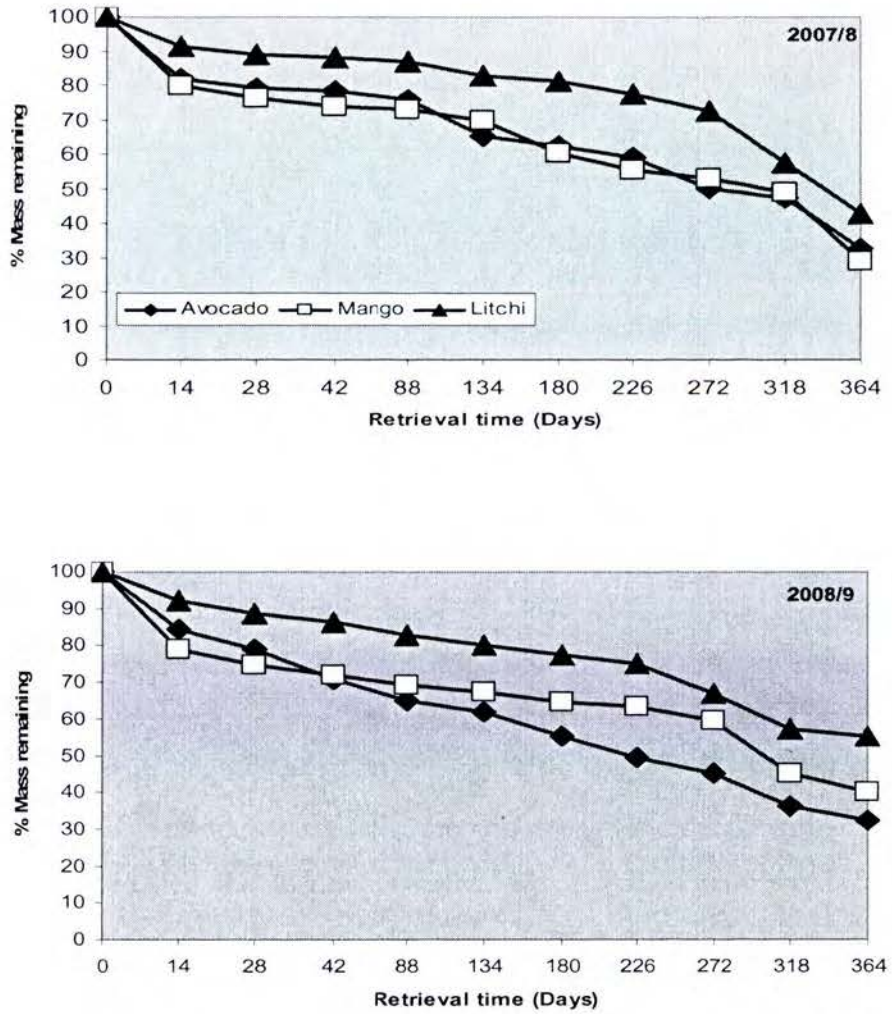


Figure 5.3 Dry matter loss of leaf litter biomass of the three tree species in nylon bags during decomposition

Table 5.4 Decomposition constant (k) for the three leaf litter biomass during the study time

Species	2007/8	2008/9	*Mean*
Avocado	0.78	0.74	*0.76*
Mango	0.79	0.85	*0.82*
Litchi	0.63	0.75	*0.69*
Mean	*0.73*	*0.78*	*0.76*

Table 5.5 Time taken for 50% of mass to disappear

Species	Time (Days)	
	2007/8	2008/9
Avocado	318	226
Mango	318	318
Litchi	364	Not yet reached

5.5.3 Nutrient release from leaf litter during decomposition

Summaries of the results from the ANOVA for polyphenols, lignin, cellulose and nutrients in the decomposing leaf litter presented in Tables 5.6 and Table 5.7 respectively. The decomposition of PP, Ash, and Cell was significantly influenced by growing season while Li was not. Species and time (retrieval time) shows significant ($P<0.001$) effects on almost all variables that were measured. However, the interactions of growing season by species and species by retrieval time were significant indicating that growing seasons, species and time do not independently influence the concentration of PP, Ash, Cell, Li and nutrient elements alone. There were also some significant interactions between growing season and species and species and time. The interaction between growing season and species was significant to Cell, Li:N, PP+Li:N, C:N, and manganese.

Table 5.6 Summary of the results from the ANOVA for leaf litter quality from three fruit trees in Nelspruit

Source of Variation	df	P>f								
		PP	Ash	Li	Cell	PP:N	Li:N	PP+Li:N	C:N	N:P
		----------(%)----------								
Growing season (G)	1	**	**	ns	**	ns	ns	ns	*	ns
Species (S)	2	**	**	**	**	**	**	**	**	**
Time (T)	9	**	**	ns	**	**	*	*	**	ns
G x S	2	ns	ns	ns	**	ns	*	*	**	ns
G x T	9	ns	ns	ns	*	ns	ns	ns	ns	*
S x T	18	**	**	ns	ns	**	ns	ns	*	ns
G x S x T	18	ns	ns	ns	ns	ns	ns	ns	ns	ns

PP (polyphenols); Li (lignin); Cell (cellulose); * = $P < 0.05$; ** = $P < 0.001$; ns = not significant

Table 5.7 Summary of the results from the ANOVA for carbon and nutrient elements from three fruit trees in Nelspruit

		P>f								
Source of Variation	df	N (%)	C (%)	P	K	S	Ca	Mg	Zn	Mn
				---------- (mg kg^{-1}) ----------						
Growing season (G)	1	**	**	ns	ns	**	ns	ns	**	**
Species (S)	2	**	**	**	**	**	**	**	**	**
Time (T)	9	**	**	**	**	**	**	ns	*	**
G x S	2	**	*	**	ns	**	ns	ns	*	ns
G x T	9	ns	ns	ns	ns	ns	ns	ns	ns	*
S x T	18	*	**	ns	ns	*	ns	ns	ns	*
G x S x T	18	ns	ns	ns	ns	ns	ns	ns	ns	ns

* = P < 0.05; ** = P < 0.001; ns = not significant

The amount of nutrients predicted to be released during the decomposition of leaf litter from three tree species are presented in Tables 5.8, 5.9 and 5.10. Mineralization of nutrients such as P, K and Zn occurred while immobilization was observed in N, S, Ca, Mg and Mn in all litter type. There was also immobilization of zinc from litchi leaf litter indicating possible limitation of this element in litchi leaf litter (Table 5.10). Immobilizations of nutrients are indicated by negative values. Nutrient release patterns mirrored that of leaf litter decomposition with a rapid release of nutrients in the first few days after litter incorporation followed by a long period of slow release. The release of nutrients from decomposing leaf litter did not differ between the two growing seasons (2007/8 and 2008/9). The fact that N, S, and Mn were immobilized during the decomposition process suggests the possible limitation of these nutrients in the soil which could have a negative impact on crop production.

Nutrient release pattern was determined by plotting the amount of nutrients that were cumulated during the decomposition of leaf litter against the retrieval dates (Figure 5.4). Nitrogen, calcium and zinc concentration in all litter type increased to the highest amount in the first days and remained higher than initial contents over time (Figure 5.4). Phosphorus and potassium decreased over time while magnesium and manganese remained relatively constant. The concentration of sulphur declined initially and then increased higher than the initial amount. The C:N, PP:N, Li:N, PP+Li:N ratios in all the litter types decreased over time (Figure 5.5). Cellulose and polyphenols decreased with increasing time. Ash and lignin remained relatively constant over time.

Table 5.8 Amount (mg kg^{-1}) of nutrients released during decomposition of avocado leaf litter in the 2 growing seasons

Retrieval-Time (days)	P	K	S	Ca	Mg	Zn	Mn	N
				2007/8				
14	0.038	114.003	-17.219	-0.005	-0.112	200.541	-0.005	-3.115
28	0.025	216.664	-22.287	-0.003	-0.091	301.030	-0.002	-3.185
42	0.019	302.956	-26.999	-0.002	-0.07	364.480	-0.002	-2.428
88	0.009	623.429	-53.978	-0.001	-0.039	438.050	-0.002	-5.049
134	0.005	661.756	-183.805	-0.001	-0.011	974.144	-0.001	-41.039
180	0.004	917.224	-213.873	-0.001	-0.009	1527.222	-0.001	-32.621
226	0.004	1138.385	-162.1	-0.001	-0.013	1539.253	-0.001	-14.123
272	0.003	1059.307	-204.529	-0.001	-0.010	1332.813	-0.001	-18.411
318	0.003	1158.935	-225.566	-0.001	-0.010	1365.192	-0.001	-24.690
364	0.003	896.271	-234.012	-0.001	-0.010	1007.656	-0.001	-19.388
Total	*0.113*	*7088.930*	*-1344.370*	*-0.017*	*-0.375*	*9050.381*	*-0.017*	*-164.049*
Mean	*0.011*	*708.893*	*-134.437*	*-0.002*	*-0.038*	*905.038*	*-0.002*	*-16.405*
				2008/9				
14	0.034	129.672	-13.889	-0.007	-0.057	84.461	-0.011	-4.882
28	0.017	182.809	-26.971	-0.005	-0.028	89.605	-0.010	-11.864
42	0.011	194.982	-43.281	-0.005	-0.018	89.634	-0.011	-17.978
88	0.006	365.444	-72.884	-0.003	-0.011	181.373	-0.005	-30.552
134	0.004	512.746	-110.822	-0.002	-0.007	272.599	-0.004	-39.801
180	0.003	623.496	-168.747	-0.002	-0.005	348.072	-0.003	-69.341
226	0.003	706.321	-170.308	-0.002	-0.005	415.840	-0.003	-69.955
272	0.002	761.826	-200.529	-0.002	-0.004	456.370	-0.002	-83.105
318	0.002	748.658	-215.85	-0.002	-0.004	482.228	-0.002	-84.347
364	0.002	795.899	-227.703	-0.001	-0.004	538.216	-0.002	-90.090
Total	*0.084*	*5021.853*	*-1250.98*	*-0.031*	*-0.143*	*2958.398*	*-0.053*	*-501.915*
Mean	*0.008*	*502.185*	*-125.098*	*-0.003*	*-0.014*	*295.840*	*-0.005*	*-50.192*

Table 5.9 Amount (mg kg^{-1}) of nutrients released during decomposition of mango leaf litter in the 2 growing seasons

Retrieval-Time (days)	P	K	S	Ca	Mg	Zn	Mn	N
				2007/8				
14	0.050	79.120	-4.304	-0.010	-0.597	138.370	-0.0027	-0.304
28	0.028	206.812	-4.262	-0.004	-0.610	352.687	-0.0013	-0.265
42	0.015	228.360	-5.286	-0.004	-0.450	299.700	-0.001	-0.385
88	0.009	339.940	-9.716	-0.002	-0.267	755.857	-0.0002	-0.992
134	0.006	695.990	-44.743	-0.001	-0.054	1126.329	-0.0003	-2.779
180	0.004	743.383	-41.905	-0.001	-0.061	1670.132	-0.0002	-1.769
226	0.003	830.611	-70.562	-0.001	-0.034	1236.683	-0.0004	-3.529
272	0.003	930.157	-86.240	-0.001	-0.028	1228.888	-0.0003	-2.784
318	0.002	972.283	-105.639	-0.001	-0.024	1314.476	-0.0003	-4.715
364	0.002	649.231	-122.511	-0.002	-0.020	834.657	-0.0004	-4.903
Total	*0.122*	*5675.887*	*495.168*	*-0.027*	*-2.145*	*8957.779*	*-0.007*	*-22.425*
Mean	*0.012*	*567.589*	*-49.517*	*-0.003*	*-0.215*	*895.778*	*-0.001*	*-2.243*
				2008/9				
14	0.049	77.692	-7.978	-0.0177	-0.198	45.208	-0.043	-0.388
28	0.024	137.055	-13.934	-0.010	-0.117	78.813	-0.025	-0.250
42	0.017	202.512	-18.052	-0.007	-0.086	116.770	-0.017	-0.302
88	0.008	369.813	-71.234	-0.004	-0.021	225.682	-0.001	-2.073
134	0.006	532.631	-37.237	-0.003	-0.039	388.091	-0.005	-0.461
180	0.005	661.863	-19.026	-0.002	-0.075	486.443	-0.004	-0.172
226	0.004	874.764	-41.261	-0.002	-0.036	573.605	-0.003	-0.993
272	0.003	966.593	-1.646	-0.002	-1.134	643.857	-0.003	-0.025
318	0.003	796.545	-18.302	-0.002	-0.082	544.622	-0.004	-0.125
364	0.003	810.594	-58.557	-0.002	-0.027	542.405	-0.004	-0.267
Total	*0.122*	*5430.062*	*-287.227*	*-0.0517*	*-1.815*	*3645.496*	*-0.109*	*-5.056*
Mean	*0.012*	*543.006*	*-28.722*	*-0.005*	*-0.182*	*364.550*	*-0.011*	*-0.506*

Table 5.10 Amount (mg kg^{-1}) of nutrients released during decomposition of litchi leaf litter in the 2 growing seasons

