

DECLARATION

THE EFFECTS OF *Grevillea robusta* TREES ON SOME SOIL CHEMICAL AND PHYSICAL PROPERTIES IN SEMI ARID AREAS: "A CASE STUDY OF KATHEKA-KAI AND KATELEMBU LOCATIONS OF MUMBUNI DIVISION, MACHAKOS DISTRICT, KENYA"

By.

Fidelis N. Nthenge

**A thesis submitted in partial fulfilment of
The degree of Master of Environmental Studies (M.ENV.S)
of Kenyatta University.**

2006.

Nthenge, Fidelis N.
*The effects of
Grevillea robusta*



2008/322516

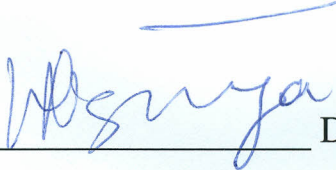
DECLARATION.

This thesis is my original work and has not been presented for a degree in any other university.

Signed  Date 19/10/2006

Fidelis N. Nthenge

This Thesis has been submitted with my approval as University supervisor.

Signed  Date 19/10/2006

Prof. W. Wamicha
Department of Environmental Science
Kenyatta University.

ACKNOWLEDGEMENTS

DEDICATION.

This work is dedicated to my family, and especially my husband, Mr. Anthony Nthenge, who kept on encouraging me to finish the course.

ACKNOWLEDGEMENTS

This work would not have been completed without the cooperation and assistance of a number of people. Particular gratitude and sincere thanks go to my supervisors Prof. W. Wamicha and the late Dr. Owino G. for their continuous guidance throughout this study.

Many thanks go to the staff of the Faculty of Environmental Studies, Kenyatta University for their encouragement. I wish to extend my gratitude to my friends and relatives for their continuous support and understanding despite the time taken to finish. My deep appreciation goes to Mr. Makau of FAWE for his assistance in typing the initial draft of the work. Special thanks to the technical staff of the department of Soil Science, University of Nairobi, Kabete Campus for assisting in the laboratory analysis.

I am most grateful to my husband Mr. Anthony Nthenge for his assistance throughout the study. I also thank ICRAF for providing resource materials and permitting this research to be carried out in a site that they had initiated a tree-planting project. Last but not least, thank you to Kenyatta University for the Scholarship and funding of this study.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION	1
1.1 BACKGROUND OF THE STUDY.....	1
1.2 STATEMENT OF THE PROBLEM.....	1
1.3 OBJECTIVES OF THE STUDY.....	2
1.4 JUSTIFICATION OF THE STUDY.....	2
1.5 SIGNIFICANCE OF THE STUDY.....	3
1.6 BASIC ASSUMPTIONS.....	3
1.7 LIMITATIONS OF THE STUDY.....	3
1.8 DEFINITION OF TERMS.....	4
CHAPTER TWO: LITERATURE REVIEW.	5
2.0 Introduction.....	5
2.1 Agroforestry Systems in general.....	5
2.2 Evolution of the National Forest Policy and Plans.....	5
2.2.1 Tree Planting in Kenya.....	6
2.2.2 Current Agroforestry Plans and Policies.....	7
2.3 On- farm research.....	8
2.3.1 Relevance of on-farm research.....	8
2.3.2 On-farm visits and individual meetings.....	10
2.3.3 Benefits from trees in agroforestry systems.....	11
2.3.4 <i>Grevillia robusta</i> in agroforestry.....	12
2.4 Adverse effects of trees on crops.....	13
CHAPTER THREE: MATERIALS AND METHODS.	16
3.0 Introduction.....	16
3.1.1 The study area.....	16
3.1.2 The pilot survey.....	19
3.1.3 Soil Sampling.....	19
3.2 ANALYTICAL METHODS.....	21
3.2.1 Chemical Analysis.....	21
3.2.1.1 pH Determination.....	21
3.2.1.2 Organic carbon.....	21

3.2.1.3 Total Nitrogen.....	21
3.2.1.4 Available Phosphorous	22
3.2.1.4 Determination of CEC (Exchangeable Cations), BS and ESP	22
3.2.1 Physical Analysis	23
3.2.2.1 Particle Size Analysis (Texture)	23
3.2.2.1 Bulk Density (BD).....	24
3.2.2.3 Porosity (f)	24
3.2.1.4 Antecedent Moisture Content (w).....	24
3.2.2.5 Moisture Retention and Release.....	25
3.3 Statistical analysis	25
CHAPTER FOUR: RESULTS AND DISCUSSION.....	26
4.0 Introduction.....	26
4.1 Properties of Alisols and Luvisols.	26
4.1.1 Alisols	26
4.1.2 Luvisols.....	27
4.2 Soil chemical properties	27
4.2.1 pH.....	27
4.2.2 Organic Carbon(% C).....	29
4.2.3. Total Nitrogen.....	30
4.2.4 C: N Ratio	31
4.2.5 Phosphorus (in ppm).....	32
4.2.6 Cation Exchange Capacity (CEC)	32
4.2.7 Exchangeable Cations (Ca, Mg, K, Na).....	33
4.2.8 Base Saturation	34
4.2.9 Exchangeable Sodium Percentage (ESP).....	35
4.3 Soil physical properties	35
4.3.1 Particle size distribution (Texture)	35
4.3.2 Bulk Density (BD).....	37
4.3.3 Porosity (f)	38
4.3.4 Soil Moisture Content.....	38
4.3.5 Moisture Retention and Release.....	39
4.4 Factors which affect soil fertility	43

4.4.1 Effect of soil pH (reaction) on soil fertility parameters	46
4.4.2 Factors affecting N.	53
4.4.3: Factors affecting C.	56
4.4.4: Available P	61
4.4.5: Factors affecting Exchangeable Ca, Mg, K and Na.....	62
4.4.6. Factors affecting CEC.....	66
4.5: Factors affecting soil physical parameters.....	69
4.5.1: Particle size distribution.	69
4.5.2: Clay.....	71
4.5.3: Bulk density.....	72
4.5.4. Soil Porosity.....	74
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS:.....	75
5.1: Conclusions.	75
5.2: Recommendations.....	76
References.....	78

LIST OF TABLES

<u>Table 4.1 Soil chemical properties of the top soils of the Alisols (Katelembu)</u>	28
<u>Table 4.2: Soil chemical properties of the sub-soils of the Alisols (Katelembu)</u>	28
<u>Table 4.3: Soil chemical properties of the top soils of the Luvisols (Katheka – kai)</u>	28
<u>Table 4.4 Soil chemical properties of the sub-soils of the Luvisols (Katheka-kai)</u> ...	29
<u>Table 4.5 Soil physical properties of the top soils of the Alisols (Katelembu)</u>	36
<u>Table 4.6 Soil physical properties of the sub soils of the Alisols (Katelembu)</u>	37
<u>Table 4.7 Soil physical properties of the top soils of the Luvisols (Katheka-kai)</u>	37
<u>Table 4.8 Soil physical properties of the sub soils of the Luvisols (Katheka-kai)</u>	37
<u>Table 4.9: Moisture retained after different suction levels (Top soils of the Alisols)</u>	40
<u>Table 4.10: Moisture retained after different suction levels (Sub soils of the Alisols)</u>	40
<u>Table 4.11: Moisture retained after different suction levels (Top soils of the Luvisols)</u>	41
<u>Table 4.12: Moisture retained after different suction levels (Sub soils of the Luvisols)</u>	41
<u>Table 4.13 Correlation Matrix of Alisols (Chemical Parameters)</u>	44
<u>Table 4.14 Correlation Matrix of Luvisols (Chemical Parameters)</u>	45
<u>Table 4.15 Correlation Matrix of Physical parameters in the Alisols.</u>	69
<u>Table 4.16 Correlation Matrix of Physical Parameters in the Luvisols.</u>	69

LIST OF FIGURES

<u>Fig 3.1 LOCATION OF MACHAKOS DISTRICT IN KENYA</u>	17
<u>Fig. 3.2 STUDY AREA – MUMBUNI DIVISION, MACHAKOS DISTRICT</u>	18
<u>Fig. 3.3 Sampled sites (from the portion enclosed by two rows of <i>Grevillea robusta</i> trees)</u>	20
<u>Fig. 4.1 Moisture retention in mm (Alisols)</u>	42
<u>Fig.4.2 Moisture retention in mm (Luvisols)</u>	42
<u>Fig. 4.3: Relationship between pH in H₂O and Na – Alisols</u>	46
<u>Fig.4.4: Relationship between pH in CaCl₂ and Na – Alisols</u>	47
<u>Fig.4.5: Relationship between pH in H₂O and ESP – Alisols</u>	47
<u>Fig. 4.6: Relationship between pH in CaCl₂ and ESP -Alisols</u>	48
<u>Fig. 4.7 Relationship between pH in H₂O and P –Alisols</u>	49
<u>Fig.4.8: Relationship between pH in CaCl₂ and P –Alisols</u>	49
<u>Fig. 4.9: Relationship between pH- H₂O and Ca- Alisols</u>	50
<u>Fig.4.10: Relationship between pH – CaCl₂ and Ca – Alisols</u>	51
<u>Fig.4.11: Relationship between pH in H₂O and Na – Luvisols</u>	51
<u>Fig.4.12: Relationship between pH in H₂O and K – Luvisols</u>	52
<u>Fig.4.13: Relationship between pH in CaCl₂ and K – Luvisols</u>	52
<u>Fig.4.14: Relationship between N and C – Alisols</u>	53
<u>Fig.4.15: Relationship between N and C – Luvisols</u>	54
<u>Fig.4.16: Relationship between N and Mg - Alisols</u>	55
<u>Fig.4.17: Relationship between N and K – Alisols</u>	55
<u>Fig. 4.18: Relationship between N and BS – Alisols</u>	56
<u>Fig.4.19: Relationship between C and Mg – Alisols</u>	57
<u>Fig. 4.20: Relationship between C and K – Alisols</u>	57
<u>Fig. 4.21: Relationship between C and BS – Alisols</u>	58
<u>Fig. 4.22: Relationship between C and C: N ratio – Alisols</u>	59

<u>Fig. 4.23: Relationship between C: N ratio and Mg – Alisols</u>	59
<u>Fig. 4.24: Relationship between C: N and K - Alisols</u>	60
<u>Fig. 4.25: Relationship between C: N and BS – Alisols</u>	60
<u>Fig. 4.26: Relationship between P and CEC – Alisols</u>	61
<u>Fig. 4.27: Relationship between P and ESP – Alisols</u>	62
<u>Fig. 4.28: Relationship between Ca and Mg – Alisols</u>	63
<u>Fig. 4.29: Relationship between Mg and K – Alisols</u>	63
<u>Fig. 4.30: Relationship between Ca and Na – Alisols</u>	64
<u>Fig. 4.31: Relationship between Ca and ESP – Alisols</u>	64
<u>Fig. 4.32: Relationship between Mg and Na – Alisols</u>	65
<u>Fig. 4.33: Relationship between K and Na – Alisols</u>	65
<u>Fig. 4.34: Relationship between Na and ESP – Alisols</u>	66
<u>Fig. 4.35: Relationship between Na and ESP – Luvisols</u>	66
<u>Fig. 4.36: Relationship between CEC and BS - Alisols</u>	67
<u>Fig. 4.37: Relationship between CEC and ESP - Alisols</u>	67
<u>Fig. 4.38: Relationship between CEC and BS - Luvisols</u>	67
<u>Fig. 4.39: Relationship between CEC and BS - Luvisols</u>	67
<u>Fig. 4.40: Relationship between Sand and Silt – Alisols</u>	70
<u>Fig. 4.41: Relationship between Sand and Clay – Alisols</u>	70
<u>Fig. 4.42: Relationship between Sand and Clay – Luvisols</u>	70
<u>Fig. 4.43: Relationship between Clay and Porosity – Alisols</u>	71
<u>Fig. 4.44: Relationship between Clay and Bulk Density – Alisols</u>	72
<u>Fig. 4.45: Relationship between Bulk Density and Porosity – Alisols</u>	73
<u>Fig. 4.46: Relationship between Bulk Density and Porosity – Luvisols</u>	73
<u>Fig. 4.47: Relationship between Bulk density and Moisture – Alisols</u>	74
<u>Fig. 4.48: Relationship between Porosity and Moisture – Alisols</u>	74

LIST OF ACRONYMS

ASALS:	Arid and Semi-Arid Lands.
BD:	Bulk density
BS:	Base saturation
C:	Organic Carbon
Ca:	Calcium
CaCl₂:	Calcium Chloride
CaCO₃:	Calcium Carbonate
CEC:	Cation Exchange Capacity
C:N:	Carbon to Nitrogen ratio
ESP:	Exchangeable Sodium Percentage
f:	Porosity
FAO:	Food and Agriculture Organisation
FAWE:	Forum for African Women Educationalists
Fe:	Iron
ha:	hectare
H₂BO₄:	Boric acid
HCl:	Hydrochloric acid
HCO₃:	Bicarbonate
HNO₃:	Nitric acid
H₂O:	Water
H₂SO₄:	Sulphuric acid
I.C.R.A.F:	International Council for Research in Agroforestry (World Agroforestry Centre)
K:	Potassium
K₂O:	Potassium Chloride
KCl:	Potassium Chloride
LDCs:	Less Developed Countries/Developing Countries.
Mg:	Magnesium
N:	Nitrogen
Na:	Sodium
NaOH:	Sodium hydroxide
NH₄:	Ammonium

- NO₂:** Nitrite
- NO₃:** Nitrate
- P :** Phosphorous in parts per million.
- ppm:** parts per million
- r:** Coefficient of correlation
- TSBF:** Tropical Soil Biology and Fertility Programme

ABSTRACT

This study was an “Analysis of the fertility of soils under *Grevillea robusta* trees in the Katheka-Kai and Katelembu locations of Mumbuni Division, Machakos District, Kenya”. On - farm research was undertaken in the settlements at Katheka-Kai and Katelembu, with Alisols and Luvisols respectively. Exotic *Grevillea robusta* trees had been planted in these farms.