Retrieval-Time (days)	P	K	S	Ca	Mg	Zn	Mn	N
				2007/8				
14	0.055	172.508	-1.387	-0.008	-0.032	-5.061	-0.323	-5.444
28	0.035	291.922	-0.086	-0.0054	-1.472	-47.291	-0.031	-0.027
42	0.025	329.939	-1.418	-0.005	-0.090	-56.373	-0.025	-1.132
88	0.012	643.961	-4.469	-0.002	-0.020	-104.84	-0.014	-3.848
134	0.011	715.593	-2.563	-0.003	-0.086	-43.029	-0.041	-0.425
180	0.004	1112.165	-46.759	-0.001	-0.011	-374.504	-0.004	-1.066
226	0.005	2128.123	-12.492	-0.001	-0.001	-147.463	-0.011	-91.025
272	0.004	2025.05	-17.002	-0.001	-0.001	-159.282	-0.011	-156.387
318	0.004	1462.024	-23.405	-0.001	-0.002	-9.118	-0.190	-65.712
364	0.004	1107.5	-28.291	-0.001	-0.004	-72.786	-0.023	-40.045
Total	*0.159*	*9988.785*	*-137.872*	*-0.028*	*-1.719*	*-1019.75*	*-0.675*	*-365.111*
Mean	*0.0159*	*998.88*	*-13.787*	*-0.003*	*-0.172*	*-101.975*	*-0.067*	*-36.511*
				2008/9				
14	0.063	181.729	-4.247	-0.009	-0.179	-4.142	-0.655	-0.389
28	0.037	236.217	-6.197	-0.007	-0.108	-3.262	-0.825	-0.360
42	0.026	302.872	-7.895	-0.006	-0.082	-15.741	-0.169	-0.187
88	0.013	528.495	-11.473	-0.003	-0.055	-30.515	-0.089	-0.623
134	0.009	789.062	-12.179	-0.002	-0.053	-32.499	-0.085	-0.232
180	0.007	1048.061	-8.422	-0.002	-0.069	-4.637	-0.605	-0.405
226	0.006	1229.437	-5.676	-0.001	-0.099	-42.577	-0.066	-0.061
272	0.005	1094.62	-8.846	-0.002	-0.062	-37.545	-0.076	-0.390
318	0.005	929.689	-8.019	-0.002	-0.067	-19.968	-0.144	-0.821
364	0.004	1126.968	-5.070	-0.002	-0.107	-57.197	-0.050	-0.451
Total	*0.175*	*7467.150*	*-78.024*	*-0.036*	*-0.881*	*-248.083*	*-2.764*	*-3.919*
Mean	*0.018*	*746.715*	*-7.802*	*-0.004*	*-0.088*	*-24.808*	*-0.276*	*-0.392*

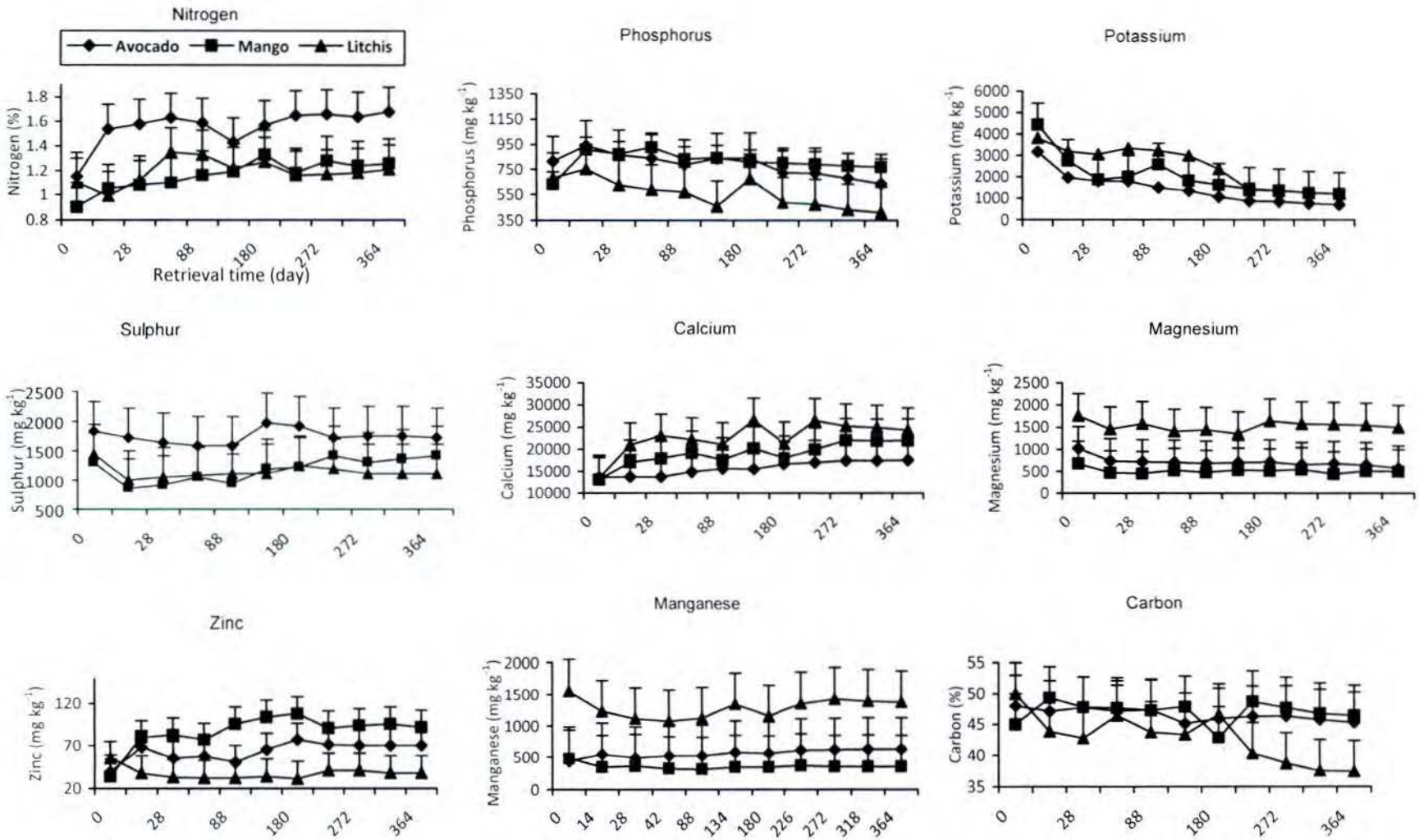


Figure 5.4 Carbon and nutrients concentration in decomposing leaf litter of three sub-tropical fruit tree plantations over time in Nelspruit. Vertical bars indicate standard errors.

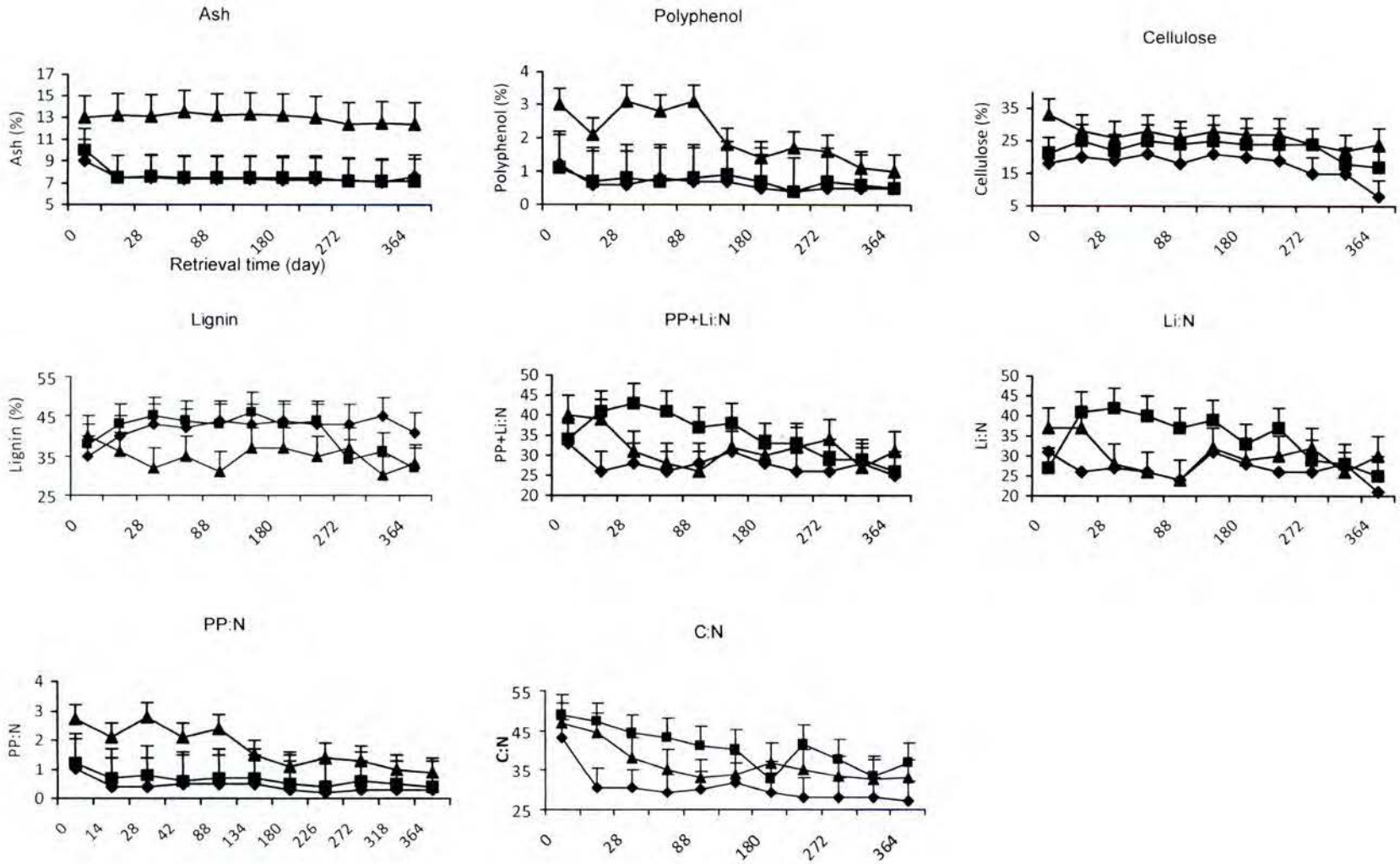


Figure 5.5 Concentration of ash, polyphenols, cellulose, lignin and their ratios in decomposing leaf litter of three sub-tropical fruit tree plantations over time in Nelspruit; Vertical bars indicate standard errors.

5.5.4 Relationships between climatic elements, leaf mass and leaf litter yield during decomposition

The relationships between climatic element, time and litter quality are shown in Table 5.11. The release of nutrients from decomposing leaf litter was influenced by a number of factors such as rainfall, maximum temperature, time, and the interactions among the nutrients themselves. The release of nitrogen in avocado leaves was significantly associated with the ratios of Li:N, C:N, and PP+Li:N. Most of the nutrients in mango leaves showed a strong relationship with time. This means that there was an increase and decrease in the concentration of certain nutrients with time. For example, there was a decrease in the concentration of potassium with time whereas nitrogen increased with time of incubation.

Table 5.11 Some significant relationships (Linear regressions) between leaf litter quality, time and climatic elements

Tree specie	Variables	Regression	P>f
A) Avocado	K vs P	y = 3.83x – 1756	*
	Ca vs P	y = -11.3x + 24854	*
	Ca vs K	y = -2.86x + 19549	*
	Cell vs Mg	y = 0.06x – 24.85	*
	Ash vs Li	y = 9.76x + 114.8	*
	N vs C:N	y = -19.5x + 60.35	*
	N vs Li:N	y = -27.31x + 69.76	*
	N vs PP+Li:N	y = -19.47x + 58.35	*
B) Mango	K vs Ca	y = -2.48x + 32962	*
	P vs Zn	y = -0.17x + 235.4	*
	Mass vs K	y = 31.71x – 205	*
	Rain vs cell	y = -1.13x + 25.15	*
	Mass vs Ca	y = -108.2x + 26335	*
	Mass vs Ash	y = 0.009x + 6.83	*
	Mass vs P	y = 4.53x + 512.8	*
	Time vs P	y = 3.60x + 2386	*
	Time vs S	y = 1.56x + 909	*
	Time vs N	y = 0.001x +1.08	*
	Time vs K	y = -3.69x + 47.3	*
	Time vs P	y = -0.690x + 1874	*
	Max.T vs N	y = -0.077x +1.97	
C) Litchi	Mass vs K	y = 59.1x – 2205	*
	Mass vs C	y = 0.197x + 26.9	*
	N vs C:N	y = -25.4x + 65.8	*
	N vs Li:N	y = -31.2x + 66.5	*

* ($P<0.05$); Li (lignin); Cell (cellulose); Mass (weight of leaf litter remained in the litterbag); Time (retrieval date); MaxT (maximum temperature).

5.6 Discussion and conclusion

5.6.1 Leaf litter decomposition

The results showed significant differences ($P<0.05$) in mass loss for the three tree species in all litterbag retrieval intervals. The loss of litter mass was more rapid in first 14 days of decomposition. This finding is consistent with the observations of other researchers and is attributed to the rapid decomposition of simple sugars, proteins and cellulose (Zaharah and Bah, 1999). After this, a more recalcitrant substrate that is left is broken down rather slowly as reflected by a slow decay phase. This is caused partly by the relative increase in lignification and the synthesis of microbial components (Stevenson, 1986). The decomposition of avocado and mango leaf litter biomass was faster compared to litchi leaf litter biomass and both lost 50% of the leaf biomass within 272 days. Litchi leaf litter biomass decomposed much slower and its half life value exceeded the period of observations. Similar observation has been reported for imperata leaf litter in Papua New Guinea by Hartemink and O'sullivan (2001). The lower mass loss for litchi could be attributed to its poor quality as shown by initial high lignin content (41.3%), and high PP:N ratio (2.70) compared with litter from the other tree species. Mugendi and Nair (1996) found that L:N ratio, PP:N ratio and PP+L:N ratio were the key factors governing the rate of decomposition and subsequent mineralization of nutrients in soils amended with various green manures.

This study has revealed two different phases of leaf litter decomposition: early rapid mass loss followed by a long period of low mass loss. Jama and Nair (1996) also observed two phases of decomposition: a rapid first phase which was predicted better by the C:N ratio and a slower second phase which was predicted better by lignin and polyphenols contents. The first phase of decomposition reflects rapid loss of easily decomposable materials while the second phase reflects the slow loss of more recalcitrant materials (Ver-Elst and Pieterse, 2006). Since decomposition took place under similar climatic conditions, differences among the three leaf litters could be attributed to differences in their chemical composition. For example, differences in mass loss could be due to the pronounced difference in the initial nitrogen concentration of the leaves which was 1.18, 0.93, and 1.09% for avocado, mango and litchi, respectively. The effect of leaf litter nitrogen content on decomposition has been demonstrated for forest tree species by Fioretto *et al.* (2003).

The high decomposition exhibited by avocado and mango leaf litters imply that these two species have a higher potential for use to replenish soil fertility while litchi leaf litter can be used for preventing soil erosion and improving soil moisture in the long-term.

5.6.2 Nutrient release pattern

Nutrient release during the early stage of decomposition is attributed to physical leaching and microbial action on water soluble components (Gosz *et al.*, 1973; Berg and Staaf, 1981; Huang and Schoenau, 1997). The relatively slower rate of release of nutrients after the leaching phase could be due to the increase in recalcitrant fractions and indicates the dominance of soil fauna in this phase of decomposition (Swift *et al.*, 1979). Nitrogen concentration in all the three leaf litter types increased to the highest amount in the first days of decomposition and remained higher than initial contents over time. The increases in nitrogen concentrations in decomposing leaf litter are due to mechanisms such as microbial immobilization of nitrogen (Koenig and Cochran, 1994), fungal translocation, throughfall and insect frass (Melillo *et al.*, 1982) which results in a decrease in the C:N ratio of residues (Musvoto *et al.*, 2000).

Much of the phosphorus in the leaf litter biomass decreased rapidly, and this is consistent with the results reported by Schroth *et al.* (1992). The rapid loss of phosphorus observed in the first few days was probably a consequence of leaching of soluble phosphorus containing compounds. Blair (1988) and Tripathi and Singh (1992) also reported leaching of phosphorus during the early stages of decomposition. The fact that potassium was decreasing during the decomposition period suggests that leaching is the dominant mode of release of potassium. Similar observations where potassium was leaching throughout the decomposition period have been reported in other studies (Bargali *et al.*, 1993; Schroth *et al.*, 1992; Tian *et al.*, 1992a; Zaharah and Bah, 1999). This leaching was ascribed to the high mobility of potassium. The release of potassium could also be attributed to its presence as a mobile cation in the cell fluid that comes after disintegration of cell membranes and results in easy leaching from the leaf litter biomass.

The results of the predicted nutrient release by the leaf litter biomass indicate that the release in the first 14 days was rapid and then continued to decrease over time. This pattern was similar to that of mass loss, suggesting that mass loss is a good indicator of

nutrient release process since the two followed a similar trend. The observation that nitrogen, sulphur and manganese and zinc were immobilized during decomposition of the litter biomasses indicates that these nutrient elements would not be available to plants after incorporation of the leaf litter and could limit crop production. In order to avoid growth and yield limitation during this period, there is need to add judicious amounts of inorganic fertilizers or manure in order not to adversely affect the crops. It also has implications on the time at which the leaf litter has to be incorporated before a crop is established on the soil. This means that immobilization of necessary nutrients in the leaf litter will take place before the crops are planted. The observation that nutrient release pattern was almost similar in both growing seasons indicates that the climatic conditions were favourable and almost similar in both years. This was in agreement with the linear regression results which showed relationship between climatic elements and leaf litter decomposition. The influence of nutrient elements on each other was significant indicating that the presence of certain nutrients can have either negative or positive influence on the other. For example, there was a positive relationship between phosphorus and potassium, calcium and potassium while a negative relationship was observed between phosphorus and zinc, and calcium and phosphorus.

The results of this study seem to suggest that, due to the low quality of leaf litter biomass from three sub-tropical fruit trees, there is need to pay attention to their use and management. Such management may involve regulating the quality, quantity, timing and methods of application of the litter as has been suggested for other green manures (Nair, 1993; Palm and Sanchez, 1991; Palm, 1995). Small scale farmers who are fortunate enough to have all the three fruit tree species on their farms could mix the leaf litter from these trees and incorporate them into the soil before planting their crops. In the process, leaves from these trees will decompose and release nutrients at different growth stages of the crop in grown. The influence of such management on the release and nutrient uptake by a crop needs to be studied. Other options of managing leaf litter include adjusting the timing of pruning and modifying the method of fruit tree litter application. It is concluded that since the quality of leaf litter biomass from the three tree species was different, it affected the decomposition and the release of nutrients into the soil. It is recommended that these litters must be incorporated at different times in order to synchronize their nutrient release with crop demand. The uptake by crop plants of the released nutrients and its impact on growth and development of food crops need to be investigated.

CHAPTER SIX

GROWTH AND NUTRIENT UPTAKE BY MAIZE (*Zea mays* L.) GROWN IN A SOIL AMENDED WITH LEAF LITTER FROM THREE SUB-TROPICAL FRUIT TREES

6.1 Introduction

In agricultural production, soil fertility is considered to be the status of a soil with respect to its capacity to provide plants with sufficient amounts of nutrients at a rate and balance needed for optimum growth (Brady, 1974). Soil plant nutrients become available to crops through biological N_2-fixation, weathering of rocks, decomposition of litter fall or pruning (Trudgill, 1977) and application of chemical fertilizers. The most commonly used method to supply nutrients to crops has been through chemical fertilizers. However, the majority of small scale farmers can not afford to buy chemical fertilizers in order to supply nutrients to crops on their farms. In the absence of chemical fertilizers, the application of leaf litter is one of the locally affordable means in which nutrient elements can be made available for plant uptake. Consequently leaf litter plays a significant role in soil fertility management and crop productivity under small scale agriculture (Nyathi and Campbell, 1993; Jama *et al.*, 2000).

Immobilisation of nutrients from leaf litter during decomposition is one of the constraints that limit crop productivity since it renders nutrients unavailable for plant use (Millar and Turk, 1948). It was observed from Chapter Five of this study that application of leaf litter biomass from the three fruit trees that were investigated resulted in the immobilization of certain nutrient elements including N, S and Mn, implying that these nutrients were not available for plant uptake during the study period. Studies on litter decomposition have provided the opportunity to manipulate the timing of nutrient release which is useful in species selection for sustainable agroforestry system (Das and Chaturvedi, 2003). Knowledge about the time of incorporating leaf litter into the soil is of paramount importance particularly when attempting to enhance synchrony in agricultural systems which have different plant nutrient demand patterns (Palm and Sanchez, 1991). In this case, synchrony refers to the timing of nutrient release from decomposing materials with crop demand (Palm and Sanchez, 1991). Lack of synchrony (asynchrony) occurs when a

nutrient is released or added at a rate exceeding the uptake or slower than the plants' need (Sanders *et al.*, 1977). This situation can be made more synchronous by applying a material that immobilizes nutrients during fallow or early crop growth, and then releases it later when crop demand is greater.

Plant species take up different amounts and different proportions of nutrients from a soil according to their requirements and stage of growth (Walsh and Beaton, 1973). Not only do species differ in uptake, but plants of the same species absorb different amounts of nutrients when growing in different soils (Walsh and Beaton (1973). As it was shown from the previous chapters, small scale farmers in the EDM collected leaf litter from sub-tropical fruit trees and applied it in their fields as a strategy for replenishing soil fertility and supplying nutrients to food crops. However, the uptake of nutrients by food crops from these leaf litter biomass is not known. The release and uptake of nutrients from leaf litter by food crops is governed by several factors including decomposition, immobilization, microbial population, soil texture, soil moisture, temperature, aeration and acidity (Jenkinson, 1977; Oades, 1988). The microbial populations play a very crucial role since they are primarily responsible in the decomposition and nutrient release from leaf litter biomass. The decomposition of leaf litter is a biochemical process and is brought about primarily by various microorganisms and any factors that affect the activities of the soil organisms will necessarily affect the rate of leaf litter decay and the uptake of nutrients (Jenkinson, 1977)

Large amounts (6.4 t ha^{-1} $year^{-1}$) of leaf litter produced by sub-tropical fruit trees (avocado, mango and litchi) in the EDM provide a good source of nutrients that may offer potential for the management of soil fertility, especially under the limited resource situation of small-scale farmers. Claims have been made of improved growth for both field crops and vegetables in areas where substantial amounts of leaf litter have been applied (Nyathi and Campbell, 1993; Musvoto and Campbell, 1995; Jama *et al.*, 2000). Litter can only become useful to soil fertility and nutrient contribution if plants growing on the litter amended soils are able to take nutrients and use them for growth. Results reported in previous chapters of this thesis suggest that the litter from different trees is of different quality and nutrient release and thus implies that it could affect plant growth differently. There is however, no quantitative evidence on the contribution of leaf litter from sub-tropical fruit trees to

improvement in soil fertility and crop productivity. The objectives of the study reported here were therefore to:

1) Quantify the growth of maize crops grown on soil amended with leaf litter from three fruit tree species and;
2) Determine the nutrient uptake by maize crops grown on soil amended with leaf litter from three fruit tree species

6.2 Literature review

6.2.1 Introduction

Nutrient uptake by plants is defined as the transfer of nutrient ions across the soil-root interface into the plant cell. The process of nutrient uptake involves desorption, transport of nutrients in soil solution toward the root, transport across root membranes and transport to shoots. The amount of nutrients that a plant may need for growth and reproduction varies among plant species or varieties (Walsh and Beaton, 1973). Each type of plant is unique and has an optimum range of nutrients as well as minimum requirements. When soil nutrients get below this minimum level, plants start to show nutrient deficiency symptoms. The phenomenon of nutrient deficiency was outlined by Liebigs' "law of the minimum" which states that plant growth is proportional to the available amount of the most limiting plant nutrient (Van der Ploeg *et al.*, 1999). This theory marked an important advance in the understanding of plant nutrition. Excessive nutrient uptake on the other hand can also cause poor growth because of toxicity. The application of balanced amounts of nutrients is therefore important.

Nutrient availability plays a major role in the growth and development of plants. Nutrients come from different sources of organic and inorganic origin and their concentration in plant components differs depending on the tree species, type of nutrient, stage of growth, water availability and the nutrient status of the soil (Walsh and Beaton, 1973). It is now known that at least 16 plant-food elements are necessary for the optimal growth of plants. In the absence of any one of these essential elements, a plant fails to complete its life cycle, though the disorder can, be corrected by the addition of that element. The 16 essential elements are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), sulphur

(S), potassium (K), calcium (Ca),magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B) and chlorine (Cl). These nutrients are further divided into the macro and micro-nutrients (Russell, 1973; Delorit *et al.*, 1984). Macro-nutrients are broken into primary (N, P and K) and secondary nutrients (Ca, Mg and S). Each nutrient has its own form in which plants can use them. The ionic forms of the various nutrient elements used by plants are indicated in Table 6.1. Also included in the table, is the sufficiency nutrient range for maize as proposed by Walsh and Beaton (1973).

Table 6.1 Ionic forms of essential elements required for plant growth and development and sufficiency range for maize

Nutrient element	Sufficiency range	Ionic form
Major nutrients (%)		
Nitrogen	2.6 – 5.0	NO_3^-, NH_4^+
Phosphorus	0.25 – 0.8	HPO_4^{-2}, $H_2PO_4^-$
Potassium	1.7 – 5.0	K^+
Secondary nutrients (%)		
Calcium	0.21 – 1.6	Ca^{+2}
Magnesium	0.21 – 0.8	Mg^{2+}
Sulphur	0.2 – 0.5	SO_4^{-2}
Micronutrients (ppm)		
Boron	6 – 20	H_3BO_3, $B_4O_7^{-2}$
Copper	6 - 20	Cu^{+2}, Cu^+
Iron	21 – 300	Fe^{+2}, Fe^{+3}
Manganese	20 - 200	Mn^{+2}, MnO_4^-
Molybdenum	0.6 – 1.0	$HMoO_4^-$, MoO_4^{-2}
Zinc	20 – 150	Zn^{+2}

Source: Walsh and Beaton (1973)

6.2.2 Factors affecting nutrient supply from organic materials

The uptake of nutrients and their distribution to different parts of the plants vary primarily with the fertility of the soil, application of chemical fertilizers, growth stage of the plant and the environmental conditions (Bates, 1971; Baldwin, 1975; Clarkson, 1985). The principal factors affecting the nutrient supply from organic materials are the total quantity of diffusible nutrient, decomposition rate, soil moisture, temperature, immobilization process, soil properties and microbial population dynamics (Pal and Broadbent, 1975; Jenkinson, 1977; Oades, 1988).

6.2.2.1 Decomposition

Decomposition refers to the process that converts organic materials into smaller and simpler compounds (Swift *et al.*, 1979; Lynch, 1984). The products of complete decomposition are carbon dioxide, water, and inorganic ions such as ammonium, nitrate, phosphate and sulphate (Zech *et al.*, 1997). When leaf litter biomass is added to the soil under favourable conditions, it is subjected to various changes involving chemical agencies and the activities of the various groups of soil organisms (Cundell, 1977). The soil organisms bring about reduction in quantity and change in the chemical composition of the litter. The decomposition of organic materials is brought about primarily by microorganisms, the most important of which in most soils are bacteria, fungi, and actinomycetes (Millar and Turk, 1948; Waksman and Starkey, 1950). The elements that plants require for their nutrition come directly or indirectly from the soil. The microbes play a prominent role in transforming these elements into forms available for plants (Lee, 1993; Gyaneshwar *et al.*, 2002). Knowledge of these microbes and their activities is, therefore, of prime importance for the understanding of soil processes and plant growth.

6.2.2.2 Mineralization and immobilization of nutrients by microbes during decomposition

During decomposition of litter biomass, nutrient elements can either be mineralized or immobilized. These two processes play a major role in the uptake of nutrients by plants since they determine the availability of nutrients. Mineralization is the microbially mediated transformation of organically bound elements such as C, N, P, S into inorganic compounds such as CO_2, CH_4, NH_4^+, NO_3^-, HPO_4^{2} and SO_4 (Scholes and Sanchez, 1990; Zech *et al.*, 1997; Prescott *et al.*, 2000). Under mineralization of nitrogenous compounds, two major processes occur, *viz*: ammonification and nitrification.