Soil samples were collected from the plough layer, using soil auger and core rings. These undisturbed samples were collected from four equidistant points in between rows of *Grevillea robusta* trees, in four replicates. The samples of about 500g – 1000g were put in polythene sample bags, later dried, ground and sieved through 2mm sieve for laboratory analysis. In the laboratory, they were analysed for pH, Organic Carbon, Nitrogen, Phosphorus, Exchangeable bases and Texture.

The physical and chemical soil properties obtained were discussed with respect to the effect of *Grevillea robusta*, by considering distance from the rows of *Grevillea robusta*, depth of the soil samples and differences between the Alisols and Luvisols. Coefficient correlations were later calculated to determine the relationship between the different soil fertility parameters. A Multiple Stepwise linear regression model was used to study the interrelationships.

The high levels of correlation between various soil fertility parameters was mainly attributed to the *Grevillea robusta* trees, because of the addition of organic matter into the soil via litter decay. This supports the general hypothesis that agroforestry systems would improve the soil as a habitat for plants. Finally, recommendations were given for greater adoption of these tree crops into the modern farming systems.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

More than two-thirds of the area of Kenya is arid and semi-arid lands (ASALS), where agriculture is practised on small-scale basis. Machakos district, where the study area is located, is part of the ASALS in Kenya. Crop production is thus mainly for subsistence and some farmers have integrated tree crops into their farming systems. However, research by the Ministry of Agriculture, Livestock and Marketing showed that there has been a problem in integrating crops, livestock and trees on the same plot/ farm so as to have maximum output (Ministry of Agriculture, 1995)

Another research carried out by ICRAF (1995) showed that farmers in the Katelembu and Katheka-Kai settlements of Machakos district have tried to integrate tree crops into their farming systems, but it was still too early to judge the effects of the trees on crop performance. From that research carried out by ICRAF's study the soils of the Katelembu region were classified as Alisols and those of the Katheka-Kai region as Luvisols. The dominant tree species in the two settlements is *Grevillea robusta*. These two settlements were the main focus of this study.

1.2 STATEMENT OF THE PROBLEM

Grevillea robusta woodlots have been shown to occur together with undergrowth of various crops. The contribution of these trees is not clearly known. The trees could be providing shade to the crops, improving the chemical soil fertility and also the soil moisture holding capacity. This study concentrated mainly on soil fertility and soil moisture holding capacity. Trees provide ground cover and litter, which have the potential of conserving soil moisture and providing organic matter for soil fertility improvement.

Research carried out by ICRAF (1994) showed that much of the research carried out in Machakos district concentrated mainly on the ICRAF station and not on the farmers' farms. Among the few exceptional areas in Machakos include the Katheka-Kai (with Luvisols) and Katelembu (with Alisols) settlements, where ICRAF initiated a tree planting exercise among farmers. They however did not concentrate on determining the effects of the trees on the soil fertility status. This is because the researchers withdrew from the area before the trees were mature enough to have significant effects on soil fertility.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study were:

- a. To study the effect of the *Grevillea robusta* trees on the chemical and physical characteristics of the soils.
- b. To assess the relationship between the soil fertility parameters and the presence of the *Grevillea robusta* trees.

1.4 JUSTIFICATION OF THE STUDY

More than two thirds of Kenya's land surface is ASAL and hence research geared at formulating policies for making this land more economically productive is vital. Machakos district is one of the areas where people have adopted agroforestry-farming systems. The people living in these areas are prone to many problems when there is a short supply of food due to the seasonality and unreliability of rainfall. Hence trying to find out how they can use their land for sustainable agricultural production is very crucial. The climatic and soil conditions in Katelembu and Katheka-Kai locations are such that they support the growth of a highland tree (*Grevillia robusta*). This is a tree therefore which needs to be studied in terms of its ability to improve the soil fertility and soil moisture retention of this region.

Moreover nearly all the rural people depend on woodfuel for their cooking, and more than 80% of the wood species grown in Kenya are used as woodfuel. This is equally true of Machakos where with already high and increasing population, the demand for fuelwood is increasing at an alarming rate and surpassing the supply, hence rendering the available trees more endangered. Wood is a bulky commodity to transport for long distances, but where it is not available to the rural people because of depleting natural sources, there is no other alternative than transporting from other areas (Government of Kenya 1989).

This study also bridges the gap of limited on-farm research on the effects of trees on soil moisture retention and soil fertility improvement. Although integration of trees with crops is recognised as an important activity to be encouraged on-farm, deliberate planting of trees is still a relatively new practice for many farmers in most parts of the tropics. That is why this research will be important, for it will make the farmers to be aware of the benefits they are foregoing or the adverse effects of having less trees on their farms.

1.5 SIGNIFICANCE OF THE STUDY.

This study has taken the approach of on-farm research which has become a legitimate part of farming systems research (Rao, 1990). It plays a key role in the development and diffusion of agroforestry technologies.

The research findings will be very vital in bridging a gap left by ICRAF organisation when they initiated the study way back in 1996. This will help in determining whether the project of tree planting has had any effect on the overall crop performance on the farms and whether fertility on the farms has been improved or not.

The findings will be used to educate farmers more on the importance of having trees on their farms, and hence help in solving the problems of woodfuel shortages, farm unproductivity and even maximum utilization of land for sustainable development especially in this ASAL areas.

1.6 BASIC ASSUMPTIONS

The basic assumptions include:

- (a) The Kamba people in this region plant trees as sources of fodder, fruits, medicines, fuelwood and construction poles. Thus it is not entirely because they know that they help in maintaining the fertility of the farm and also help in increasing crop yields.
- (b) Farmer participatory research findings and the assessment of the agroforestry technologies they have used on their farms will be vital in encouraging the farmers to plant more trees on the farms.

1.7 LIMITATIONS OF THE STUDY

- (a) ASALS like Machakos are in Agroclimatic zones iv-vii. However, this research was only carried out in a region of Agroclimatic zone iv and may not reflect the other parts of the ASALS areas.
- (b) The research also covered only two soil types and may not give a comprehensive picture of the different soil types found in ASALS.
- (c) Data on genetic variation of *Grevillia robusta* in Kenya are lacking and hence Parameters like organic carbon, nitrogen, potassium and moisture content were

higher for all samples taken next to the trees than those far from the trees limitation of the study.

1.8 DEFINITION OF TERMS.

AGROFORESTRY: A dynamic, ecologically based natural resources management system that, through the integration of trees in farmland and rangeland, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

ALLELOPATHY: Denotes that body of scientific knowledge which concerns the production of specific biomolecules (allelochemicals) by one plant, mostly secondary metabolites, that can induce suffering in, or give benefit to, another plant.

BULK DENSITY: This is a measure of the weight of the soil per unit volume (g/cc), usually given on an oven-dry (110°C) basis.

CHEMICAL SOIL FERTILITY: This is the chemical quality or condition of the soil.

FANYA JUU TERRACES: These are terraces made by digging a trench along a contour and throwing the soil uphill to form an embankment.

PHYSICAL SOIL FERTILITY: This is the physical quality or condition of the soil.

SUSTAINABLE AGRICULTURAL PRODUCTION: Agricultural production that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs.

CHAPTER TWO: LITERATURE REVIEW.

2.0 Introduction

In this chapter, the main focus will be on the Agroforestry practices in general and how they have been adopted in Kenya. The benefits of *Grevillea robusta* in Agroforestry systems will also be discussed. Agroforestry is not a new concept for trees, crops and animals have traditionally been raised together on small farms throughout the world (Gholz 1987). But the effect trees have on the farms and the crop performance has not been adequately studied. Although a large number of traditional agroforestry systems have been reported only a few have been scientifically studied, and hence there is inadequate scientific understanding of such systems.

2.1 Agroforestry Systems in general.

Some available research findings have shown the scientific merits of these systems and points to several possibilities for improving them (Nair 1990). Similarly, Rocheleau *et al*, (1989), stated that agroforestry is frequently invoked as a solution to problems of land and water degradation as well as an answer to shortages of food, fuelwood, cash income, animal fodder and building materials in sub-Saharan Africa. That is why research is still important and especially in determining the effect of certain specific tree species on soil fertility status of farmland.

2.2 Evolution of the National Forest Policy and Plans.

The administration of forests in Kenya started around 1900 and the Forest Department (FD) was set up in 1910. The main management interventions at that time were protection of natural forests and exploitation of their indigenous hardwoods. The main catchment areas were gazetted in 1932, which comprised of areas around Mt. Elgon, Londian, Tinderet, Maji Mazuri and Mt. Kenya, while Aberdare Ranges were gazetted in 1943.

A full statement of a forest policy for Kenya made in the late 1950s was later modified and published as the Sessional Paper No.1 of 1968 (Government of Kenya, 1968). Since then there has been no formal review of the policy, except for the draft Forest Act in 1999. However, as the national needs have changed over the years, there have been various statements by the government to address the change. In 1983, it was realized that the forest cover, which was less than 3 per cent, was decreasing because of population and other pressures. For this reason therefore, the government put the tree seedlings production target

at 200 million per year and launched the idea of 'tree farmer' in order to extend more vigorously, tree planting on the farms (Mwamunga, 1983).

In 1986, the government, after having realised the dangers posed to the environment by bad land management and usage, decided to tackle the problems in a two-pronged policy approach, viz, the policy of forest conservation and protection, and that of better land management and usage (Nyaga, 1989). In the same year, a national development strategy, 'Economic Management for Renewed Growth' was published as Sessional Paper No. 1 (Government of Kenya, 1989). More recently, the Sixth Development Plan 1989-1994 addressed the issues of development. All these policy guidelines have stressed the need of forestry to address the peoples' needs, the proper management of the environment and sustained soil productivity. In addition field guides have been published (Chavangi and Zimmermann, 1987; Getahun and Reshid, 1989) to enhance farmers' participation.

2.2.1 Tree Planting in Kenya

Exotic tree planting in Kenya started in 1910 when 6.6 ha of exotic tree species were planted through the compensatory afforestation programme. This was started as a programme to replace some natural forests (which were termed as slow growing) with exotic forest plantations, which, as they were fast growing, could ensure adequate supply of wood to the country in the future. By 1960, 32,319 ha of forest plantations had been established. By 1970, 1980, and 1990 the areas planted with exotic forest plantations were 68,000, 120,000, and 165,000 ha, respectively (FAO/World Bank 1989).

Even though there was a programme to replace indigenous forests with exotic plantations, an attempt was made to manage some natural forests on the basis of sustained yield. Experiments established in the 1950s explored ways of establishing mixed forests using indigenous tree species. The management of natural forests has, however, not been successful partly due to pressure on them from human and livestock populations (FAO/World Bank 1989). The human pressure on the natural forests has led to encroachment and excisions for settlement and agricultural production (FAO/World Bank, 1989).

The management of forests on private land and trustlands has been largely in the hands of the landowners and the local authorities, respectively. Tree planting on privately owned

land has been commendable, with about 141,000 hectares planted (FAO 1982). However, on trustlands there has been a tendency to over exploit the available trees rather than to undertake tree planting.

Attention has been directed to the arid and semi-arid lands (ASALs), which account for about 80 per cent of Kenya's land surface. About 20 percent of the 29 million Kenyans (approximately), also live in the ASALS. Population influx from the high potential areas to the ASALs has continued as a result of human pressure on the small land base in the high potential areas. The main thrust for forestry development in Kenya must therefore focus on the farms, and the ASALS" (Nyaga, 1989).