Ammonification is defined as the formation of ammonia by soil organisms as a product of the decomposition of organic nitrogenous compounds. Ammonia is formed by a large number of soil organisms, including various fungi, actinomycetes and aerobic and anaerobic bacteria. The rate of ammonification and the quantity of ammonia produced are influenced markedly by soil conditions, nature of the organic material, and the nature of the microbial population (Stevenson, 1986). Another beneficial effect of soil organisms is the conversion of ammonia nitrogen to nitrate nitrogen (nitrification). The conversion is

carried out on largely by two specific types of bacteria, often referred to as nitrifying bacteria (Jenkinson, 1977; Oades, 1988). The conversion of biological ammonia into nitrate nitrogen is the result of two distinct processes. First, the ammonia is changed to nitrite nitrogen principally by the action of two groups of bacteria called Nitrosomonas and Nitrosococcus, and secondly, the nitrite nitrogen is changed to nitrate nitrogen by the action of a group of bacteria called Nitrobacter.

Immobilization is defined as the conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to plants (Ladd *et al.*, 1977a). Soil organisms have, in general, the same nutrient element requirements as higher forms of life. For their growth and development they all require supplies of energy in addition to the several essential elements, including carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur and others (Delorit *et al.*, 1984). During the process of microbial decomposition of plant litter especially those low in nitrogen, much of the nitrogen is converted to organic forms. Initially the nitrogen is probably tied up in microbial tissue (Ladd *et al.*, 1977a). As the role of microbial activity subsides, some of the immobilized nitrogen will be mineralized and ammonium and nitrate will again appear in the soil solution (Krasilnikov, 1958; Ladd *et al.*, 1977b).

6.2.2.3 Environmental conditions and soil texture

Nutrient availability and uptake by plants is also dependent on the prevailing environmental conditions and soil physical properties (Millar and Turk, 1948). Environmental conditions and soil properties determine the nature of the microbial populations present at any given time in the soil, which in turn affects the decomposition and nutrient release from decomposing leaf litter biomass and consequently nutrient uptake by growing plants (Gyaneshwar *et al.*, 2002). Microorganisms that are responsible for decomposition of leaf litter biomass survive under different temperature regimes (Agehara and Warncke, 2005). If the temperature becomes extremely high or low, this affects the manner in which microbes decompose leaf litter. The optimum temperatures for the growth of most soil microbes are considerably high. Within a rather narrow range, the rate of biological reactions increases two or three times with each increase in temperature of 10°C. Roughly, the limits of microbiological functions are reached with a temperature of 80°C (Millar and Turk, 1948). In the savanna zones of Senegal, Wild (1972) found that

microbial activity occurred at temperatures as high as 55-66°C with maximum mineralization occurring at about 50°C. For the majority of the soil organisms, the optimum temperature is about 35°C, although they can grow and function at rather wide temperature ranges and may adapt themselves readily to gradual changes in temperature (Robertson, 1984).

Another major factor affecting the numbers and activities of soil microorganisms is soil moisture. The influence of moisture depends to a large extent upon the nature of the soil and the nature of soil organisms concerned (Ladd *et al.*, 1977a). The optimum amount of water for most soil organisms is between 50 and 70% of the water-holding capacity (WHC) of the soil (Millar and Turk, 1948). Pal and Broadbent (1975) reported high nitrogen release from decomposing rice straw at 60% WHC than at 30% WHC. Similar observation has been reported by Agehara and Warncke (2005). The majority of soil organisms have the ability to withstand rather wide extremes in soil moisture content, thus ensuring their wide distribution in soils in spite of periodic changes in the environment.

The degree of acidity or alkalinity of the soil is of particular importance in influencing the activities and relative abundance of the different groups of soil organisms. It is frequently noted that the proportion of fungi to bacteria and actinomyces is greater in acid than neutral soils. Actinomyces prefer a range of 7.0 to 7.5, the bacteria and protozoa from 6.0 to 8.0, and the fungi from 4.0 to 5.0 (Millar and Turk, 1948). The nitrifying organisms are also sensitive to highly acidic conditions. Under extremely high acidic conditions the nitrifying bacteria can not function properly implying that there will be a poor release of nitrogen for plant uptake (Gyaneshwar *et al.*, 2002).

The development and activities of soil organisms are greatly affected by the concentration and rate of supply of certain gases (particular oxygen, carbon dioxide and nitrogen) in the air. Oxygen is needed for oxidation processes, carbon dioxide as a source of carbon for autotrophic organisms, and nitrogen for the nitrogenous fixing organisms (Millar and Turk, 1948). Abundant oxygen favours the activities of the nitrite and nitrate formers, the nitrogen fixers, fungi and other organisms which oxidise organic materials. Poor aeration favours reduction processes (Tiedje, 1988; Eichner, 1990). Aeration increases with a decrease in the soil moisture while excess of water tends to encourage anaerobic

conditions. Oxygen deficiency disturbs metabolic processes in plants, resulting in the accumulation of toxic substances in plants and low uptake of nutrients.

Soil texture refers to the relative amounts of mineral particles i.e. Sand, Silt and Clay in the soil. The available water holding capacity of soil is related to soil texture which in turn determines the microbial activities (Scott *et al.*, 1996). The pore size distribution of soil influences the ability of decomposer organisms to reach potential organic substrate (Franzluebbers, 1999). Kilbertus (cited in Franzluebbers, 1999) reported that bacteria can only enter >3.0 μm pore size. Within the pore sizes less than this lower limit, decomposition of organic carbon can only occur via diffusion of extracellular enzymes away from organisms. Similar results have been reported by Van der Linden *et al.* (1989). If the movement of microbes is restricted, this implies that there will be less decomposition of organic materials and consequently low nutrient available for plant uptake (Scott *et al.*, 1996).

6.2.3 Mechanisms of nutrient uptake by plants

There are three mechanisms by which plants take up nutrients from the soil *viz*: (i) contact exchange and root interception, (ii) mass flow or convection, and (iii) diffusion (Wilkins, 1969; Lamont, 1982). In the case of contact exchange and root interception, the exchangeable nutrient ions from clay-humus colloids migrate directly to the root surface through contact exchange when plant roots come into contact with soil solids. Nutrient absorption through this mechanism is, however, insignificant as most of the plant nutrients occur in soil solutions (Sanders *et al.*, 1977; Smith *et al.*, 1997). Many scientists have come to a conclusion that the uptake of immobile ions like phosphate is enhanced by the existence of mycorrhizae that are increasingly being found on a wide range of higher plants (Sanders *et al.*, 1977; Jehne and Thompson, 1981; Smith *et al.*, 1997). Mycorrhizal fungi can provide a parallel path for nutrient uptake and it has been found that their availability can increase plant growth (Sanders *et al.*, 1977; Smith *et al.*, 1997). Mycorrhizae improve the absorption of all nutrients because their fungal hyphae can exploit soil volumes far exceeding those exploited by roots hairs (Sanders *et al.*, 1977). There is also increasing evidence that mycorrhizas are capable of gaining access to phosphorus and other nutrients that are complexed with iron and aluminum oxide (Jehne and Thompson, 1981; Tiessen *et al.*, 1991).

The second mechanism is mass flow or convection, which is considered to be the important mode of nutrient uptake. This mechanism relates to nutrient mobility with the movement of soil water towards the root surface where absorption into the root takes place along with water (Barber *et al.*, 1963; Lamont, 1982). Nutrient uptake through mass flow is largely dependent on the moisture status of the soil and is highly influenced by soil physical properties that control movement of soil water. The major ions moved primarily by mass flow are nitrate (NO_3^-) and chloride (Cl^-) anions, and to a moderate degree the sulfate (SO_4^{2-}) anion, plus the cations, potassium (K^+) and magnesium (Mg^{2+}) (Walsh and Beaton, 1973). Also, other ions may be carried in the moving soil water, depending on the physical and chemical characteristics of the soil and the concentration and characteristic of that element in the soil (Barber *et al.*, 1963; Wilkins, 1969; Delorit *et al.*, 1984).

The third mechanism is diffusion. This is an important phenomenon by which ions in the soil medium move from a point of higher concentration to a point of lower concentration. In other words, the mechanism enables the movement of nutrient ions without movement of water (Lamont, 1982). The amount of nutrient-ion movement in this case is dependent on the ion-concentration gradient and transport pathways which, in turn, are highly influenced by the content of soil water (Barber *et al.*, 1963; Wilkins, 1969). This mechanism is predominant in supplying most of the phosphorus and potassium to plant roots.

6.2.4 Methods of measuring nutrient uptake by crops

The total nutrient accumulation in the plant during growth mirrors the release characteristics of the media in which plant is grown. Data related to the quantity of nutrients accumulated during a cropping season give an idea of fertility depletion and help in maintaining soil fertility for the succeeding crops (Berger and Troug, 1945). The best time to determine nutrient uptake depends on the type of the crop. Some authors have claimed that the best time to determine nutrient accumulation is at flowering or at harvest, when accumulation is expected to be at a maximum. Roots, shoots and grains should be analysed and their weights per unit area determined to calculate total accumulation (Fageria and Baligar, 2005).

The amount of nutrients absorbed by plants can be determined by growing plants in soils and comparing the growth with those in nutrient cultures with known amounts of nutrients (Berger and Troug, 1945; Munson and Nelson, 1973). Chemical analysis of plant tissue is one of the most reliable tools for estimating nutrient uptake and fertilizer needs of plants. Chemical analysis suggests some relationship between nutrient supply and the chemical composition of the plant. For example, Berger and Troug (1945) showed that the amount of boron in the leaves of table beets (*Beta vulgaris* L.) gave an indication of the amount of available boron present in the soil on which the beets were grown. Munson and Nelson (1973) have recognised leaf analysis as a valuable tool for diagnosing plant nutritional problems. Apart from tissue analysis, several other methods have been proposed as indirect measures of nutrient uptake by growing plant. These methods include determination of total dry matter yield, plant height and stem diameter measurements (Wilkins, 1969).

6.3 Materials and methods

6.3.1 Collection of leaf litter and soil

Leaf litter used in this investigation was drawn from bulk samples which were collected during the leaf litterfall study (Chapter 4). Leaf litter was collected from three fruit tree species which are common and readily available to small scale farmers within the EDM. The procedure that was used for selecting the trees is described in Chapter Four (section 4.3.3). The three fruit tree species are avocado (*Persea americana*), mango (*Mangifera indica*) and Litchi (*Litchi chinensis*). Sub-samples of leaf litter biomass from each tree species were bulked to form composite sample. The composite sample was air dried and cut into pieces of about 20 mm using a pair of scissors so that they could fit into the PVC pots and to ensure good contact with soil. The soil that was used to fill the pots was collected from the same site that was used for the litter decomposition study reported in Chapter Five. A spade was used to collect soil at a depth of 0–20 cm during the month of September 2007. The bulk soil was air dried and passed through a 2.0 mm sieve in order to remove plant debris and other foreign particles.

6.3.2 Treatments and experimental design

The experiment was a 3 x 3 x 3 factorial laid in a completely randomized design with 3 levels of species (S) (avocado, mango and litchi), 3 application rates (R) equivalent to 0 (without leaf litter), 3 g pot^{-1} (equivalent to 1.6 t ha^{-1}) and 6 g pot^{-1} (equivalent to 3.3 t ha^{-1}), and 3 incubation periods (T) (0, 6 and 12 months). Each treatment was replicated five times. Table 6.2 shows the different treatment combinations of the experiment.

Table 6.2 Treatment combinations in the nutrient uptake study

Treatment(T)	**Treatment combination**	**Description**
T1	S1 x T1 x R1	Avocado x 12 months x without litter
T2	S1 x T2 x R1	Avocado x 6 months x without litter
T3	S1 x T3 x R1	Avocado x At planting x without litter
T4	S2 x T1 x R1	Litchi x 12 months x without litter
T5	S2 x T2 x R1	Litchi x 6 months x without litter
T6	S2 x T3 x R1	Litchi x At planting x without litter
T7	S3 x T1 x R1	Mango x 12 months x without litter
T8	S3 x T2 x R1	Mango x 6 months x without litter
T9	S3 x T3 x R1	Mango x At planting x without litter
T10	S1 x T1 x R2	Avocado x 12 months x 1.6 t ha^{-1}
T11	S1 x T2 x R2	Avocado x 6 months x 1.6 t ha^{-1}
T12	S1 x T3 x R2	Avocado x At planting x 1.6 t ha^{-1}
T13	S2 x T1 x R2	Litchi x 12 months x 1.6 t ha^{-1}
T14	S2 x T2 x R2	Litchi x 6 months x 1.6 t ha^{-1}
T15	S2 x T3 x R2	Litchi x At planting x 1.6 t ha^{-1}
T16	S3 x T1 x R2	Mango x 12 months x 1.6 t ha^{-1}
T17	S3 x T2 x R2	Mango x 6 months x 1.6 t ha^{-1}
T18	S3 x T3 x R2	Mango x At planting x 1.6 t ha^{-1}
T19	S1 x T1 x R3	Avocado x 12 months x 3.3 t ha^{-1}
T20	S1 x T2 x R3	Avocado x 6 months x 3.3 t ha^{-1}
T21	S1 x T3 x R3	Avocado x At planting x 3.3 t ha^{-1}
T22	S2 x T1 x R3	Litchi x 12 months x 3.3 t ha^{-1}
T23	S2 x T2 x R3	Litchi x 6 months x 3.3 t ha^{-1}
T24	S2 x T3 x R3	Litchi x At planting x 3.3 t ha^{-1}
T25	S3 x T1 x R3	Mango x 12 months x 3.3 t ha^{-1}
T26	S3 x T2 x R3	Mango x 6 months x 3.3 t ha^{-1}
T27	S3 x T1 x R3	Mango x At planting x 3.3 t ha^{-1}

S=species, T= incubation period, R= rate of litter application

6.3.3 Management of pots

6.3.3.1 Pot filling and incubation of leaf litter amended soils

The incubation of the litter amended soils was commenced in December 2006 with 0 months, and then June 2006 (6 months) and December 2007 (12 months), June 2007 and December 2007 for the 12, 6 months and 0 months of incubation respectively. About 250 g of air dried soil was mixed with leaf litter and filled into PVC pots. PVC pots measuring 15 cm in diameter and 12 cm high were used for the study. The pots had three holes at the bottom for draining water. Each pot was placed on a PVC saucer in order to collect and capture excess water and leached nutrients during and after irrigation. The mixture of soil and leaf litter was wetted to 70% of the water holding capacity of the soil and incubated in a greenhouse where the average day and night temperatures were 26 and 15 °C for 48 days (08 December 2007 to 25 January 2008). The pots were watered once a week in order to maintain the soil at approximate field capacity.

6.3.3.2 Growing of maize

A maize hybrid (cv PAN 6671) was used as a test crop in the study due to its high demand for nutrients during early stages of growth and its popularity amongst small scale farmers within the EDM. Three seeds of maize were sown at a depth of 2.0 cm in each pot. These were thinned after germination to leave two plants in each pot. The pots were laid on a large steel bench (Figure 6.1). Plants were grown for 48 days in a greenhouse at the ARC-ITSC research station in Nelspruit where day and night temperatures in the greenhouse were kept at 26 and 15 °C, respectively. Soil in the pots was kept moist by watering daily with distilled water. Any water collected in the pot saucers was returned to the pot.

6.3.3.3 Harvesting and data collection

At the end of the growing period, plant height and dry matter yields of the maize seedlings in each pot were measured. Roots were retrieved by washing the soil over a 200 mm sieve. Plant height was measured with a ruler from the base of each plant to the end of the tallest leaf. Each plant was separated into roots and shoots (stems and leaves). The components were dried in the oven at 65 °C for 48 hours and weighed to obtain root and shoot dry mass. The dry material (shoots and roots) was ground in a Willy mill to pass through a 1.0 mm

sieve and analyzed for N, P, K, S, Ca, Mg, Zn, and Mn using procedures described in Chapter four (section 4.3.5). Nutrient uptake was determined by multiplying nutrient concentration by the respective dry mass.



Figure 6.1 Pots used for nutrient uptake study during incubation (a) and after planting (b)

6.4 Analysis of data

All data were subjected to analysis of variance (ANOVA) using GenStat ® (Payne, 2008). The LSD test was calculated using Fishers' least significant difference method where F-values were significant (Snedecor and Cochran, 1980). The model used was:

$$Yijkl = \mu + Si + Tj + Rk + (ST)ij + (SR)jk + (TR)kl + (STR)ijk + Eijkl \quad \textbf{(12)}$$

Where:

μ = overall mean

Si = effects of the i^{th} species

Tj = effects of the j^{th} time

Rk = effects of the k^{th} rate

$(YS)ij$ = interaction of the i^{th} species and j^{th} time

$(YT)jk$ = interaction of the i^{th} species and k^{th} rate

$(ST)kl$ = effects of the j^{th} time and k^{th} rate

$(YST)ijk$ = interaction of i^{th} species, j^{th} time and k^{th} rate

$Eijkl$ = residual

6.5 Results

6.5.1 Growth and dry matter yields

A summary of the analyses of variance for dry matter and plant height is presented in Table 6.3. Both species and period of leaf litter incubation had significant influence ($P<0.01$) on shoot, roots and plant height of maize plant while the rate of leaf litter application had no significant influence on the same parameters. The interaction between species and rate of application was significant.

Table 6.3 Summary of the analyses of variance for dry matter yields and plant height of maize plants

Source	df	Dry matter yields (g pot^{-1})		Plant height (cm)
		Shoot	Root	
Species (S)	2	0.35 ns	0.54 ***	28.80 ns
Time (T)	2	4.51 ***	1.06 ***	1859.32***
Rate (R)	2	0.27 ns	0.02 ns	98.86 ns
S x T	4	0.28 ns	0.10 ns	25.44 ns
S x R	4	0.34 ***	0.19 ***	56.48 ns
T x R	4	0.25 ns	0.01 ns	85.54 ns
S x T x R	8	0.11 ns	0.07 ns	64.76 ns

** *= $P<0.01$; ns = not significant

Table 6.4 shows the effects of tree species and leaf litter application rate on the dry matter yield of maize plants. The results show that there was a significant influence ($P<0.01$) of all the factors on the dry matter yields of maize plants by the interaction between species and application rate of leaf litter. Dry matter yields were significantly higher ($P<0.01$) on maize plants grown in the soil treated with 3.3 t ha^{-1} of avocado leaf litter. The lowest dry matter yields were found on the maize plants grown in the soil amended with 3.3 t ha^{-1} of mango leaf litter. Except for avocado leaf litter, the application of 3.3 t ha^{-1} of leaf litter from both mango and litchi trees produced the lowest dry matter yield.

Table 6.4 Effect of species and application rates of leaf litter from sub-tropical trees on the dry matter yields of maize plants

Species	Rates of application ($t\ ha^{-1}$)	Shoots	Roots
		---------- ($g\ pot^{-1}$)----------	
Avocado	0	1.00b	0.93b
	1.6	0.91b	0.84b
	3.3	1.30a	1.15a
	Mean	***1.14***	***1.01***
Mango	0	1.00a	0.88a
	1.6	1.06a	0.93a
	3.3	0.86b	0.73b
	Mean	***0.97***	***0.85***
Litchi	0	1.08a	0.93a
	1.6	0.89b	0.82b
	3.3	1.06a	0.92a
	Mean	***1.01***	***0.89***

Means within each column with similar letters are not significantly different by the Fishers' least significant difference method

6.5.2 Nutrient concentration in shoots and roots of maize plants

A summary of the analysis of variance (ANOVA) for the concentration of N, P, K, S, Ca, Mg, Zn, and Mn in the shoots and roots of maize plants grown in the soil amended with leaf litter biomass from sub-tropical fruit trees is shown in Table 6.5. The results show that there was a significant effect ($P<0.01$) of species, time and rate of leaf litter application on the concentration of all nutrient elements studied. There was also a significant interaction ($P<0.01$) in the concentration of nutrient elements by species and time, species and rate, and time and rate of litter application. There was, however, no significant interaction of species and rate of application (S x R) on the concentration of phosphorus in the roots by species and rate of litter application.

Table 6.5 A summary of ANOVA for nutrient concentration in the shoots and roots of maize plants grown on soil amended with leaf litter from sub-tropical fruit trees

Source of variance	df	N (%)	P	K	S	Ca	Mg	Zn	Mn
						(mg kg^{-1})			
Shoots									
Species (S)	2	***	***	***	***	***	***	***	***
Time (T)	2	***	***	***	***	***	***	***	***
Rate (R)	2	***	***	***	***	***	***	***	***
S x T	4	***	***	***	***	***	***	***	***
S x R	4	***	***	***	***	***	***	***	***
T x R	4	***	***	***	***	***	***	***	***
S x T x R	8	***	***	***	***	***	***	***	***
Roots									
Species (S)	2	***	***	***	***	***	***	***	***
Time (T)	2	***	***	***	***	***	***	***	***
Rate (R)	2	***	***	***	***	***	***	***	***
S x T	4	***	***	***	***	***	***	***	***
S x R	4	***	ns	***	***	***	***	***	***
T x R	4	***	***	***	***	***	***	***	***
S x T x R	8	***	***	***	***	***	***	***	***

*** = P<0.01; ns = not significant

The accumulation of nutrients in the components of maize grown on soil amended with leaf litter biomass from sub-tropical fruit trees is given in Table 6.6. There was a significantly higher (P<0.01) accumulation of P, K, Ca, Mg, and Zn in the shoots of maize while the concentration of N, S and Mn was significantly higher (P<0.01) in the roots.

Table 6.6 Accumulation of nutrient elements in the shoots and roots of maize plants grown on soil amended with leaf litter biomass

Component	Nutrient elements							
	N	P	K	S	Ca	Mg	Zn	Mn
	(%)	----------	----------	----------	(mg kg^{-1})	----------	----------	----------
Shoot	0.56	1646	30169	1077	3162	3662	38	212
Roots	0.61	760	2101	1837	2091	1372	36	432
SEM	0.00237	10.96	94.1	19.1	15.8	18.3	0.284	2.78
LSD	0.00877	40.61	348.6	70.9	101.6	67.9	1.051	10.30
CV	3.6	8.2	5.2	11.8	5.4	6.6	6.9	7.8

The effects of three way interactions in the concentration of nutrients in the shoots and roots of maize plants that were grown on soil amended with leaf litter from three fruit tree species is shown in Figure 6.2 and Figure 6.3 respectively. The results show that there was a higher concentration of nitrogen in the shoots of maize plants grown on soil incubated for 6 months before planting (Figure 6.2). For both avocado and mango, higher nitrogen content was observed in the shoots of maize plants grown on soil amended with 3.3 t ha^{-1} of leaf litter biomass. The concentration of phosphorus was higher in the shoots of maize plants that were grown in soil that was incubated for 12 months before planting with higher accumulation in soil that was not amended with leaf litter and those amended with 3.3 t ha^{-1} of leaf litter. The accumulation of K was relatively higher in the shoots of maize plants grown in soil amended with 3.3 t ha^{-1} leaf litter biomass. Increasing the rate of avocado and mango leaf litter biomass to 3.3 t ha^{-1} also resulted in high accumulation of sulphur in the shoots of the maize crop (Figure 6.2).

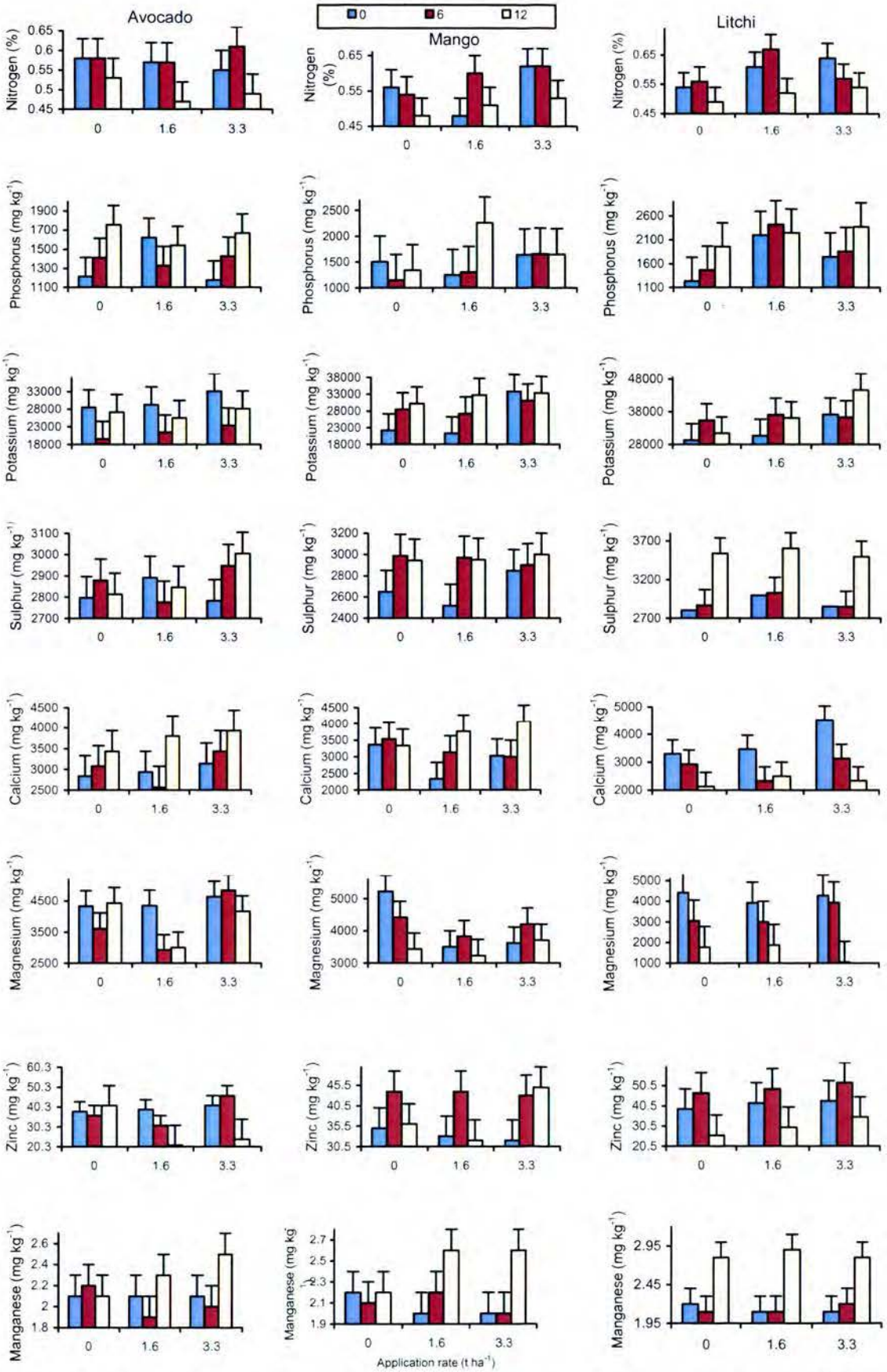


Figure 6.2 Effects of incubation period and rate of litter application on the accumulation of nutrient elements in the shoots of maize plant. Vertical bars indicate standard errors.

Increasing leaf litter application rate to 3.3 t ha^{-1} resulted in a decrease in the concentration of N and Zn in roots of the maize crop while on the other hand increased the concentration of P, K, S, Ca, Mg and Mn (Figure 6.3). Low concentration of Mg and Mn was observed in the roots of maize grown on soils that were incubated for 6 months prior to planting. This could be due to immobilization of these nutrient elements by the decomposers. Higher concentrations of P, and K were also observed in the roots of maize grown on soil amended with avocado leaf litter but not incubated. High concentrations of P, Ca, Mg and Mn were observed in the roots of maize grown on soil amended with mango leaf litter that was incubated for 12 months before planting. Incubating leaf litter biomass for 12 months resulted in low concentration of Zn in the roots of maize crop while incubating for 6 months resulted in a decline of Mg and Mn concentrations in the roots of the maize crops.