2.2.2 Current Agroforestry Plans and Policies

The government has identified the potential of agroforestry to address the many issues related to rural development. In the Sessional Paper No.1 of 1986, the Government of Kenya has identified national priorities and objectives of agroforestry development in Kenya (Government of Kenya, 1986). These are to convert 3 million hectares of land in the high potential areas to agroforestry land uses, increase crop productivity and sustainability, satisfy rural wood products and fuel wood demands, increase rural cash income, and to encourage tree planting in the ASALs through appropriate agroforestry practices and improved range management.

The Government of Kenya (1989), undertook to popularise and promote the development of agroforestry at the community and individual levels with the objective of effective management and conservation of forest areas to ensure adequate future supply of fuel wood, materials for industrial use, water and soil conservation and protection of the natural forests. Even though the legislative changes in support of agroforestry have been less obvious, part of the explosion in rural tree growing activities in the past few years is due to a rapidly growing commercial trade in fuel wood, poles and other products of multipurpose tree species (MPTS) coming from agroforestry systems. Despite their cultural norms about land, farmers need to intensify and diversify production on their small pieces of land in the densely populated areas.

The increased concern for the diversification of agroforestry practices led to increased use of "Multiple Tree Systems" in soil conservation. Also increased public commitment to tree growing has been due to the many government supported programmes of publicity,

extension, training, tree nursery development, the promotion of self-help groups and a well established seed supply (Scherr, 1989). According to Lundgren (1989), one of the reasons for this success has been the fact that agroforesters have been able to supply the farmers with tree species that effectively meet their needs. In some cases it has been difficult to meet the demand for seeds of such popular tree species like *Grevillea robusta*. This tree is popular with African farmers because the species provides economically viable products, is easy to propagate and establish, its proteoid roots help it grow in low-fertility soils, it does not compete strongly with adjacent crops, and tolerates heavy pruning of its roots and branches (Gholz, 1987).

Nair (1990) noted that alley cropping seems to be receiving most of the attention of agroforestry experts and scientists, at the expense of other time-tested indigenous technologies. These include looking at effects of integrating certain tree species into agroforestry systems, which was a major objective in undertaking this study.

2.3 On- farm research.

On- farm research has been a legitimate part of farming systems research (Rao, 1990). It is one of the most powerful tools in developing and diffusing agroforestry technologies. However, most of the agroforestry research done by I.C.R.A.F around the study region was on-station, and therefore the need to spread on-farm research.

2.3.1 Relevance of on-farm research.

This research was carried out in farmer's fields. Gholz (1987) noted that the inclusion of compatible and desirable species of woody perennials on farmland can result in a marked improvement in soil fertility. This was associated with increased organic matter content, more efficient nutrient cycling within the system, biological nitrogen fixation and an increase in the plant cycling fraction of nutrients.

Researchers have also been interested mainly in components and their interactions whereas extensionists have been interested mainly in tree planting. However, for applied and adoptive agroforestry research projects, judicious mix of research and technology transfer tests is essential. Scherr (1992), stressed that it is essential to understand how the basic "prototype technology", actually performs and agroforestry should be encouraged to evaluate trees not as isolated components, but within a specific land use and management

framework. On-station experimentation is invariably carried out using regular layouts, and the work at ICRAF's Research Station at Machakos has been no exception (Huxley, *et al* 1994) The researcher strives to create a situation (an experimental design) that addresses specific hypothesis. Replication and blocking are often used to improve precision and reduce bias. However, these designs cannot answer what happens under irregular patterns of planting often found in farmers' fields

On-farm research has become a legitimate part of farming systems research (Rao, 1990). It plays a key role in the development and diffusion of agroforestry technologies. This kind of research helps in gauging the farmers' reaction to new technologies, and to make them partners in the process of the research and any technology development. Rao (1990), also emphasize the need for combining the scientific knowledge of researchers and the practical experience of farmers.

Gholz (1987) noted that in the process of conceptualization and principle formulation of agroforestry a number of hypotheses and attributes have been advanced in the recent past. One of the most significant and often repeated among these is the suggested potential of agroforestry as major practical land management alternative for maintenance of soil fertility and productivity in a variety of situations in the tropics. Gholz (1987) further stated that most of these hypotheses have not been tested and proven, and hence the need for further research. However, past experience and accrued knowledge on the behaviour and management of tropical soils suggest that some of the agroforestry options can overcome at least a few of the drawbacks of mono cultural (crop) production systems.

Nair (1984) elaborated the role of agroforestry in soil conservation, taken in its broader sense to mean conservation of fertility as well as prevention of erosion. However, he did not show how the crops performed with trees on the same farm. Young (1986) elaborated the potential of agroforestry as a practical means of sustaining soil fertility and discussed the research needs in this direction.

One of the continuing major research needs is for in-depth and long-term research on local traditional agroforestry systems. Ethno-historical information indicates that even some of the market-oriented systems have existed, with some modifications, for about a century. However lasting effects on soils, changes in fallow structure and composition, and

behaviour of individual agroforestry species within mixed stands, have yet to be adequately investigated (Gholz, 1987).

Gholz (1987) also emphasized on the importance of giving advice on both agricultural and forestry problems, to traditional agroforesters. While there is often enthusiasm expressed in designing entire systems for small cultivators, little attention is given to helping present practitioners improve or refine their existing systems.

2.3.2 On-farm visits and individual meetings.

On-farm visits are considered an essential means of providing feedback from farmers to the researchers (Huxley *et al*, 1994) Two divergent approaches to on-farm research are the researcher-controlled approach and the farmer-controlled approach. The latter encourages farmers to carry out their own (unstructured) research from the beginning. Between the two approaches, there is a middle ground where researchers and farmers participate in joint trials. Moreover, farmers generally possess invaluable knowledge about their indigenous agroforestry systems, which can both lead to the identification of pertinent research questions and a shortening of the research process. This is because agroforestry is not a new practice for many rural societies. It is a land use strategy that is already well accepted by many agricultural communities in the world, and many have been experimentally developing different forms of agroforestry for centuries (Gholz, 1987)

The success of any agroforestry intervention ultimately depends on how well the research results are integrated with farmers' needs and that is why this research will involve the farmers. Monitoring and evaluation of technology performance in agroforestry projects may be approached from different angles; farmer evaluation and field testing (Scherr, 1992). Scherr, (*opcit*) further suggested three different aspects to be considered while evaluating the performance of agroforestry technologies:

- * First, quality and quantity of products from technology components and trade-off resulting from the combined production of crops, trees and/or livestock.
- * Second, the quality of service functions of technology like their effectiveness and efficiency (such as provision of shade, aesthetic functions, marking of boundaries, fencing, improving of micro-climate, wind-breaks and so on).
- * Third, is the socio-economic costs and benefits of the technology (input/output relations, opportunity costs, risk, tenure effects and division of labour).

Generally priority variables that were considered in this study were biological (such as tree survival, growth characteristics and condition of crops) and socio-economic variables (such as farmers' preference for species and technologies, economic yields, changes in risk and access to resources, and quality of human environment).

2.3.3 Benefits from trees in agroforestry systems

It is now widely believed that agroforestry holds considerable potential as a major land-management alternative for conserving the soil, maintaining soil fertility and sustaining agricultural productivity in the tropics. This belief is based on the assumption that trees and other vegetation improve the soil beneath them (Nair, 1990). Nair (*opcit*) also stated that from time immemorial, farmers had known that they would get a good crop by planting in forest clearances and also soils that develop under natural woodland and forest were known to be well structured, with good moisture-holding capacity and high organic matter content.

According to Young (1989), some of the beneficial effects of trees on crops and soil have not yet been fully demonstrated, while others already have well demonstrated evidence. The role of tree in nutrient addition to the soil through rainfall or moisture supply increment for example has not been adequately demonstrated (Young 1989). That is why this research is vital. Young (*opcit*) also emphasized on the inadequate information concerning the extent to which trees help in the reduction or moderation of the soil's acidity, alkalinity or sodicity.

It is also suggested but not demonstrated that, trees planted on farms increase the nutrient uptake by crops. (Nair, 1990). Nair (*opcit*) further suggested that the hypothesis was that, in general, trees were more efficient than herbaceous vegetation in taking up nutrients released by the weathering of deeper soil horizons. Potassium, phosphorus, bases and micronutrients are released by rock weathering, particularly in the B/C and C-horizons into which tree roots often penetrate

Observations of interactions in natural ecosystems have identified that the ability of trees to restore soil fertility is illustrated by experiences in many LDC's. In India, it has been shown that the best way to reclaim degraded land is through afforestation or a similar type of tree-based land use (Nair, 1990). That is why such a study is vital in other LDCs like Kenya and

especially in the ASALS. Nair also quoted that the conversion of natural ecosystems to arable farming systems led to a decline in soil fertility and a degradation of other soil properties unless appropriate, and often expensive, corrective measures were taken. To avoid such expenses, trees could be incorporated into farming systems, which easily restore the soil properties and the farmer will also benefit from the tree products. That is why a study on their effects on soil fertility is crucial. The microsite enrichment qualities of trees such as '*Acacia albida*' in West Africa and '*Prosopis cineraria*' in India (Mann and Sacena, 1980) have long been recognised in many traditional farming systems. It is thus important to carry out research on the effects of similar agroforestry species in the ASALS of Kenya.

2.3.4 *Grevillea robusta* in agroforestry.

Grevillea robusta was introduced to Kenya early this century as a shade tree in tea and coffee plantations and it also continues to be planted as an ornamental because of its beauty. It can be planted in nearly all agroforestry systems both within the farm and along the farm boundary (Getahun and Reshid, 1989). In this way, the tree provides good amounts of fuel wood and leaf litter. Getahun and Reshid (*opcit*) have suggested several agroforestry land-use systems incorporating *Grevillea robusta* as the tree component. Some of these are with agricultural crops, in fodder systems, soil conservation structures, and in boundaries or windbreaks.

On agricultural land, *Grevillea robusta* can be planted either randomly or intercropped with agricultural crops such as maize and beans. This practice is common in many parts of the country especially in the highlands. Kerkhof (1990) has reported the successful use of *Grevillea robusta* in soil conservation work in Rwanda, where rows of *Grevillea robusta* were planted in soil conservation strips on the contours of sloping ground. Under this practice, the highest combined production from the trees and food crops was obtained with 400-600 *Grevillea robusta* trees per hectare at an age of 4-6 years, and 250-300 trees per hectare at 9-10 years. In both cases, the maximum crown cover was about 20%.

Young (1989) has indicated the potential of agroforestry systems in the rehabilitation of the wastelands. Results from Kibwezi (Milimo, 1989) have shown that *Grevillea robusta* can grow in semi - arid areas. In the highlands of Eastern and Central Africa, the leaves of *Grevillea robusta* are used as mulch and dry season fodder. In the production of leaf fodder, it is necessary to reduce the competition between the grass and the young *Grevillea*

robusta saplings in order to maximise the leaf production (FAO, 1986). According to Getahun and Reshid (1989), *Grevillea robusta* is used to establish boundaries or to act as windbreaks in Central Kenya. Management for windbreaks and boundary marking is the same as when the tree is grown together with agricultural crops.

2.4 Adverse effects of trees on crops

Trees both as individual plants and when grown in association with herbaceous plants, can have adverse effects on soil and crops (Nair 1990). One such case is where Nair (*opcit*) reported loss of organic matter and nutrients in the tree harvest. There is normally a depletion of soil resources by fast-growing trees, and the effect of this will be a reduction in crop production. Trees accumulate large quantities of nutrients in their biomass, part of which is removed in harvest. The problem is greatest where there is a whole tree harvesting for example, the gathering of fine branches and litter by local people after a harvest. From a soil management point of view, it is desirable to allow all branches and litter to decay *in situ* and even to return the bark (Nair 1990)

Gholz (1987) stated that fast growing species (of trees) may place a heavy demand on soil moisture, and unless properly managed, this could lead to adverse effects, especially in dryer environments. He further added that a badly managed tree stand, as with any vegetation, could cause accelerated soil erosion. There may also be adverse chemical/biological effects from certain tree species, leading to: acidification, allelopathy, accumulation of toxic exudates, the provision of alternate hosts of pests and pathogens. Furthermore, shading and changes in spectral quality of light on the growth of other species in close proximity (though not a direct effect on the soil) can have considerable significance in agroforestry. Gholz (*opcit*) further stated that most of these attributes, both beneficial and adverse, were either inferred from land-use systems related to agroforestry, or were still only untested hypothesis. This was one of the reasons why this study was carried out in order to address this issue.