6.5.3 Nutrient uptake by maize plants grown on soil amended with leaf litter from sub-tropical fruit trees

A summary of analysis of variance (ANOVA) for N, P, K, S, Ca, Mg, Zn and Mn uptake by maize plant grown on soil amended with leaf litter from three sub-tropical fruit trees is shown in Table 6.7. The results show that there was a significant effect ($P<0.01$) on plant parts (shoot and roots) by species, time of incubation and rate of litter application on the uptake of nutrient elements by maize plant. There was also a significant ($P<0.01$) interaction of plant parts by species, plant parts by incubation time, species by incubation time and species by rate of litter application on the uptake of nutrients by maize plants. All nutrients were significantly influenced ($P<0.01$) by the three way interactions (Table 6.7).

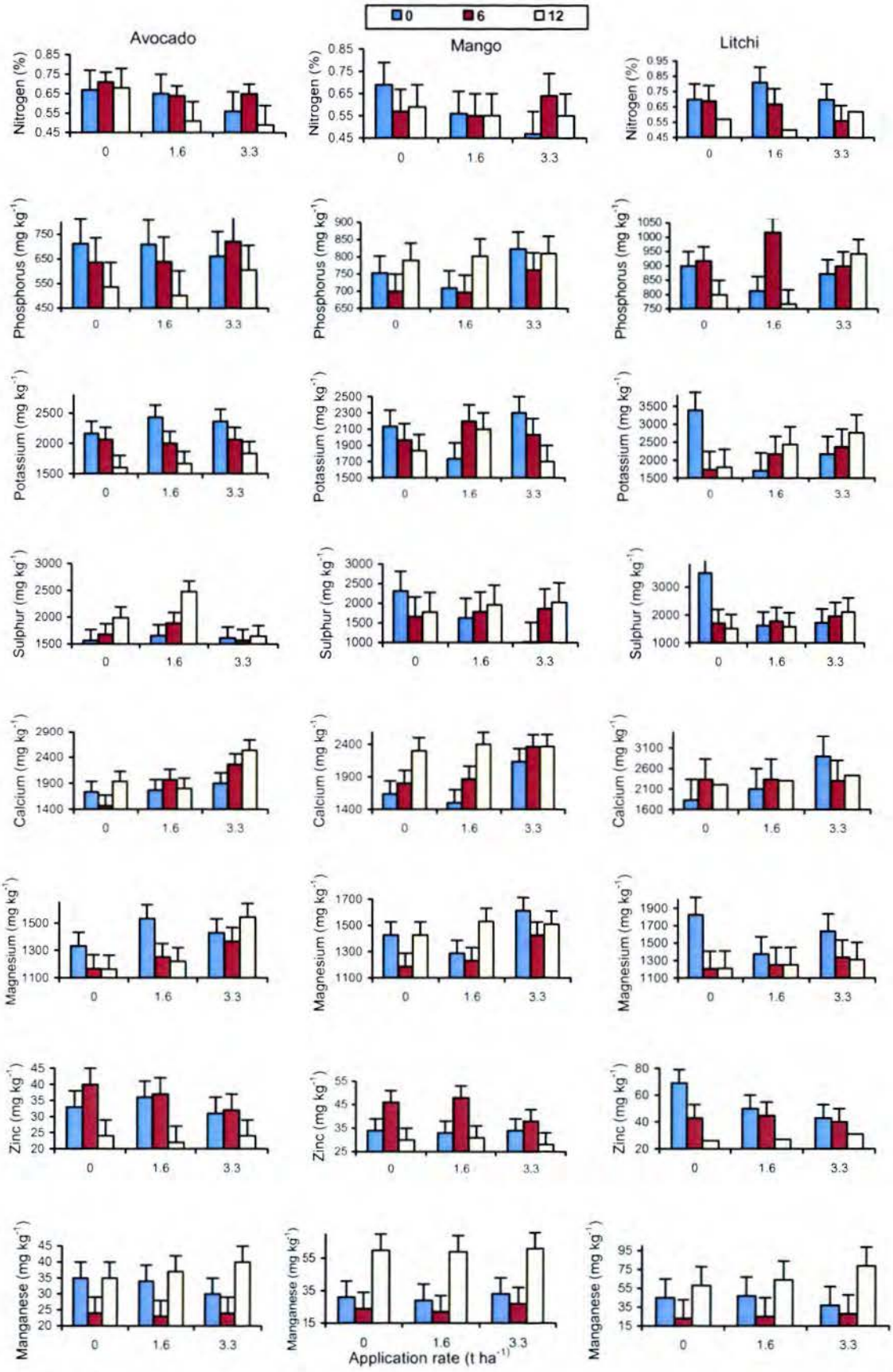


Figure 6.3 Effects of incubation period and rate of litter application on the accumulation of nutrient elements in the roots of maize plant. Vertical bars indicate standard errors.

Table 6.7 Summary of analyses of variance (ANOVA) for N, P, K, S, Ca, Mg, Zn and Mn uptake by maize plants grown on soil amended with leaf litter from three sub-tropical fruit trees

Source of variance	df	N (%)	P	K	S	Ca	Mg	Zn	Mn
			----------	----------	----------	(mg kg^{-1})	----------	----------	----------
Species (S)	2	***	***	***	***	***	***	***	***
Time (T)	2	***	***	***	***	***	***	***	***
Rate (R)	2	***	***	***	***	***	***	***	***
S x T	4	***	***	***	***	***	***	***	***
S x R	4	***	***	***	***	***	***	***	***
T x R	4	***	***	***	***	***	***	***	***
S x T x R	8	***	***	***	***	***	***	***	***

*** = P<0.01; ns = not significant

The effect of leaf litter type, incubation period and application rate on the uptake of nutrient by maize plants is given in Figure 6.4. Increasing the rate of leaf litter biomass resulted in increasingly higher nutrient uptake by the maize crop. For avocado and litchi leaves, increasing the rate of leaf litter biomass resulted in increasingly higher uptake of N, P, K, Ca and Mg. For mango leaves, increasing the rate of leaf litter biomass application resulted in lower uptake of sulphur. High uptake of N, P, S, Mg and Zn was observed in the maize plants grown on soils amended with avocado and mango leaf litters incubated for 6 months before planting while in mango leaves, higher uptake of N, P, K, Ca, Mg and Zn was observed in maize plants grown on soil incubated for 12 months before planting. Generally the results of this study demonstrate the significance of incorporating leaf litter biomass into the soil prior to planting since this practice enhances litter decomposition and nutrient release.

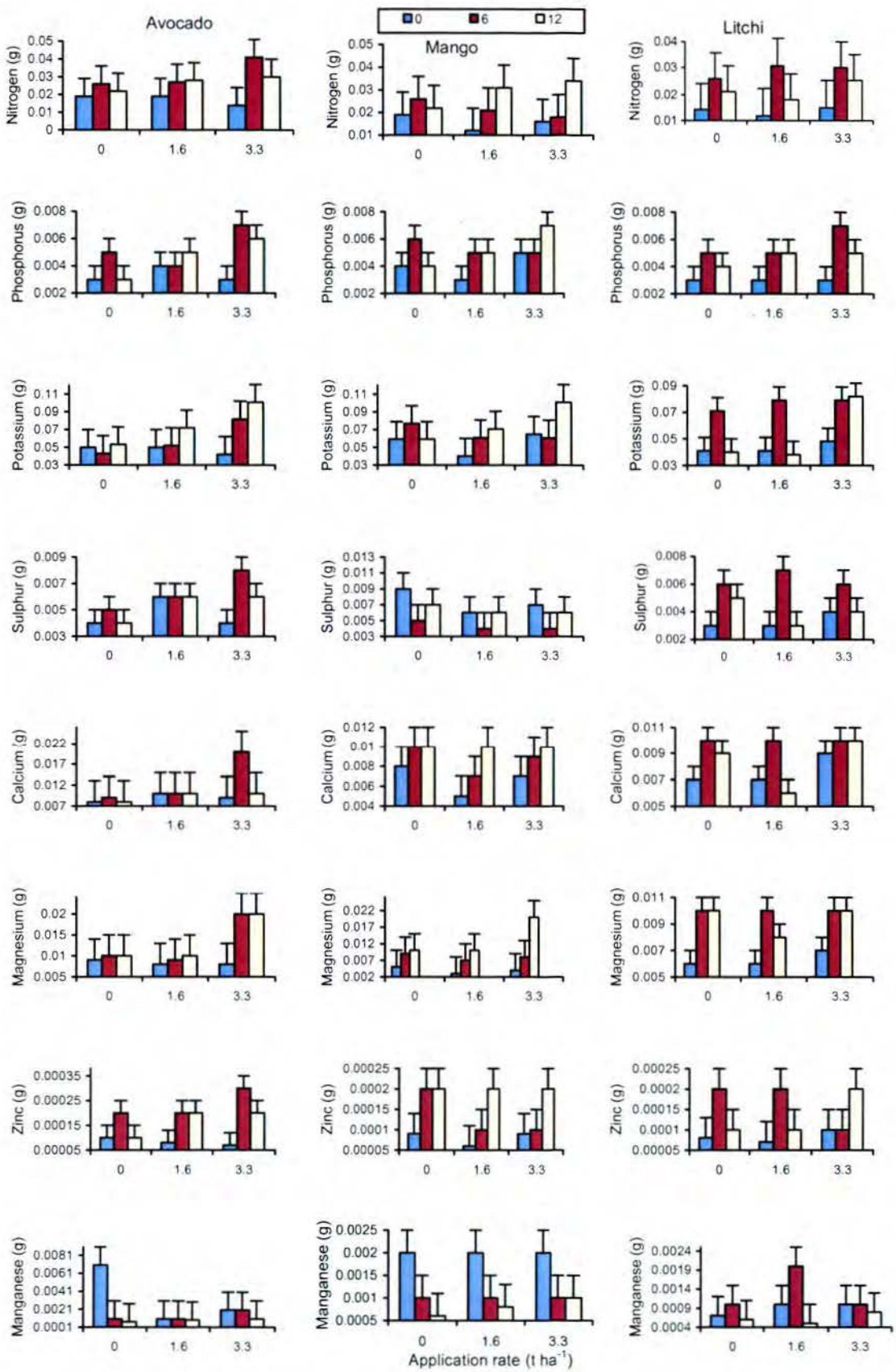


Figure 6.4 Effects of incubation period and rate of leaf litter application on the uptake of nutrients by maize grown on soil amended with leaf litter from three tree species. Vertical bars indicate standard errors.

The response by maize to the application of leaf litter biomass from the three tree species was determined by the dry matter yields, plant height and leaf discoloration. Figure 6.5 show the response by maize planted on soils that were amended with 0, 1.6 and 3.3 t ha^{-1} of mango leaf litter biomass respectively. The crops that were growing on soil without leaf litter biomass looked greener compared to those that received 1.6 and 3.3 t ha^{-1} of leaf litter biomass. Figure 6.6 shows that for the high quality litter (avocado, far right), increasing rate of leaf litter biomass application resulted in higher growth while in the low quality litter (mango, far left), the increase of leaf litter application was associated with reduced growth and purple coloration of leaves. Figure 6.7 compares the height of maize plants that were grown on an un-incubated soil amended with 3.3 t ha^{-1} of avocado, mango and litchi leaf litter, respectively. There was no obvious difference in plant height of the three maize crops implying that there was no immobilization of nutrients which could have negatively affected the growth of the maize plants.

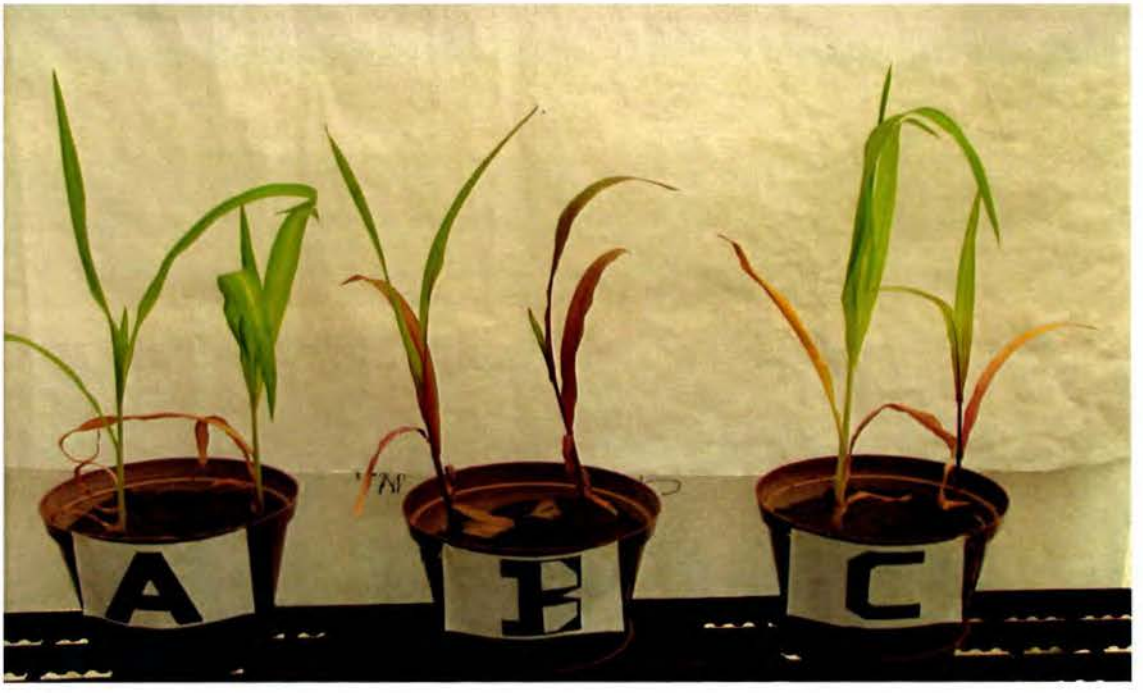


Figure 6.5 Maize plants grown on soil amended with mango leaf litter applied at 0 (A), 1.6 (B) and 3.3 t ha^{-1} (C), respectively (48 days after planting)

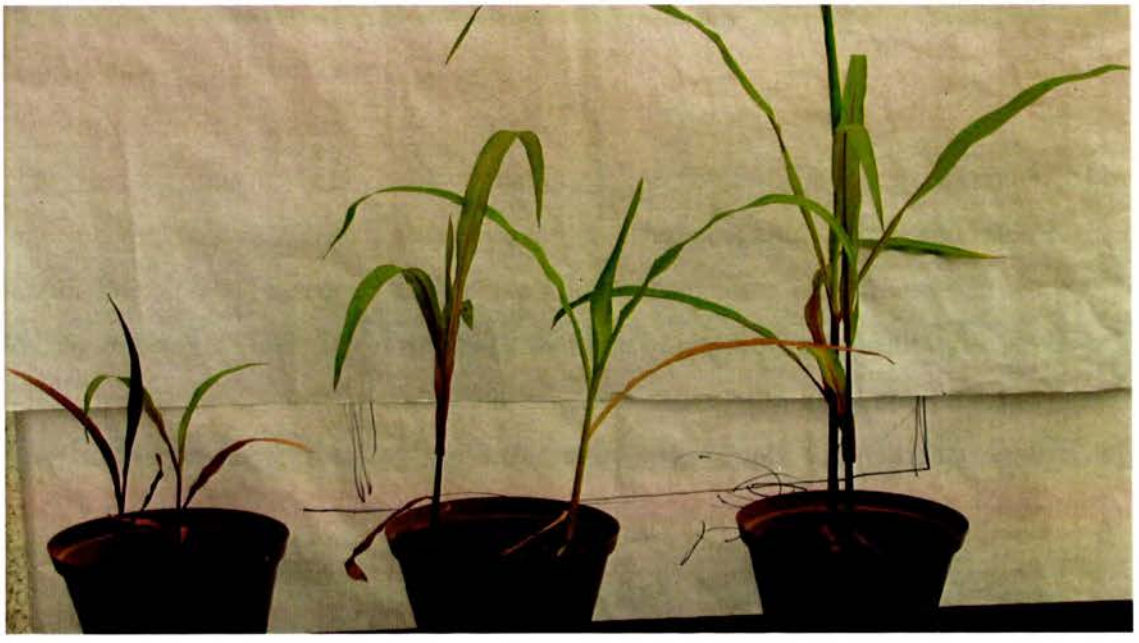


Figure 6.6 Maize plants grown on soil amended with 3.3 t ha^{-1} of litchi, mango and avocado leaf litter biomass respectively (48 days after planting)



Figure 6.7 Maize plants grown on soil that was not incubated (48 days after planting)

6.6 Discussion and conclusion

The results of this study have shown that dry matter yields of maize were influenced by the species, time and rate of leaf litter application. The incubation period and rate of leaf litter applied also played a crucial role in determining the amount of nutrients that were released during decomposition. The observation that rate of leaf litter application had no significant influence on the dry matter yields and height of maize crop can imply that the amount of leaf litter that was applied was not large enough to supply the nutrients required by the maize plants. However, applying too much leaf litter did not necessarily mean that plants would obtain more nutrients from the decomposing litter. The application of avocado leaf litter biomass at the rate of 3.3 t ha^{-1} resulted in high growth and dry matter yields. Due to its better quality compared to mango and litchi leaf litter, the avocado litter decomposed and released nutrients more rapidly so that it might have coincided with nutrient demand by the maize plants.

The low response by maize plants to mango and litchi leaf litter could therefore be attributed to a slow rate of mineralization and possible immobilization of nutrients due to their large C:N ratio and high lignin contents. Several studies have indicated that high quality litter decomposes fast and releases nutrients rapidly (Hebert *et al.*, 1991; Cadisch and Giller, 1997; Nyathi and Campbell, 1993). The finding in this study suggests that the incubation period of between 6 and 12 months was not long enough particularly for mango and litchi leaf litter to break down and pass through the nutrient immobilization stage. It is suggested that the leaf litter from the three fruit trees need to be mixed together during incorporation into the soil since they decomposed and released nutrients at different times. This can help to enhance synchronisation of nutrient release and crop demand. Several authors have found that mixing litter from different species is a better way of enhancing synchronisation of nutrient release with crop uptake since different leaf litter decompose and release nutrients at different times (Jama *et al.*, 2000; Mapfumo and Giller, 2001; Palm *et al.*, 2001).

An interesting observation was the higher concentration of nutrients in tissues of maize plants that were grown in soil that was not amended with leaf litter. This is consistent with the results from Chapter Five which found that there was immobilization of nutrients (N, S, Ca, Mg and Mn) in soils amended with leaf litter, whereas the nutrients that were present in

the soils which were not treated with leaf litter were readily available for uptake by maize plants. Similarly, Nyamangara *et al.* (2001), in Zimbabwe found that, after 77 days of incubation of mango litter, the control (treatment without leaf litter) mineralized more nitrogen than soil amended with untreated or composted mango litter.

Immobilization of nutrients is common particularly when litter of poor quality is incorporated into the soil (Schmidt, 1999; Mafongoya *et al.*, 1998). The decomposer organisms utilize the available nutrients for their own benefit until such a time when they perish and the nutrients become available for plant uptake (Millar and Turk, 1948; Schmidt *et al.*, 2002). This comes not as a surprise since it was reported in the previous chapters of this study that the quality of these three tree species was poor compared to species such as *Tithonia diversifolia* (Jama *et al.*, 2000), *Leucaena leucocephala* (Tian *et al.*, 1993), and *Gliricidia sepium* (Tian *et al.*, 1993) that are commonly used for replenishing soil fertility. Poor green colour and purple coloration in the leaves of maize grown in soils amended with poor quality leaf litter was a deficiency symptom of nitrogen, sulphur and manganese. Several authors have reported the importance of these three nutrient elements on the growth and development of maize crops particularly at an early stage (Osmond and Riha, 1996; Hitsuda *et al.*, 2005; Lisuma *et al.*, 2006).

There was a higher concentration of nutrients in the shoots of maize plants than in roots. The accumulation of P, K, Ca, Mg and Zn were higher in shoots while more N, S and Mn accumulated in the roots. This trend could be due to differences in mobility of the nutrients within plants (Brown and Shelp, 1997; Aphalo *et al.*, 2002; Papadaksi *et al.*, 2007). It was very interesting to find that the nutrients that were reported to have been immobilized in Chapter Five had high accumulation in roots implying that there was indeed a limitation of these nutrients in the soil. Higher concentration of K, Ca and Mg in shoots of maize plants was also reported by Materechera (2002) who also attributed this difference to nutrient mobility. The pattern in nutrient uptake mirrored that of growth and dry matter yields. Except for Zn, the uptake of other nutrient elements by maize grown on soil amended with avocado leaf litter biomass was significantly lower ($P<0.05$) than that from the other treatments. The increase in nutrient uptake due to application of leaf litter biomass was higher on maize plants grown on soil amended with mango leaf litter. This finding seems to support the claim that plants that are grown on nutrient poor soils have greater capacity

of absorbing nutrients from the soil than those grown on nutrient rich soils (Mackie-Dawson *et al.*, 1990; Hegde, 1997).

In order to avoid immobilization of nutrient elements by microorganisms during decomposition of leaf litter biomass, it is necessary to supplement or mix the low quality litter with judicious amounts of inorganic fertilizers so that the growing food crops can also have an access to nutrients for better growth and development (Palm *et al.*, 2001). In cases where chemical fertilizers such as superphosphate and lime ammonium nitrate are not available, farmers could mix the low quality leaf litter biomass with other high quality materials such as chicken manure, kraal manure and or wood ash. Another available option is to incorporate the leaf litter for a longer period of time prior to the establishment of food crops so that the leaf litter can have an adequate time to decompose and release nutrients to the soil. Based on the responses of the maize, this study suggests that the amount of litter applied by farmers might not sustain the yield of food crops grown by farmers. It was found from this study that the application of about 3.3 t ha^{-1} of mango and litchi leaf litter biomass did not result in a significant increase in growth and dry matter yields of maize. Small scale farmers could therefore be advised to mix leaf litter with other amendments that are rich in nutrients, especially chicken and / or kraal manure. This can be achieved by collecting animal manures from the kraal or collecting manure from their neighbors who have animals.

This study has demonstrated the importance of applying leaf litter from sub-tropical fruit trees to replenish soil fertility. Among the leaf litter types that were studied, avocado leaf litter produced high dry matter yields. The study also revealed the importance of incubating leaf litter which gives it enough time to decompose and release nutrients for plant uptake. The study however indicates that the time of incubation is important in enhancing synchronization of nutrients with crop demand. It is also concluded that, for high quality litter, increasing the rate of litter application results in increased dry matter yields whereas for poor quality litter, increasing the rate of litter application results in reduced growth and dry matter yields. The utilization of leaf litter by small scale farmers for nutrient cycling requires special attention to those management strategies in order to maximize the benefits for soil fertility management. It is therefore suggested that farmers should incubate leaf litter into the soil for at least 12 months before planting or rather subjected leaf litter to composting before they are applied to the crop fields.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMENDATIOS

The point of departure in this study was that there is a problem of low soil fertility within the Ehlanzeni District Municipality particularly in the small scale sector. Low soil fertility is a problem not only within the EDM. Many countries around the globe are facing the same problem. There are different approaches that are used by farmers to deal with the problem of poor soil fertility depending on available resources. The dynamic nature of the concept of soil fertility has meant that its definition has changed over time and so have the management practices (Nath, 1940). This thesis has adopted the biological management paradigm which emphasises the use of organic plus inorganic inputs to manage fertility. The study has identified two unique, valuable resources within the EDM that can be used as a solution to low soil fertility problem. These resources include indigenous knowledge and leaf litter from sub-tropical fruit trees. However, in order to use these resources successfully there is a need for understanding of how best the two resources can be linked together to improve crop productivity. The farmers do possess knowledge related to production, management and utilization of the resources. This knowledge is being used to improve soil fertility and increase crop productivity. It was established in this study that some of the knowledge has scientific basis in the sense that some of the practices that they use have agreed with some of the research results conducted at the research station. This study has contributed to an understanding of the biomass produced by three fruit tree species during litterfall and the factors that influence its decomposition and nutrient release.

Farmers indicated that they collected large amounts of leaf litter from litchi and mango tree species which was consistent with station results. Furthermore, farmers indicated that they collected leaf litter from fruit tree species and composted or mixed them with other amendments such as kraal manure, chicken manure and wood ash in order to improve quality of the litter. This was a clear indication of their knowledge about aspects of litter quality and how to manage it. The results of quality analysis at the station confirmed that the quality of the three species that were studied was poor. Leaf litter from all three tree species was generally characterized by low nitrogen content, high C:N ratio, high lignin and cellulose content. According to Palm *et al.* (2001), this type of litter biomass cannot be incorporated directly into the soil without being amended with other high quality materials.

Another litter management practice by farmers involved the synchronisation with crop growth. Farmers collected leaves in spring and incorporated them before ploughing which is usually done in summer. This practice indicates that farmers knew that the litter from fruit trees needs time to decompose before it is applied to crops. This was also consistent with the outcomes of the uptake study which showed a poor response by a maize crop grown on soil amended with leaf litter. In some cases, plants that were grown in soil without leaf litter grew better compared to those grown in soil amended with leaf litter.

Although farmers have some knowledge about the production, utilization and quality of leaf litter, the study identified some gaps that need to be closed in order to get maximum benefits of using leaf litter biomass for replenishing soil fertility and increase crop productivity. The amount of leaf litter that the farmers applied is very small compared to what other researchers have suggested (Nyathi and Campbell, 1993; Musvoto and Campbell, 1995; Mapfumo and Giller, 2001). Majority of the responding farmers indicated that they applied less than 100 kg of leaf litter per hectare. This low rate of biomass application could be due to unavailability of enough leaf litter and it is therefore suggested that farmers must be encouraged to use other sources of nutrients such as animal manure in order to improve soil fertility and increase crop production. This result suggests that the leaf litter that farmers have is limited and hence could be better used on smaller areas such as those of vegetables. Since the knowledge of the farmers related quite well with scientific results, it is of paramount importance for researchers to conduct some trials on farmer's fields in order to properly interface indigenous knowledge with scientific knowledge.

Small scale farmers in the study area are already aware that there are certain periods of the year when they collect more leaf litter from trees and that the leaf litter needs to be stored until time of field preparation. During this storage period, certain management practices can be done in order to improve quality of the litter. For those farmers who own cattle, the litter could be cured in cattle pens for a certain period of time. This practice is common in the Central Himalayan Mountains of India where farmers collect leaf litter from oak trees and cure them in cattle pens as a means of improving quality (Rao *et al.*, 2003). Some farmers in Zimbabwe also use the same strategy (Naythi and Campbell, 1993). Furthermore, leaf litter can be composted in order to enhance its decomposition. It is very important for researchers to recognize farmers' knowledge and use it in conjunction with

scientific knowledge particularly where the research is aimed at improving rural people's lives.

An important observation made from the study that the poor quality litter immobilised some nutrients (N, S, and Mn) during the decomposition process. The implication of this is that if crops were grown in this soil at this time there would be insufficient amounts of these nutrients for crop growth unless other sources of nutrient such as fertiliser, ashes and manure are added to the litter biomass. The results also revealed that the decomposition of this litter biomass proceeded at very slow rate and requires a long time for it to complete decomposition implying the need for longer incorporation period for the litter biomass to decompose before crops are planted. Another possibility to deal with immobilization could be to mix the litter of different qualities. It is important that studies be conducted to understand the effect of these different litter management practices on nutrient release and crop response to them especially when mixed with other amendments.