The magnitude of benefit or adverse effect that could be experienced will depend upon a number of site-specific factors. Moreover, many of the attributes of trees, as compared to annual crops can be realized only over a relatively longer period of time. Similarly, the proportion of species occupied by tree components in an agroforestry combination, in order to derive the suggested benefits to any tangible extent will depend upon several factors such

as soil type, plant (tree) species and tree-crop arrangement (Gholz 1987). Managing a mixed plant community effectively depends upon understanding the processes involved, designs and mixtures that will minimize competition, prevent unfavourable biological interferences and exploit beneficial interactions.

Nair (1990) has pointed out that the work that had been carried out indicated that in perennial-annual mixtures, the perennial usually had a greater and more long-lasting effect on the environment, and this adversely affected the performance of the annual crops. According to the competitive production principle, a mixture becomes successful only when both components can exploit available resources more efficiently than when grown in monocultural situations. The facilitative production principle may also come into play, that is, the environment of one species (usually the annual) is modified by the presence of a second species (the perennial) in such a way as to facilitate the growth of the first species. Often these principles operate simultaneously and inseparably.

The net effect of these interactions will manifest itself in terms of the performance of the individual plants and of the system as a whole.

According to Nair (1990) also, scientists continue to express concern about the lack of scientific data to support widely held assumptions on the advantages of agroforestry and the inadequate methodologies currently being used in agroforestry research. Extension workers are torn between policy-makers directives and the enthusiasm of the farmer to adapt agroforestry, on the one hand, and absence of tested and proven technologies on the other.

Nair (1990) also stated the recognition of the need for organized research in agroforestry as a relatively recent development. Even more recent is the recognition of serious deficiencies in agroforestry education and training. Concern has also been expressed about a number of issues such as the lack of serious attention being paid to established land-use practices, the fact that current educational opportunities are too specialised, and the need for people to be trained at various levels to conduct research, implement development projects and undertake extension work. In addition, there is yet no organized curriculum in agroforestry, nor a uniform approach to educational programme development.

According to Lundgren and Nair (1985), the lack of an institutional niche for agroforestry is a serious drawback. In most national and international institutions, agroforestry is an

'appendage' to forestry or agriculture and these institutions are still run on conventional disciplinary lines, with the result that interdisciplinary activities such as agroforestry are given low priority. Fortunately, with the growing need to tackle environmental issues that cut across long-established disciplinary boundaries, this compartmentalisation is steadily, albeit very slowly, breaking down (Getahun and Reshid, 1989). A very welcome development is the decision by the Consultative Group on International Agricultural Research (CGIAR) to bring agroforestry research into CGIAR system and to establish institutional mechanisms necessary to implement this decision (Fernandes and Nair, 1986)

This brief recounting of the literature review concerning a very old, yet little known practice indicates broad opportunities for scientific involvement. Above all, peasants throughout the world have accumulated much empirical knowledge. To retrieve such knowledge, careful reviews of farmers' practices need to be made. This in itself would yield valuable results (Gholz 1987).

CHAPTER THREE: MATERIALS AND METHODS.

3.0 Introduction

This chapter focuses on the fieldwork that was carried out, the methods used to collect data and how data was analysed in the laboratory.

3.1.1 The study area

The study was carried out in one of the areas classified as ASALS of Kenya, namely Machakos district in the Eastern Province. The district lies within the foreland plateau, between the Eastern Rift Valley and the Nyika plateau. It has an area of approximately 14,250 sq. km (Machakos District Development Plan 1989-1993). The area is characterized by extremely variable rainfall, which mostly follows the altitudinal change. Crops that are grown are mainly maize, beans, pigeon pea, cowpea, and green grams.

On-farm research was taken up in the settlements at Katheka-Kai (with Luvisols) and Katelembu (with Alisols) of Central Mumbuni Division on either side of the Machakos road (Fig: 3.1). The natural vegetation of the area is savanna woodland, dominated by acacia shrubs/trees. The common indigenous tree species in both Katheka-Kai (Luvisols) and Katelembu (Alisols) villages are *Acacia tortilis*, *Acacia mellifera*, *Balanites aegyptica* and *Terminalia brownii*. At the time of the study, the area had been planted with exotic *Grevillea robusta*.

Fig 3.1 Map of Machakos District, Kenya

LOCATION MAP

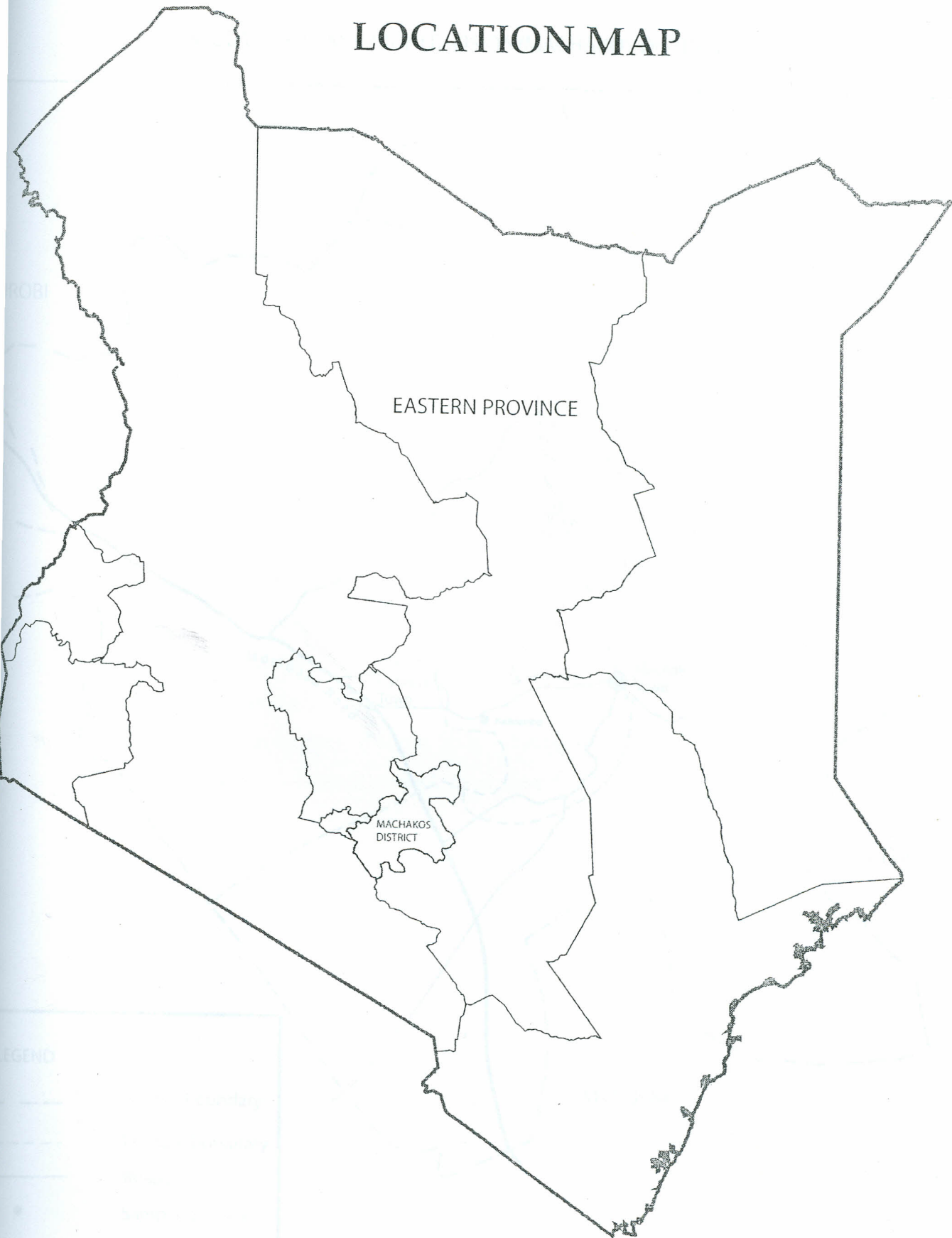


Fig 3.1 LOCATION OF MACHAKOS DISTRICT IN KENYA

STUDY AREA - MUMBUNI DIVISION/MACHAKOS DISTRICT

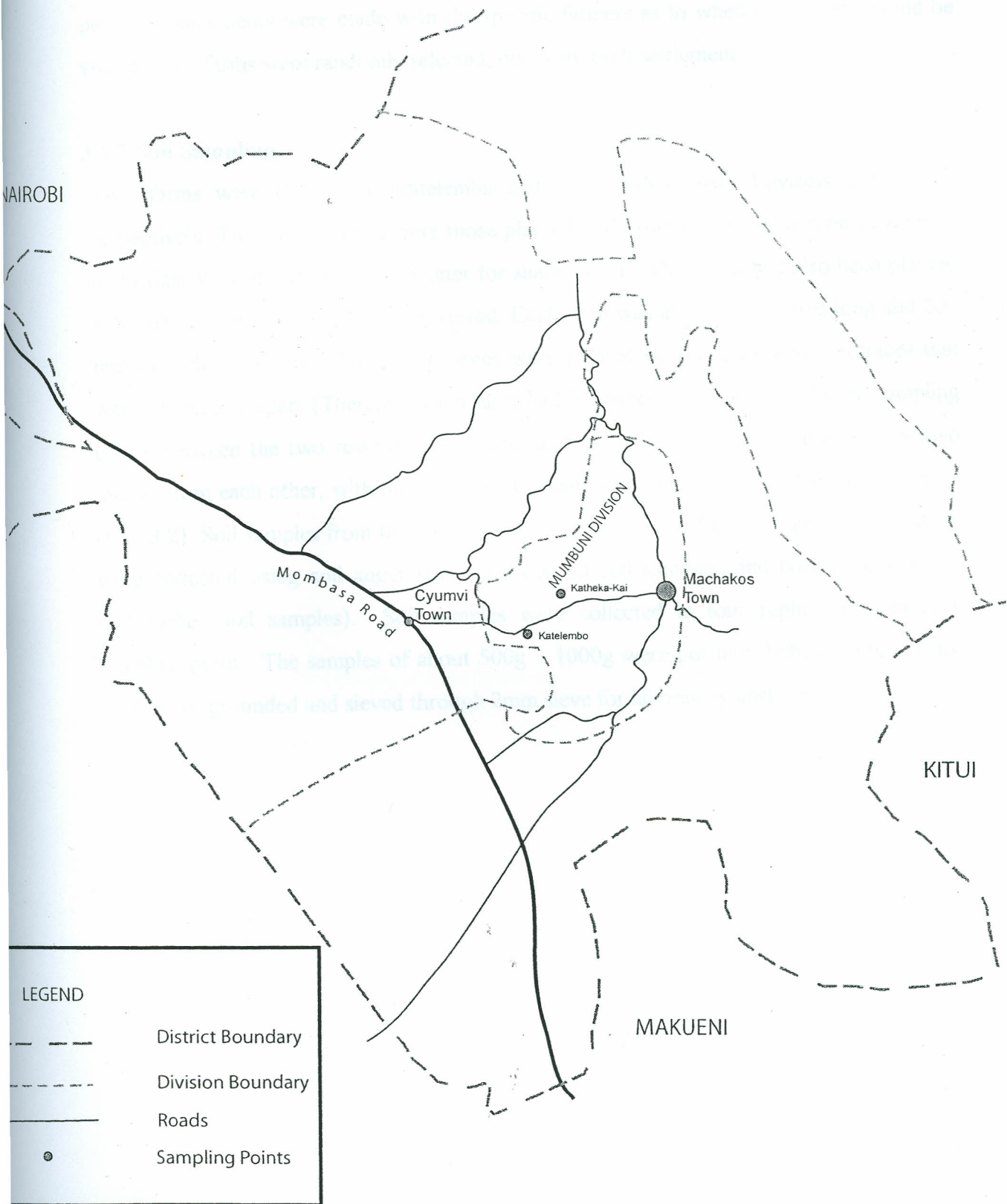


Fig. 3.2 STUDY AREA – MUMBUNI DIVISION, MACHAKOS DISTRICT

3.1.2 The pilot survey.

A pilot survey was carried out in August 1999, with the aim of identifying the two sites of research and finding out how the trees had been planted in the settlements. During this period arrangements were made with the specific farmers as to when their farms would be visited. Two farms were randomly selected, one from each settlement.

3.1.3 Soil Sampling.

Two farms were chosen, in Katelembu and Katheka-Kai, with Luvisols and Alisols respectively. The farms chosen were those planted with rows of *Grevillea robusta* running in an East-West direction so as to cater for shade effect. The farms had also been planted with maize, which had just been harvested. Each farm was about 250 metres long and 200 metres wide. The *Grevillea robusta* trees were planted on the “*fanya juu*” terraces that were 10 metres apart (Therefore each farm had 20 terraces). Four equidistant sampling points between the two rows of trees were marked. These equidistant points were two metres from each other, with the first and last being also two metres from the row of trees (Fig: 3.2). Soil samples from the plough layer, at two depths of 0-15cm and 15cm – 30cm were collected using soil auger (for the disturbed soil samples) and core rings (for the undisturbed soil samples). Soil samples were collected in four replicates from each sampling point. The samples of about 500g – 1000g were put in polythene sample bags, later dried, grounded and sieved through 2mm sieve for laboratory analysis.

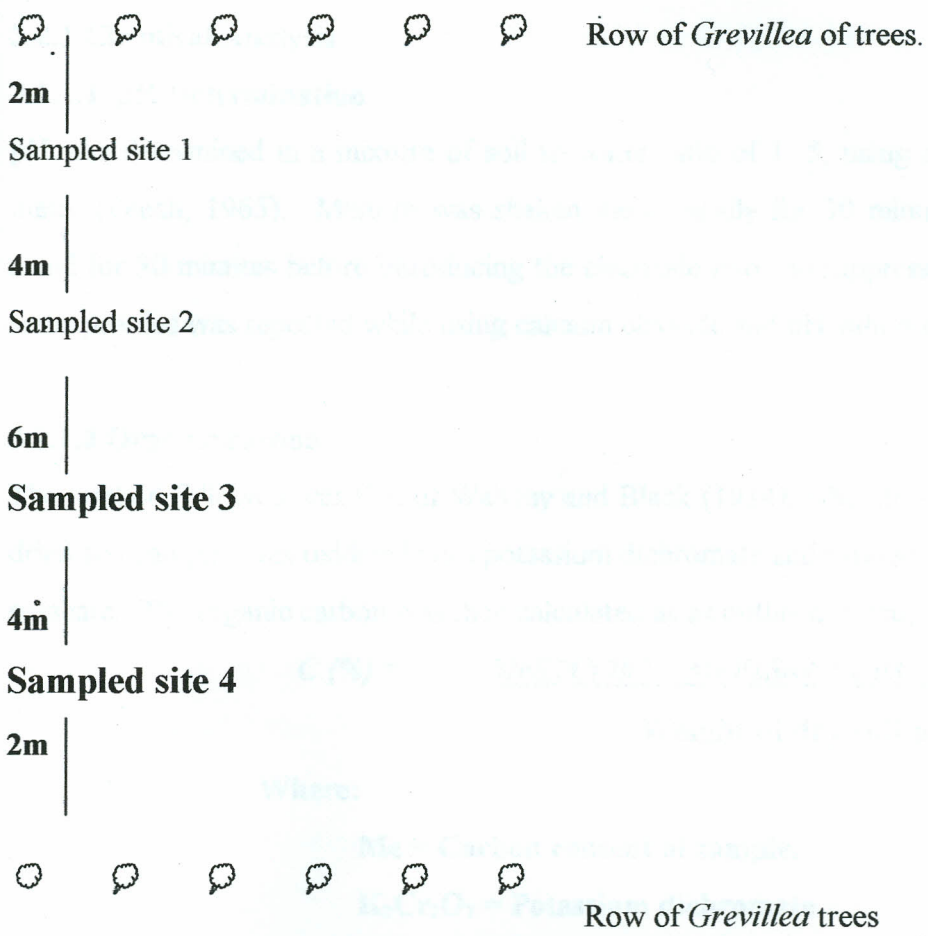


Fig: 3.3 Sampled sites (from the portion enclosed by two rows of *Grevillea robusta* trees)

3.2 ANALYTICAL METHODS

3.2.1 Chemical Analysis

3.2.1.1 pH Determination

pH was determined in a mixture of soil to water ratio of 1: 5, using a glass electrode pH meter (Peech, 1965). Mixture was shaken mechanically for 30 minutes and then left to stand for 30 minutes before introducing the electrode into the suppressant suspension. The same process was repeated while using calcium chloride and pH values obtained.

3.2.1.2 Organic carbon

The method followed was that of Walkley and Black (1934), whereby one gram of the fine dried soil samples was oxidized with potassium dichromate and titrated against 0.5N ferrous sulphate. The organic carbon was then calculated as as outlined in Page *et al* 1996

$$C (\%) = \frac{MeK_2Cr_2O_7 - MeFeSO_4 * 0.03 * 100 * 1}{\text{Weight of dry soil used}}$$

Where:

Me = Carbon content of sample.

K₂Cr₂O₇ = Potassium dichromate

FeSO₄ = Ferrous sulphate

3.2.1.3 Total Nitrogen

1.0g of air-dry soil sample was passed through 0.5mm sieve and digested with concentrated sulphuric acid (conc. H₂SO₄) in the Kjeldahl apparatus/flask in a digestion block (Page *et al* 1996). The digest was diluted and made alkaline with addition of sodium hydroxide then distilled. The ammonia gas released was finally trapped in a solution of boric acid (H₃B₃O₄). Titration followed, where by the trapped ammonia was titrated against sulphuric acid (H₂SO₄) with an indicator solution (mixed indicator). The amount of acid used was directly related to the amount of ammonia originally present and therefore the original nitrogen concentration.

The amount of nitrogen was calculated as percentage of the sample weight as follows:

$$\%N = \frac{\text{Titre} * \text{Normality of acid used} * 14 * 100\text{g of soil}}{\text{Weight of soil sample} * 1000}$$

Where,

14, represents the pH value

1000, represents the conversion factor of grams into kilograms

3.2.1.4 Available Phosphorous

1g of air-dried soil sample in a centrifuge tube with concentrated sulphuric acid was shaken and centrifuged. A clear suppressant was pipetted and distilled water and ammonium molybdate added. After mixing, stannous chloride dilution solution ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) was added and mixed and percentage transmittance was measured by spectrophotometer. A standard curve was also prepared by plotting the optical density (OP) of standard solution against P concentration in ppm.

Then the content of extractable phosphorus was calculated as follows:

$$P(\text{ppm}) = \frac{\text{Graphreading} * 50\text{g of soil} * \text{dilution factor}}{\text{Weight of sample used}}$$

3.2.1.4 Determination of CEC (Exchangeable Cations), BS and ESP

The method used is as given by Rhodes (1986). 5 grams of soil were leached using 50ml of NH_4OAc adjusted at pH 7.0. Five portions of this solution were added and the leachate was collected in a 250ml volumetric flask and made to the mark with NH_4OAc . The atomic absorption spectrophotometer (AAS) was used to determine the Exchangeable Cations, Ca and Mg while Na and K were determined using the flame photometer. The soil was then washed with five portions of 95% ethanol and the leachate kept back for distillation. The soil was then leached with 100ml of 1N KCl, administering the KCl in four portions of 25ml each. The leachate was collected in a 100ml volumetric flask and made to the mark with KCl. An aliquate of 5ml was pipetted and distilled and the distillate (liquid ammonium) was collected in 1% boric acid and back titrated with 0.05 N H_2SO_4 .

The CEC was calculated as follows:

$$CEC = \frac{\text{Titre} * \text{Normality of } H_2SO_4 * \text{Dilution} * 100g \text{ of soil}}{\text{ml. of aliquate} * \text{weight of soil}}$$

The BS is a derived value and was calculated from the following formula:

$$BS\% = \frac{(Ca + Mg + Na + K) * 100}{CEC}$$

Where Ca, Mg, Na and K are exchangeable values given in me/100g of soil. The exchangeable sodium percentage (ESP) is also a derived value and was calculated as follows:

$$ESP = \frac{\text{Exchangeable Na} * 100}{CEC}$$

3.2.1 Physical Analysis

3.2.2.1 Particle Size Analysis (Texture)

The hydrometer method was used as outlined by Klute (1994). The airdried samples, sieved through 2mm sieve were treated with hydrogen peroxide to destroy organic matter component. The residue sample was dispersed by a sodium salt (sodium hexametaphosphate) and by mechanical shaking for six hours. A hydrometer was used to take the readings at different times and these were used to calculate the percentage silt, clay and sand as follows:

$$\text{Sand \%} = 100 - (H_1 + 0.2) (T_1 - 68) - 2$$

$$\text{Clay (\%)} = (H_2 + 0.2) (T_2 - 68) - 2$$

$$\text{Silt (\%)} = 100 - [\% \text{ sand} + \% \text{ clay}]$$

Where:

H₁ = Hydrometer reading at 40 seconds.

T₁ = Temperature reading at 40 seconds.

H₂ = Hydrometer reading at 3 hours.

T₂ = Temperature reading at 3 hours.

Temperature correction is $0.2 (T_1 \text{ or } T_2 - 68)$ while T_1 and T_2 are given in $^{\circ}\text{C}$ while the salt correction is -2.0 . The results obtained were converted into Textural classes as outlined in Klute, 1994

3.2.2.1 Bulk Density (BD)

The undisturbed samples collected in core-rings were oven dried at 105°C for 24 hours.

The bulk density was calculated as given by Klute, 1994, as follows:

$$BD = \frac{Ms}{Vt}$$

Where:

BD = bulk density in g/cm^3

Ms = weight of oven dry sample in g

Vt = Volume of sample which is the volume of core-ring in cm^3 .

3.2.2.3 Porosity (f)

This value was calculated from the bulk density values and assuming the particle density as $2.65\text{g}/\text{cm}^3$ (Klute, 1994) the following was used.

$$F (\%) = [1 - \frac{BD}{e_p}] \times 100$$

Where: e_p = particle density of $2.65 \text{ g}/\text{cm}^3$

BD = bulk density in g/cm^3 .

3.2.1.4 Antecedent Moisture Content (w)

Moisture content was determined as outlined by Klute, 1994. The moist samples were weighed then oven dried at 105°C for 24 hours. This gave the initial (moist) weight of samples and their oven dry weights.

The water content was then calculated as follows:

$$W(\%) = \frac{Ww - Wd}{Wd - Wc}$$

Where: **W** = gravimetric water content (%)

Ww = weight of wet sample + moisture can in g.

Wd = weight of oven dry sample + moisture can in g.

Wc = weight of moisture can alone in g.

3.2.2.5 Moisture Retention and Release

The method used is adopted from Klute (1994). The undisturbed soil samples in core-rings were used for this determination. After the preparation of the samples, they were saturated with water for 24 hours. When samples were completely saturated, they were weighed and placed in pressure plates apparatus. Suction pressure was applied and the samples weighed after all the water had been driven out. The suction were at pressures of 10, 30, 50, 70, 100, 300, 500, 700, 1000 and 1500 K pascals.

Soil moisture retention in each sample was calculated using the following equation

$$Q = \frac{Wt(i) - Wt(od)}{Vs * ew}$$

Where:

Q = Volumetric water content in cm^3/cm^3 .

Wt(i) = Weight of sample at corresponding soil moisture suction in g.

Wt(od) = Weight of sample at oven dry in g.

ew = Density of water in g/cm^3 .

Vs = Volume of soil sample in a core-ring in cm^3 .

Soil moisture characteristic release curves were then drawn.

3.3 Statistical analysis

The data obtained from laboratory analysis was further analysed by using Analysis of Variance (ANOVA). Measures of precision were accounted for by calculating the least significant difference (LSD) and the standard error of the difference between means (SED). Further discussions were generated in relation to the presence of *Grevillea robusta* trees. In order to assess the relationship between the soil parameters, coefficient correlations were calculated and a Multiple Stepwise linear regression model was used to study the interrelationships.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

The soil properties obtained from the research were discussed with respect to the effect of *Grevillea robusta*, by considering the following:

(a) Distance from the rows of *Grevillea robusta*. The expectation here was that the effect would be highest for the samples collected next to the trees and least for those collected far away from the trees. Since samples were collected from portions that were all enclosed by two rows of *Grevillea robusta*, then the effect would be least for those samples taken from the centre of each portion.

(b) Depth of the soil samples. Two depths were considered in each case, 0-15 cm and 15-30 cm. Samples collected from these depths would show differences due to the effect of the litter fall from the trees. The expectation was that leaves from *Grevillea robusta* trees would enrich the soil below them. This contribution would vary with depth and also depend on the rate of leaching.

(c) Differences between the Alisols and Luvisols. The contribution made by *Grevillea robusta* in the Alisols and Luvisols was expected to be different for certain soil properties. This would be explained by the fact that the two soils had different inherent characteristics.

4.1 Properties of Alisols and Luvisols.

Soil classification in the two settlements had already been done by ICRAF when they initiated the tree-planting project. Therefore this was adopted from ICRAF's findings. The properties of the two soils were identified as follows.