When leaf litter biomass is added to the soil under favourable conditions, they are subjected to various changes involving chemical agencies and the activities of the various groups of soil microbes (Cundell, 1977). The microbes play prominent roles in transforming nutrient elements into forms available for plants (Gyaneshwar *et al.*, 2002). However, small scale farmers have so far little knowledge about the role of microorganisms on the decomposition of leaf litter from sub-tropical fruit trees that were investigated in this study. There are several types of microbes that perform the decomposition process and they operate under different climatic and environmental conditions (Cundell, 1977). There is a need to identify microbial populations and types that are responsible for the decomposition of litter for each of the three tree species in order to understand how they could be managed to optimise decomposition and nutrient release processes. This can also assist in devising strategies of nurturing the organisms that are responsible for the decomposition of litter biomass.

One of the major gaps that were identified in this study was the lack of knowledge by small scale farmers on the issue regarding the quality of litter biomass. Several studies have identified litter biomass quality as one of the prominent factors that govern its decomposition and nutrient release process (Swift *et al.*, 1979; Cadisch and Giller, 1997; Mafongoya *et al.*, 1998; Mapfumo and Giller, 2001). Several management practices have

been suggested in order to manipulate the quality of litter biomass (Mafongoya *et al.*, 1998; Palm *et al.*, 2001). However, there seemed to be little understanding by small scale farmers about the meaning, importance and management of litter biomass quality. One other way of dealing with this constraint is to create awareness to the farmers about litter biomass quality and this can be done through workshops and seminars and or by publishing leaflets that define litter quality, its importance and management practices that can be applied in order to enhance quality of litter biomass. Extension agents can play a major role in organizing or transferring this information since they spend most of their time with small scale farmers.

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APPENDIX 1

Questionnaire used to evaluate the perception of rural farmers within the Ehlanzeni District Municipality regarding the management and utilization of fruit tree litter as an integral part of improving soil fertility on their farms.

Name of the farmer :

Municipality :

Location :

Tel/Cell No :

ID No :

A. Litter fall and litter quality

1. How do you consider leaf litter on your farm?
    a. as a waste/nuisance in your field
    b. as a useful organic amendments
    c. don't consider their existence
    d. other (specify) _____
2. Approximately how much litter do your trees produce per year? (considering 25kg bag)
    a. 1 – 20
    b. 21– 40
    c. >41
3. Does the yield of leaf litter from your trees vary in seasons?
    a. yes
    b. no
4. If yes which season do you get more leaf litter from your trees?
    a. summer (Dec - Feb)
    b. spring (Sep - Nov)
    c. winter (Jun - Aug)
    d. autumn (Mar - May)
    e. I don't know
5. What do you do with fruit tree leaf litter on your farm?
    a. burn them
    b. collect them for compost
    c. use them as mulch
    d. incorporate them into the soil
    e. other (specify)_____
6. When do you apply fruit tree leaf litter to the soil?
    a. any time
    b. summer
    c. winter

d. autumn
e. spring

7. Why do you apply fruit tree leaf litter to the soil?
8 How do you apply fruit tree leaf litter in your field?
   a. apply them around the tree
   b. scatter them on the entire field
   c. apply them as a compost
   d. other (specify) _____
9. Why do you apply fruit tree litter in this way?

10. To which plants do you apply fruit tree leaf litter?
   a. fruit trees
   b. field crops
   c. vegetables
   d. flowers
   e. other (specify)_____
11. How long does it take for leaf litter to be decomposed?
   a. >1 month
   b. 1 – 2 months
   c. 3 – 4 months
   d. < 6 months
12. What do you think are the primary decomposers of fruit tree litter on your field?
   a. termites
   b. earthworm
   c. fungi
   d. other (specify) _____
13. Do you apply fruit tree litter to the:
   a. whole field
   b. part of the field
14. Is there any means of enhancing leaf litter decomposition that you use?
   a. yes
   b. no
15. If yes what is it and how? (Explain)

16. Which factor do you think has a greater influence on litter decomposition on your farm?
   a. temperature
   b. litter quality
   c. other (specify) _____
17. According to your knowledge which tree species produces more leaf litter?
   a. avocado
   b. litchi
   c. macadamia
   d. mango
   e. no idea

18. Do you prune your trees?
   a. yes
   b. no

19. If yes how often do you prune your trees?
    a. once a year
    b. twice a year
    c. once in two years
    d. other (specify)_____
20. Why do you prune your trees?
    a. to shape the tree
    b. to stimulate new growth and flowering
    c. to obtain leaves
    d other (specify)_____
21. What do you do with the pruned material thereafter?
    a. burn them
    b. use them as mulch
    c. use them as fuel
    d. leave them scattering in the field
    e. incorporate into the soil
    f. I don't know
    g. other (specify)_____
22. Do you incorporate?
    a. leaves and stems
    b. leaves only
    c. stem only
23. Why do you incorporate them like this?

24. Do you make compost with the leaf litter from your fruit trees?
    a. yes
    b. no
25. Why do you make compost?
    a. to recycle nutrients for your trees
    b. to sell it
    c. as part of waste management
    d other (specify)_____
26. Do you think leaf litter influences soil properties on your farm?
    a. yes
    b. no
27. If yes how does leaf litter affect soil properties on your farm?
    a. by improving soil fertility
    b. adds organic matter
    c. improves water holding capacity
    d. improves water infiltration
    e. reduces bulk density
    f. other (specify)_____
28. Is there a different between leaf litters of different fruit trees?
    a. yes
    b. no
    c. do not know
29. If yes, explain _____

30. Does different tree litter have different effects on soil and trees?
    a. yes
    b. no
    c. do not Know
31. If yes, how do they differ, explain_____
32. How do you apply leaf litter to your trees?
    a. burry them into the soil
    b. place them on the soil surface
    c. I do not
    d. other (specify)_____
33. Why do you use this method of application?
    a. it is cheap
    b. it is quick
    c. it promote decomposition process
    d. other (specify)_____

B. Soil fertility

1. How do you rate the fertility status of the soil on your farm?
    a. good
    b. average
    c. poor
    d. do not know
2. What measures do you take to improve soil fertility on your farm?
    a. apply inorganic fertilizers
    b. use organic amendments
    c. use manure
    d. none
    e. other (specify)_____
3. How do you compare leaf litter and fertilizer for soil fertility management?
    a. inorganic fertilizers are best
    b. organic fertilizer are best
    c. they have the same effects
    d. do not know
    e. other (specify)_____
4. Do you use fruit tree leaf litter to improve soil fertility?
    a. yes
    b. no
5. How often do you use fruit tree leaf litter for soil fertility?
    a. every year
    b. once in 2 years
    c. once in three years
    d. other (specify)_____
6. When you use leaf litter for soil fertility, do you mix them with anything else?
    a. yes
    b. no

7. If yes what do you mix leaf litter with?
    a. chicken manure
    b. kraal manure

c. wood ashes
d. crushed bones
e. other (specify)_____

8. Why do you mix litter with that material?
   a. to increase nutrients contents
   b. to prevent soil acidification
   c. to prevent nutrients immobilization
   d. other (specify)_____
9. How much leaf litter is used per tree per year?
   a. 1 – 50 kg
   b. 51 – 70 kg
   c. 71 – 100 kg
   d. >100 kg
10. How often do you use inorganic fertilizers in your field?
   a. every year
   b. once in two years
   c. once in three years
   d. nothing at all
11. What kind of fertilizers do you have access to?
   a. inorganic fertilizers
   b. organic fertilizers
   c. other (specify)_____
12. How did you determine the fertility status of your soil?
   a. by looking at the colour of the soil
   b. through soil sample results
   c. through tree performance
   d. I do not
13. How often do you take soil samples?
   a. every year
   b. once in 2 years
   c. once in 3 years
   d. nothing at all
15. What analysis do you conduct on them?
   a. chemical analysis
   b. physical analysis
   c. biological analysis
   d. all of the above
   e. other (specify)_____
16. Where do you send samples for analysis?
   a. private laboratories
   b. government laboratories
   c. no where
   d. other (specify)_____
17. Where do you get fertilizers?
   a. from the co-ops
   b. from the animals
   c. other (specify)_____
18. Do you consider mixing fruit trees with other tree/shrubs on your field?
   a. yes
   b. no

19. How can you benefit from incorporating other trees/ shrubs on your field?
    a. generating extra income
    b. protecting soil from erosion
    c. increasing plant litter on your farm
    d. nothing
    e. other (specify)_____
20. What type of trees/ shrubs would you consider incorporating on your farm?
    a. pine trees
    b. gum trees
    c. indigenous trees
    d. other (specify)_____
21. Why do you consider these trees?
22. Which food crops do you integrate with fruit trees on your farm?
    a. maize
    b. vegetables
    c. medicinal plants
    d. none
    e. groundnuts
    f. other (specify)_____
23. Do you practice agroforestry on your farm?
    a. yes
    b. no
24. If yes explain_____
25. What is the most limiting factor in implementing agroforestry?
    a. lack of finance
    b. lack of land
    c. lack of knowledge
    d. other (specify)_____
26. What type of cropping system is you practicing on your farm and why?
    a. multiple cropping
    b. relay cropping
    c. multi-layer cropping
    d. pure stand
    e. other (specify)_____
27. Do you have animals in your farm?
    a. yes
    b. no
28. If yes what type of animals do you have on your farm?
    a. goats
    b. cattle
    c. sheep
    d. other (specify)_____
29. How many animals do you have on your farm?
    a. 1 – 5
    b. 6- 10
    c. 11 – 15
    d. 16 – 20
    e. >20

30. How do you integrate animals into the fruit cropping
    a. use them for ploughing land
    b. use them for accessing manure
    c. other (specify)_____
31. How much manure do you get from your animals per year?
    a. 10 – 50kg
    b. 60 – 100kg
    c. 110 – 200kg
    d. >300 kg
32. Do you use the animal manure for soil fertility?
    a. yes
    b. no
33. Is that manure good enough to improve soil fertility on your farm
    a. yes
    b. no
34. How do you apply the animal manure?
35. Do you plant leguminous crops on your farm?
    a. yes
    b. no
36. If yes why are you planting them?
    a. for consumption
    b. to generate income
    c. for fixing atmospheric nitrogen
    d. as a cover crops
    e. other (specify)_____
37. What kind of leguminous crops do you plant?
    a. cowpeas
    b pigeaonpeas
    c. groundnuts
    d. bambaranuts
    e. other (specify)_____
38. Are the legumes:
    a. pure stand
    b. mixed stand

C. Fruit tree establishment and management

1. How do you establish your fruit trees?
    a. seed
    b. seedlings
    c. grafting
    d. air layering
    e. arching
    f. other (specify)_____
2. What do you use your fruit trees for?
    a. shading
    b. wind breaks
    c. food security
    d. income generation
    e. other (specify)_____

3. What kind of trees do you have on your farm?
    a. mango
    b. avocado
    c. litchi
    d. macadamia
    e. other
4. How many trees of each do you have on your farm?
    a. 5 - 20
    b. 21 - 45
    c. 46 - 85
    d. > 86
5. What do you consider to be the major factors that limit growth and development of your fruit trees?
    a. poor soil fertility
    b. lack of water
    c. lack of production knowledge
    d. disease and pests
    e. poor management
    f. other (specify)_____
6. Do you take leaf samples from your trees for analysis?
    a. yes
    b. no
7. Why do you take leaf samples?
    a. to determine nutrients requirements by trees
    b. to determine nutrient available in the soil
    c. to determine type and amount of fertilizer to apply
    d. other (specify)_____
8. How do you collect leaf samples from your fruit trees?
9. When do you collect leaf samples from your fruit trees?
    a. every time of the year
    b. before harvest
    c. after harvest
    d. other (specify)_____
10. How often do you take leaf samples?
    a. every year
    b. once in 2 years
    c. once in 3 years
    d. not at all
11. What analysis do you conduct on them?
    a. nutrient element analysis
    b. dry matter analysis
    c. all of the above
    d. other (specify)_____
12. Where do you send samples for analysis?
    a. private laboratories
    b. government laboratories
    c. other (specify)_____

D. Fruit production

1. What do you do with the fruit after harvest?
    a. sell them
    b. save them for household consumption
    c. dry them for future use
    d. other (specify)_____
2. How much fruit do you harvest per tree per year?
    a. 10 – 50 kg
    b. 55 – 100 kg
    c. 105 – 150 kg
    d. 155 - 200 kg
    e. > 200 kg
3. Where do you sell your fruits?
    a. in local market
    b. international market
    c. free market
    d. other (specify)_____
4. What is the total income from your fruits per year?
    a. R100 – R300
    b. R400 – R700
    c. R800 – R1000
    d. > R1000
5. Which fruit tree do you think is the best in terms of generating income in your area?
    a. mango
    b. avocado
    c. litchi
    d. other (specify)_____
6. What do you do if you produce more than what you can sell?
    a. share with the neighbours
    b. dry the fruits
    c. throw them away
    d. other (specify)_____
7. Apart from fruits what other products do you get from your trees?
    a. wood
    b. seeds
    c. fodder
    d. compost from leaves
    e. medicine
    f. wax
    g. other (specify)_____
8. What do you do with these products?
    a. sell them
    b. reserve them for future use
    c. other (specify)_____

E. Demographics

1. What is the source of your income?
    a. Grant
    b. Salary
    c. farm sale
    d. other (specify)_____
2. Are you: (select one)
    a. male
    b. female
3. Which of the following group include your age?
    a. 16 – 35
    b 33 – 64
    c > 65
4. What is the highest level of education you have achieved?
    a. primary education
    b. secondary education
    c. tertiary level
5. What is the size of your farm?
    a. < 1.0 ha
    b. 1.0 – 10 ha
    c. >10
6. Do you:
    a. own land
    b. communal land
    c. other (specify)_____
7. What are the major sources of labor on your farm?
    a. self
    b. family members
    c. hired labor
    d. other (specify)_____
8. Are the hired labors:
    a. full time
    b. part time
    c. other (specify)_____
9. Are you:
    a. a subsistence farmer
    b. an emerging farmer
    c. a commercial farmer
    d. a small-scale farmer
    e. other (specify)_____

THANKS FOR PROVIDING ME WITH THIS VALUABLE INFORMATION