4.1.1 Alisols

Highly weathered, deep, well-drained, acidic soils. These soils have low base status (base saturation was less than 50% and a CEC of greater than 24). Texture range from sandy to clayey. These soils show an increase in clay with depth as indicated in FAO (1986). Hence they have an argic B - horizon

4.1.2 Luvisols

Highly weathered, deep, red or yellowish soils. They are also well-drained, acidic and with high base status (base saturation was more than 50%). These soils generally have a good soil structure. The texture ranges from sandy to clayey with clay content increasing with soil depth. They include the more fertile tropical red soils. Luvisols are dominant soils of West African sub-humid tropics and savannas. Other names are Alfisols, sols ferrugineux (French), Red Earths (Australia), Ochrosols (Ghana), as given by Sanchez (1979)

4.2 Soil chemical properties

4.2.1 pH

The pH values for the soil samples were significantly different depending on the distance from the trees. This can be seen in tables 4.1 and 4.2 below. It was observed that samples taken from sites 1 and 4 (near the trees) had lower pH values than sites 2 and 3 (far from trees). Next to the trees, microbial activities lead to the release of CO₂ that in turn combines with H₂O to form carbonic acid. This contributes to lower pH values for the soils next to the trees. For the Alisols, the pH values varied from 5.40 to 6.70. These PH values are described as moderately acid to near neutral and are favourable to the maize crops that had been grown in this farm (Okalebo, 1993).

From Tables 4.3 and 4.4, it was also observed that the pH values for the samples of Luvisols were significantly different. The pH values for sampled sites 1 and 4 were higher than those of sites 2 and 3. The pH values varied from 6.50 to 8.20. These pH values are described as near neutral and slightly to moderately alkaline. The pH values are favourable to most crops and are one of the attributes of a fertile soil, and therefore this would not affect crop growth, (Okalebo, 1993).

In addition, the Luvisols were observed to have higher pH values than the Alisols. However in both cases the values are favourable to crops and the difference could have been due to the inherent soil properties of each soil or the differences in rainfall that would affect the microbial activities.

Table 4.1 Soil chemical properties of the top soils of the Alisols (Katelembu)

Sample d site	pH- H ₂ O	PH- CaCl ₂	% N	% C	C:N	P (ppm)	Exc. Ca	Exc. Mg	Exc. K	Exc. Na	CEC	% BS	% ESP
1	6.10	5.70	0.10	0.85	10:1	19.80	2.03	1.13	1.03	0.58	9.60	45.00	1.90
2	6.60	6.20	0.06	0.79	13:1	29.00	1.88	1.00	1.03	0.20	9.00	45.00	2.00
3	6.70	6.50	0.00	0.44	14:1	29.00	1.53	0.66	0.61	0.30	9.20	34.00	2.79
4	6.00	5.80	0.10	0.71	11:1	18.50	4.10	1.00	1.09	0.31	9.19	41.00	1.70
SED	0.10	0.09	0.01	0.10	1.97	0.35	1.51	0.13	0.06	0.15	0.91	0.76	0.03
LSD	0.21	0.18	0.03	0.20	4.04	0.72	3.09	0.27	0.12	0.31	1.87	1.56	0.07

LSD = least significant difference (P = 0.05)

SED = standard error of the difference between two means.

Table 4.2: Soil chemical properties of the sub-soils of the Alisols (Katelembu)

Sampled site	pH- H ₂ O	pH CaCl ₂	% N	% C	C:N	P (ppm)	Exc. Ca	Exc. Mg	Exc. K	Exc. Na	CEC	% BS	% ESP
1	5.90	5.50	0.05	0.64	13:1	16.00	2.00	1.03	0.80	0.16	14.50	28.00	1.10
2	6.40	6.00	0.02	0.25	13:1	23.00	1.80	0.92	0.80	0.19	12.40	30.00	1.50
3	6.50	6.10	0.01	0.19	19:1	20.00	1.74	0.54	0.60	0.25	13.50	23.00	1.90
4	5.80	5.40	0.05	0.61	12:1	15.50	1.93	1.04	1.11	0.17	13.90	31.00	1.20
SED	0.09	0.09	0.00	0.01	0.83	0.61	0.04	0.01	0.01	0.01	0.06	0.79	0.07
LSD	0.17	0.18	0.00	0.02	1.70	1.24	0.07	0.02	0.02	0.01	0.13	1.63	0.14

Table 4.3: Soil chemical properties of the top soils of the Luvisols (Katheka – kai)

Sampled site	pH- H ₂ O	pH CaCl ₂	% N	% C	C:N	P (ppm)	Exc. Ca	Exc. Mg	Exc. K	Exc. Na	CEC	% BS	% ESP
1	8.20	7.63	0.24	1.71	9:1	79.00	5.64	1.74	2.41	0.19	15.50	64.00	1.20
2	8.00	7.50	0.09	0.97	11:1	125.0	5.23	2.58	1.66	0.18	14.60	66.00	1.20
3	6.80	6.50	0.16	1.45	9:1	92.00	5.42	1.19	2.65	0.21	14.60	68.00	1.50
4	6.60	6.50	0.20	1.08	6:1	104.0	4.80	2.17	2.80	0.26	10.80	93.00	2.40
SED	0.09	0.12	0.01	0.24	1.09	1.02	0.03	0.01	0.02	0.01	0.05	0.65	0.05
LSD	0.19	0.25	0.01	0.48	2.24	2.09	0.07	0.01	0.04	0.02	0.09	1.34	0.11

Table 4.4 Soil chemical properties of the sub-soils of the Luvisols (Katheka-kai)

Sample d site	pH- H ₂ O	pH CaCl ₂	% N	% C	C:N	P (ppm)	Exc. Ca	Exc. Mg	Exc. K	Exc. Na	CEC	% BS	% ESP
1	8.10	7.50	0.04	0.53	13:1	71.0	4.45	1.50	2.20	0.20	10.00	84.0	2.00
2	8.00	7.60	0.03	0.35	12:1	69.0	6.35	2.03	1.67	0.17	11.24	91.0	1.50
3	7.00	6.83	0.10	0.59	15:1	52.0	4.9	2.00	2.60	0.20	9.80	99.0	15.3
4	6.90	6.60	0.04	0.64	16:1	60.0	4.63	2.00	2.91	0.20	9.70	100.0	2.10
SED	0.05	0.06	0.04	0.03	1.58	0.77	0.01	0.01	0.04	0.02	0.28	0.51	9.37
LSD	0.10	0.13	0.08	0.05	3.24	1.58	0.03	0.03	0.08	0.04	0.56	1.05	19.22

The pH changed with distance from the trees. For the Alisols, the pH increased with distance from the trees. (both top soils and sub soils). This shows lower pH near the trees. Litter decomposition next to the trees is likely to have influenced the formation of carbonic acid next to the trees. Differences in pH are noted from one sampled site to that only a few inches away. Such variation results from local microbial action and the uneven distribution of organic residues in the soil (Brady, 1974).

For the Luvisols, it was different. The pH values decreased with distance from the trees (Top soils). This could have been due to the inherent properties of the soil. Any process, which will encourage the maintenance or build up of the exchangeable bases such as calcium, magnesium, potassium, and sodium, will contribute toward a reduction in acidity and an increase in alkalinity. Therefore conditions, which permit the exchangeable bases to remain in the soil, will encourage high pH values and this was the case with the Luvisols.

4.2.2 Organic Carbon(% C)

Percentage organic carbon varied significantly with distance from the trees. It was observed that the % organic carbon was higher for the samples collected next to the trees than those collected far from the trees (Tables 4.1, 4.2, 4.3 and 4.4). This could be due to the high litter fall from the trees, which are then decomposed to form organic carbon. Soil organic matter plays an important role in maintaining soil structure, water holding capacity, the microbial biomass and soil fauna, and also in nutrient cycling.

The top soils of Alisols (0-15 cm deep) were noted to have on average a percentage organic carbon of 0.73 % (Table 4.1 above). On average, the percentage value for the sub soils was

0.42 % (Table 4.2). The bulk of the organic matter and nutrients that are so added to the soil are located in the top soil (Batjes and Sombroek, 1997). This explains why the %C for the top soils of all sampled sites was higher than for the sub-soils. It is also known that agroforestry trees show preferential enrichment of the soil below them, hence the sampled sites next to the trees are the beneficiaries.

On the other hand the top soils of the Luvisols were observed to have a mean value of 1.45 % (Table 4.3 above). The mean value for the sub soils was observed to be 0.53 % (Table 4.4). The decomposition of litter from the trees as cited by Gholz (1987), could be used to explain this difference. He further argues that the inclusion of compatible and desirable species of trees on farmland can result in a marked improvement in soil fertility, by increasing the organic matter content of the soil through addition of leaf litter and other plant parts. The improvement in organic matter status of the soil can result in an increased activity of the favourable micro-organisms in the root zone.

However the differences in % C content for the two soils could be attributed to the varied effects of the *Grevillia robusta* tree in the two farms that differed due to the inherent soil characteristics of each of these soils and different temperatures in the two farms. In general, these % C values are low. Probably this could be due to the minimal microbial activity that takes place in the semi-arid regions because of limited moisture content. Alternatively, oxidation is also faster in such areas and hence increased loss of organic matter, following the Batch effect (Batch, 1958).

4.2.3. Total Nitrogen

The Nitrogen values in both Alisols and Luvisols were not significantly different. However the Nitrogen values varied from 0.00 to 0.1. It is important to note that least significant difference (LSD) and the standard error of the difference between two means (SED) were used to test for the significant levels and therefore no significant difference was identified. Although N values were generally low, there was still a variation in these values.

The Nitrogen content in both Alisols and Luvisols was higher for the samples collected next to trees than those collected far from trees. For the Alisols the % mean values were 0.07 % for top soils and 0.03 % for sub-soils (Tables 4.1 and 4.2 respectively). The high levels of microbial activity next to the trees led to the release of Nitrogen (Gholz 1987). The

variation with distance could be associated with the difference in litter fall, which was higher for the sites next to the trees.

Total Nitrogen content for the Luvisols also showed the same variation. The mean values were 0.17 % for top soils and 0.04 % for sub-soils. (Tables 4.3 and 4.4 respectively). Agroforestry systems have been associated with a moderating effect of additional organic matter on extreme soil reactions and, consequently, improved nutrient release in the soil (Gholz, 1987). This could be associated with the litter decomposition next to the trees.

In all cases it was observed that the % N values for top soil samples were higher than for sub-soil samples. This was attributed to the effect of *Grevillea robusta* trees since the leaves of this tree are known to be rich in Nitrogen (Rao 1990). That is why the % N values for the sampled sites 1 and 4, which were closer to the trees were higher than for sites 2 and 3 (far from trees). The sites closer to the trees benefited from the litter fall from the trees. However the litter decay of these leaves is moderately slow and this could be the reason why the %N values were generally low. The reason for low decomposition in the site is due to the low levels of micro – organisms that could survive the high temperatures associated with this region. The % N values for the Luvisols were higher than those of the Alisols. Tefera (2001) had obtained similar results. This could be attributed to the inherent properties of the soil.

4.2.4 C: N Ratio

The C: N ratios for the Alisols varied significantly. Top soils had SED and LSD values of 1.97 and 4.04 respectively, while sub soils had SED and LSD values of 0.83 and 1.70 respectively. They were lower for the samples collected next to the trees than those far from trees. C:N ratios may be used to show the level of microbial activity in the soil. Newly formed soils will be found next to the trees due to litter decomposition (Batjes and Sombroek, 1997). The same argument could be used to explain why the C: N ratio of topsoil samples for the Alisols were lower compared to those of the sub-soil samples (12:1 for top soils and 14:1 for the sub-soil as shown in Tables 4.1 and 4.2 respectively).

The C: N ratios for the Luvisols were also lower for top soils than for the sub-soils (9:1 for top soils and 14:1 for sub-soils as shown in Tables 4.3 and 4.4 respectively). This could be

attributed to the microbial activity that leads to higher % C next to the trees (Rao, 1990). The same reasoning could be used to explain why the C: N ratios were lower for the top soils than sub soils.

Nitrogen mineralization depends on temperature, soil PH, clay mineralogy, and moisture status (Brady, 1984). Perhaps the factor affecting N mineralization rates in the tropics is the low soil moisture status which limits the microbial activity in these areas. Therefore the C: N ratio differences could be associated with the climatic and the existing soil properties of these soils rather than the contribution of the *Grevillia robusta* trees.

4.2.5 Phosphorus (in ppm).

The P (in ppm) for the Alisols was observed to be lower for the samples collected next to the trees as compared to those collected far away from trees . For the top soils, at sites 1 and 4, P values were 19.80 and 18.50 (in ppm) respectively, while for sites 2 and 3 the values were both 29.0 (in ppm).The SED and LSD values were 0.35 and 0.72 respectively. For the sub soils, at sites 1 and 4, the P values were 16.00 and 15.50 (in ppm) respectively, while for sites 2 and 3 the values were 23.00 and 20.00 (in ppm) respectively. The SED and LSD values were 0.61 and 1.24 respectively. This represents a significant variation. The decomposition of organic matter tends to result to the release of nutrients such as N, P and K (Batjes and Sombroek, 1997). This process is more prevalent next to the trees as compared to sites far from the trees. However, oxides of iron and manganese easily fix available P and this may have contributed to its lower values next to the trees. For the Luvisols, the P values did not show such a trend in relation to distance from the trees. However, P values for the Luvisols were higher than for the Alisols, which could be attributed to the different properties of the two soils rather than the effect of the trees.

4.2.6 Cation Exchange Capacity (CEC)

The CEC (Cmol/Kg) values for the samples were significantly different. For the Alisols, the values decreased with distance from the trees. In the top soils of the Alisols, the CEC values for sites 1 and 4 were 9.60 and 9.19 respectively, while for sites 2 and 3 the values were 9.00 and 9.20 respectively. The SED and LSD values were 0.91 and 1.87 respectively. In the sub soils of the Alisols, CEC values for sites 1 and 4 were 14.50 and 13.90 respectively, while for sites 2 and 3 the values were 12.40 and 13.50 respectively. The SED and LSD values were 0.06 and 0.13 respectively. CEC is essentially a measure of negative charge on

the colloidal fraction, derived from the clay and organic matter fraction. In this case it was probably the high organic matter content that led to the CEC being higher next to trees than far from trees. CEC for the Alisols was however higher for the sub soils than the top soils. (mean of 9.6 for the top soils and 13.6 for the sub-soils). CEC being related to the clay content in the soil could have been higher for sub soils which also contained more clay. Scherr, 1992, obtained similar results while determining the role of extension in agroforestry development in some parts of western Kenya.

In the case of Luvisols the CEC values did not show a certain pattern in terms of distance from the tree. However, the CEC values for the top soils were higher than for the sub soils, as shown in Tables 4.3 and 4.4. The variation in the CEC for the Alisols and Luvisols could be attributed to the differences in organic matter and clay that was at different levels for the two soil types.

4.2.7 Exchangeable Cations (Ca, Mg, K, Na)

The exchangeable cations were significantly different for both Alisols and Luvisols. Exchangeable Ca for the Alisols was observed to be higher for the sites next to trees than those far from trees. This variation could be attributed to the positive effect of the trees next to the trees. The exchangeable Ca for the top soils ranges from 4.10 meq/100g to 1.53 meq/100g, as shown in Table 4.1 above. For the sub-soils the range was from 2.00 meq/100g to 1.74 meq/100g (Table 4.2). The difference could be associated with a number of aspects. First, if the percentage calcium saturation of the soil is high, the displacement of this cation is comparatively easy and rapid (Brady, 1974). Therefore this difference in the top and sub soils could be associated with the CEC, which was also higher for the sub soils in this case. Second, these results could be associated with high rates of leaching from the top soils to the sub soils.

The exchangeable Ca for the Luvisols did not show any distinct difference with distance from the trees. However, in the case of top soils, the variation was between 5.64 meq/100g to 4.80 meq/100g for the top soils, as shown in Table 4.3 above. The range for the sub-soils was from 6.35 meq/100g to 4.45 meq/100, as shown in Table 4.4. The top soils on average therefore had more exchangeable Ca than the sub-soils. This could be associated with some soil properties, like the CEC, which was observed to have the same variation in this study region.

For the Alisols, the exchangeable Mg was observed to be higher for the sites next to the trees than those far from trees. Mg increases with increased decomposition, which happens to be a prevalent activity next to the trees and also in the top soils. Also, availability of cations is influenced by ions held in the soil. For example, potassium availability has been shown to be limited by the excessive quantities of exchangeable calcium. Likewise, in some cases high exchangeable Potassium contents have depressed the availability of magnesium (Smaling, 1993). A flush of exchangeable Ca accompanied sometimes by exchangeable Mg, increases the top soil base status, and may be related to tree stump and the trees capacity to capture such nutrients (Sanchez, 1979).

The exchangeable Na did not vary significantly with distance from the trees, for both Alisols and Luvisols. However, exchangeable K values of the Alisols decreased with distance from the trees. For example, in the top soils of the Alisols, K values were 1.03 and 1.09 for sites 1 and 4 respectively. This was significantly different from sites 2 and 3 where the values were 1.03 and 0.61 respectively. Organic matter decomposition around the trees could be associated with the release of K and hence increased K values near the trees. The same argument could be used to explain the variation in K for the Luvisols where the values also decreased with distance from the trees. Exchangeable K in the soil is highly influenced by the available exchangeable Ca. Excessive amounts of Ca limits the exchangeable K (Gholz, 1987). Therefore the variation could also be associated with the exchangeable Ca, which in turn was affected by the CEC. The fact that Luvisols had higher values could be due to the inherent soil properties and not the effect of the trees. K is however not limiting in most Kenyan soils.

4.2.8 Base Saturation

In both the Alisols and Luvisols, Base saturation values did not show a certain pattern in terms of distance from the tree. However, Base saturation values for the samples of Alisols varied significantly with depth, ranging from 34% to 45% for the top soils and from 23% to 31% for the sub soils, as shown in Tables 4.1 and 4.2 above. Base saturation measures the ratio of the quantity of exchangeable bases to the CEC. The high base saturation values for the top soils could be associated with the high Organic matter content that would contribute to high exchangeable bases. These values are adequate and indicate favourable soil fertility status for the soils.

The base saturation values for the Luvisols range from 64% to 93% for the top soils and that of the sub-soils range from 84% to 100%, as shown in tables 4.3 and 4.4 respectively. Therefore the base saturation values for the sub-soils were higher than for the top soils. The value of base saturation varies according to whether the CEC includes only the salt extractable acidity. As the % Ca, Mg and K on the exchange sites of a soil increase, the pH also increases. Also, as the base saturation in the top soil is lowered through leaching of bases like Ca from the top to sub soils, pH in the top soil also goes down (Brady, 1974). The difference in the % base saturation for the two soils could be associated with the difference in their pH values and also other inherent soil properties like the metallic constituents of the soils.

4.2.9 Exchangeable Sodium Percentage (ESP)

This value is used to classify sodic soils and it measures the extent to which the adsorption complex of the soil is occupied by sodium. Salts lower fertility status of soil. The %ESP values for both soil types did not seem to differ with distance from the trees. However, the %ESP values for the Alisols range between 1.7 and 2.79 for the top soils, while for the sub soils the range was between 1.1 and 1.9. The %ESP decreased with soil depth. Tefera (2001) obtained similar results, when a similar research was carried out in the same study region. This variation could be associated with minimal leaching activity associated with this semi- arid region. High Organic matter content around the trees may also have contributed to minimal leaching to the sub soil.

For the Luvisols the %ESP range from 1.2 to 2.4 for the top soils, while the range for the sub soils is from 1.5 to 15.3 as shown in tables 4.3 and 4.4 respectively. This variation could be associated with the inherent soil properties of this particular region or even leaching of Sodium to the sub soil. Soils where the ESP is less than 6.0 are said to be non- sodic (FAO, 1986). Furthermore, these values do not seem to have been influenced by the trees.

4.3 Soil physical properties

4.3.1 Particle size distribution (Texture)

The textural class for both top soil and sub soil of the Alisols range from clay (C) to sandy clay (SC) and sandy clay loam (SCL). The % sand content for the samples of the top soils was between 70 and 73, while for the sub soil the % range was between 44 and 52, (Tables

4.5 and 4.6 below). There was no considerable difference in sand content with relation to distance from the trees. However sand content decreased with depth. This could be due to the leaching of the finer particles (clay and silt) from the top soil to the sub soil, leaving the coarse particles (sand) on the top. When Aisols are being formed, eluviations of clay particles from the top soil and deposition in the sub soil takes place. They therefore have the argic B- horizon. (FAO, UNESCO 1988). The same theory could be used to explain the sand variation in the Luvisols. The % sand content varied from 65 to 66 for the top soils, while for the sub soils the range was between 58 and 60, (Tables 4.7 and 4.8 below).

In both study areas, there was no considerable difference in Silt content in relation to distance from the trees. Silt content, however varied with depth. The Silt content for the Alisols varied from 2 to 5 (Top soils). In case of the Sub soils the range was from 3 to 7, (Tables 4.5 and 4.6 below). This could be due to silt and clay migration from the top to sub soils.

For the Luvisols the Silt content varied from 2 to 3, for the top soils, while for the sub soils the range was the same, (Tables 4.7 and 4.8 below). This could be due to the eluviations of silt from the top soil.

In all the sampled sites 1 to 4, for the Alisols, the percent clay values were lower for topsoils (25%-27%) than sub soils (45% – 49%) as shown in Tables 4.5 and 4.6 below. In the Luvisols, the percentage clay values were higher for the sub soils (37% to 40%) than for the top soils (32% to 33%), as shown in Tables 4.7 and 4.8 below. This suggests that there were clay eluviations, as with argic B- horizon (FAO, 1986).

Table 4.5 Soil physical properties of the top soils of the Alisols (Katelembu)

Sampled site	% Sand	% Silt	% Clay	BD(g/cm ³)	% Porosity	% Moisture
1	72.00	2.13	26.00	1.70	37.00	3.00
2	73.00	2.00	24.75	1.60	41.00	3.00
3	70.00	3.00	27.00	1.70	37.00	3.00
4	70.00	5.00	25.00	1.58	41.00	3.88
SED	1.08	0.21	1.04	0.01	0.43	0.21
LSD	2.22	0.43	2.14	0.02	0.88	0.43

Table 4.6 Soil physical properties of the sub soils of the Alisols (Katelembu)

Sampled site	% Sand	% Silt	% Clay	BD(g/cm ³)	% Porosity	% Moisture
1	52.00	3.00	45.00	1.70	36.00	3.88
2	48.00	6.00	45.88	1.70	36.00	11.12
3	46.00	5.00	49.00	1.68	37.00	6.00
4	44.00	7.00	49.00	1.70	36.00	17.00
SED	0.59	0.27	0.42	0.01	0.33	0.49
LSD	1.22	0.56	0.86	0.01	0.68	1.00

Table 4.7 Soil physical properties of the top soils of the Luvisols (Katheka-kai)

Sampled site	% Sand	% Silt	% Clay	BD(g/cm ³)	% Porosity	% Moisture
1	65.0	3.00	32.0	1.45	46.0	6.00
2	66.0	2.00	32.0	1.33	50.0	4.00
3	66.0	2.00	32.0	1.31	51.0	5.00
4	65.0	2.00	33.0	1.50	43.0	13.00
SED	0.47	0	0.47	0.01	0.39	0.43
LSD	0.97	NS	0.97	0.02	0.79	0.88

Table 4.8 Soil physical properties of the sub soils of the Luvisols (Katheka-kai)

Sampled site	% Sand	% Silt	% Clay	BD(g/cm ³)	% Porosity	% Moisture
1	58	3	39	1.40	47	6
2	58	2	40	1.55	42	7
3	60	3	37	1.32	50	10
4	59	2	39	1.47	45	12
SED	0.69	0.19	0.72	0.00	0.56	NS
LSD	1.42	0.39	1.48	0.01	1.15	NS

4.3.2 Bulk Density (BD)

For the top soils in both cases, there was no considerable difference in the bulk density in relation to distance from the trees (Tables 4.5 and 4.7 above). In the Alisols, bulk density

values for the top soil samples ranged from 1.58-1.70g/cm³. However, BD results showed an increase with depth. The range for the sub soils for the Alisols was from 1.68 to 1.70, (Table 4.6 above). In the Luvisols, the values for the top soils ranged from 1.31 g/cm³ to 1.50 g/cm³ and. The values for the sub soils ranged from 1.32 g/cm³ to 1.55 g/cm³, (Tables 4.7 and 4.8 above). This is due to the more compact sub soil that arises from less tillage or less organic matter that increases soil porosity. It therefore means that the BD for the sub soil will be higher than for the top soil. These values would not be expected to cause hindrance to root penetration. Hindrance to root penetration in a soil lowers the soil physical fertility (Nair, 1993)

4.3.3 Porosity (f)

For both sites, porosity results did not show any considerable difference with distance from the trees. However, for the Alisols, porosity values of the top soils were observed to range from 37%-41%, (Table 4.5 above). Those of the sub soils the range was between 36-37%, (Table 4.6). In the Luvisols the range was between 43% and 51% (top soils). For the sub soils the range was between 42% and 50%, (Tables 4.7 and 4.8 above). It is noted that sand soils with a total pore space of less than 40% are liable to restrict root growth due to excessive strength, whilst in clay soils, limiting total porosities are higher, and less than 50% can be taken as the corresponding approximate value (Brady, 1974). These values were therefore favourable for root penetration.

The top soils were found to be more porous since the top soil usually contain more organic matter that contributes to increased porosity in the soil (Gholz, 1987). This is associated with the litter fall from the trees and also organic matter decomposition under the trees. However, it must be stressed that values of total porosity should not be used as conclusive evidence for over-compaction problems in soil, but rather as indicators of likely risk.

4.3.4 Soil Moisture Content

There was no considerable horizontal variation in moisture content for the Alisols. Moisture content in relation to distance from the trees and also in relation to depth was of no considerable difference. The moisture content ranged between 3%-3.88% (top soils) as shown in Table 4.5 above. The range for the sub soils was between 3.88%-17%, as shown in Table 4.6 above. This could be explained by the fact that the less compact top soil retained less water than the finer (clay and silt) and more compact sub soil.

In the Luvisols, the range for the top soils was between 4%-13%, (Table 4.7, above). The values of the sub soils ranged between 6%-12%, (Table 4.8, above). However these values were higher than those of the Alisols. This could be due to the difference in other physical properties, like clay, sand and even the humus content for these two sites. Generally, the sampling was done during the dry season, and hence the moisture content might have been of some considerable difference in the two sites.

According to Gholz (1987), fast growing species of trees may place a heavy demand on soil moisture, and unless properly managed, this can lead to adverse effects, especially in drier environments. He further argued that the inclusion of trees and woody perennials on farmlands can, in the long run, result in marked improvements in the physical conditions of soil – in permeability, water – holding capacity, aggregate stability, and soil temperature regimes.

4.3.5 Moisture Retention and Release

The amount of moisture retained after different suction levels increased with distance from the trees. Soil samples taken from points next to the trees contained more moisture, but lost the moisture at a higher rate also (Table 4.9 and 4.10, below). Similarly, from tables 4.9 and 4.10 below, it was observed that the average moisture retained after different suction levels for the top soils (Alisols) was higher than for the sub soils (from 0.297mm-0.074mm for top soils and from 0.282mm-0.106mm for the sub soils). For the Luvisols (Tables 4.11 and 4.12), the average moisture retained for the top soils was from 0.333mm-0.103mm, with a field capacity of 0.020mm. That of the sub soils was from 0.316mm-0.116mm, and a field capacity of 0.020mm.

At the initial stages, the top soils retained more moisture than the sub soils. However, the rate at which the top soils lost the moisture was higher than for the sub soils. This could be attributed to the fact that soils next to the trees and also the top soils have more organic matter and are also more porous than the sub soils. Therefore the rate at which moisture is lost is also higher for the top soils. The sub soil have finer particles (due to clay migration) and therefore retains more water. In this case, the field capacity for the top soils was 0.005mm, while that of the sub soils was 0.006mm.

Although the effect of water use by a tree component on water availability to crop plants in different climatic conditions is not yet fully understood, there is evidence that the hydrological characteristics of catchment areas are favourably influenced by the presence of trees (Gholz, 1987).

Table 4.9: Moisture retained after different suction levels (Top soils of the Alisols)

Sampled site	Moisture retained in millimetres at different suction levels								
	Suction levels in millibars	0	0.3	0.5	1	3	5	7	15
1		0.338	0.116	0.106	0.099	0.092	0.086	0.081	0.076
2		0.258	0.138	0.123	0.115	0.110	0.098	0.092	0.087
3		0.293	0.115	0.103	0.099	0.095	0.081	0.075	0.069
4		0.290	0.097	0.084	0.077	0.070	0.065	0.062	0.059
Mean value		0.297	0.116	0.104	0.098	0.092	0.080	0.079	0.074

Table 4.10: Moisture retained after different suction levels (Sub soils of the Alisols)

Sampled site	Moisture retained in millimetres at different suction levels								
	Suction levels in millibars	0	0.3	0.5	1	3	5	7	15
1		0.260	0.121	0.105	0.097	0.088	0.081	0.077	0.073
2		0.234	0.079	0.068	0.060	0.051	0.046	0.044	0.042
3		0.239	0.087	0.075	0.068	0.059	0.054	0.059	0.047
4		0.386	0.338	0.148	0.316	0.309	0.302	0.295	0.289
Mean value		0.282	0.150	0.100	0.128	0.120	0.115	0.112	0.106

Table 4.11: Moisture retained after different suction levels (Top soils of the Luvisols)

Sampled site	Moisture retained in millimetres at different suction levels								
	Suction Levels in millibars	0	0.3	0.5	1	3	5	7	15
1		0.310	0.153	0.139	0.131	0.120	0.110	0.103	0.091
2		0.367	0.193	0.178	0.169	0.167	0.157	0.125	0.102
3		0.301	0.206	0.195	0.189	0.185	0.176	0.151	0.130
4		0.353	0.175	0.162	0.153	0.151	0.141	0.112	0.089
Mean value		0.333	0.182	0.169	0.161	0.156	0.146	0.123	0.103

Table 4.12: Moisture retained after different suction levels (Sub soils of the Luvisols)

Sampled site	Moisture retained in millimetres at different suction levels								
	Suction Levels in millibars	0	0.3	0.5	1	3	5	7	15
1		0.336	0.223	0.211	0.200	0.198	0.180	0.157	0.137
2		0.323	0.234	0.211	0.199	0.194	0.179	0.151	0.129
3		0.315	0.193	0.180	0.170	0.167	0.156	0.137	0.117
4		0.291	0.202	0.177	0.161	0.151	0.135	0.097	0.079
Mean value		0.316	0.213	0.195	0.183	0.178	0.163	0.136	0.116

Moisture retention curves were also drawn to compare the retention capacities of the soils sampled close to the trees and those taken far from the trees. The less porous soils retained less moisture after different suction levels.

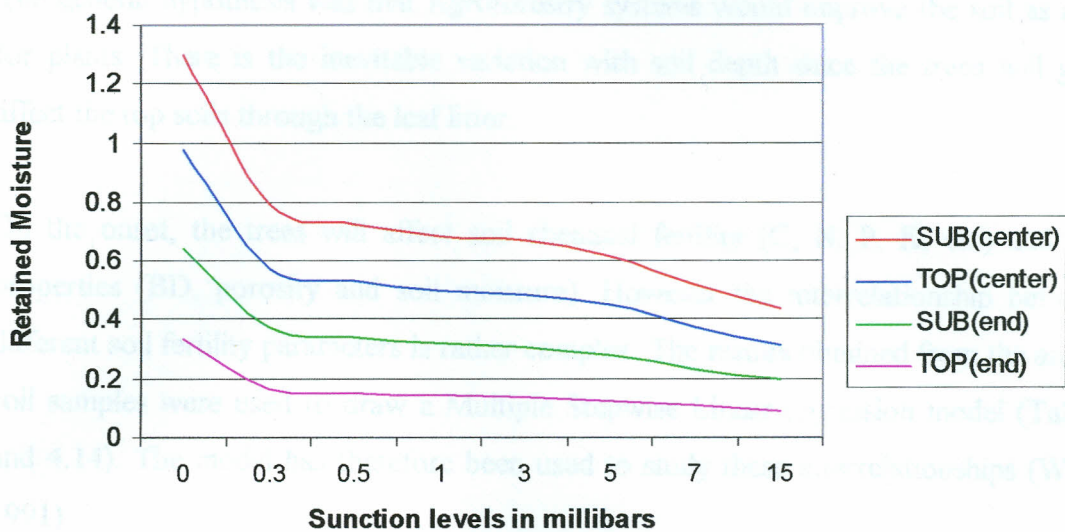


Fig. 4.1 Moisture retention in mm (Alisols)

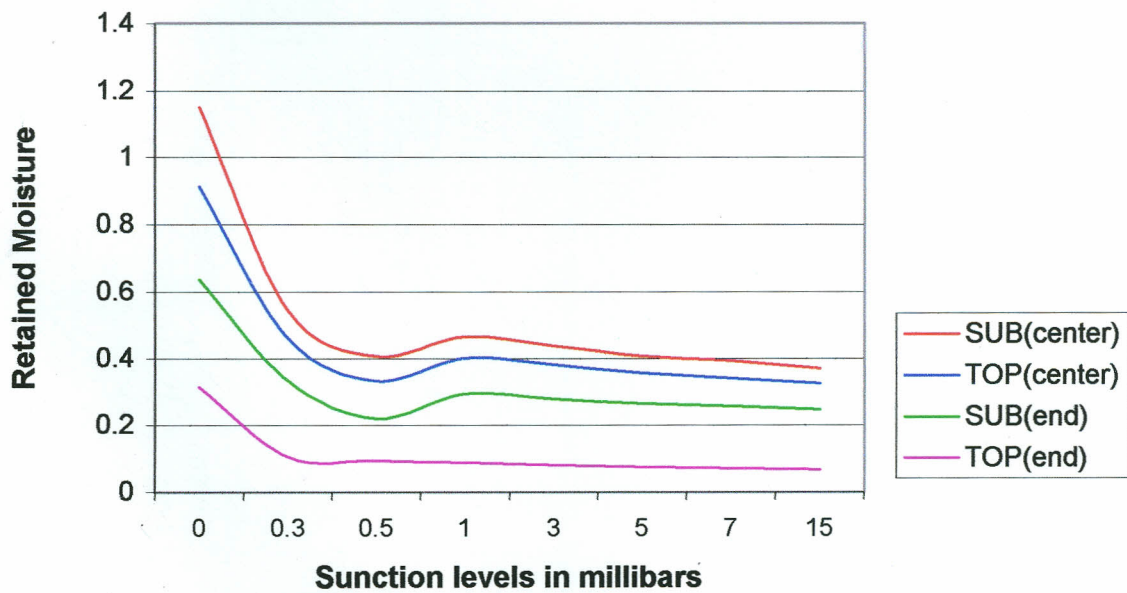


Fig.4.2 Moisture retention in mm (Luvisols)

4.4 Factors which affect soil fertility

The general hypothesis was that Agroforestry systems would improve the soil as a habitat for plants. There is the inevitable variation with soil depth since the trees will generally affect the top soils through the leaf litter.

On the onset, the trees will affect soil chemical fertility (C, N, P, K, etc) and physical properties (BD, porosity and soil moisture). However the interrelationship between the different soil fertility parameters is rather complex. The results obtained from the analysis of soil samples were used to draw a Multiple Stepwise Linear regression model (Table 4.13 and 4.14). The model has therefore been used to study these interrelationships (Wamicha, 1991).

Table 4.13 Correlation Matrix of Allisols (Chemical Parameters)

	PH (H ₂ O)	PH (CaCl ₂)	N	C	C:N	P	Ca	Mg	K	Na	CEC	BS	ESP
pH -H ₂ O	1												
PH-CaCl ₂	0.9693**	1											
N	-0.4677	-0.4256	1										
C	-0.4660	-0.4121	0.9753**	1									
C:N	0.5187	0.4436	-0.8199*	-0.8015*	1								
P	0.9080**	0.9093**	-0.1927	-0.1568	0.1581	1							
Ca	-0.7985*	-0.850**	0.6990	0.6723	-0.5710	-0.6900	1						
Mg	-0.6480	-0.6520	0.7865*	0.8045*	-0.8878**	-0.3246	0.8088*	1					
K	-0.5923	-0.5325	0.7465*	0.7822*	-0.8058*	-0.2800	0.6391	0.8397**	1				
Na	0.7423*	0.7840*	-0.5977	-0.6317	0.6997	0.5064	-0.8771**	-0.9385**	-0.7301*	1			
CEC	-0.5306	-0.6083	-0.4369	-0.4292	0.3503	-0.7462*	0.2524	-0.0914	-0.2227	-0.2179	1		
BS	0.0280	0.0800	0.8214*	0.8255*	-0.7155*	0.3471	0.3135	0.6099	0.6719	-0.3457	-0.8232*	1	
ESP	0.8006*	0.8807**	-0.0956	-0.1088	0.2120	0.8072*	-0.7432*	-0.5359	-0.3464	0.7784*	-0.7671*	0.2900	1

* Significant level less than 0.05, ** Significant level less than 0.01 (2- tailed)

Table 4.14 Correlation Matrix of Luvisols (Chemical Parameters)

	PH (H ₂ O)	PH (CaCl ₂)	N	C	C:N	P	Ca	Mg	K	Na	CEC	BS	ESP
pH -H ₂ O	1												
PH-CaCl ₂	0.9908**	1											
N	-0.1056	-0.0851	1										
C	0.0458	0.0444	0.9383**	1									
C:N	0.0850	0.0512	-0.8438**	-0.6522	1								
P	0.0650	0.0580	0.4700	0.3659	-0.6846	1							
Ca	-0.3845	0.4454	0.1436	0.1786	-0.2519	0.0771	1						
Mg	0.0977	0.1674	-0.1690	-0.2483	0.0622	0.3619	0.0263	1					
K	-0.7845*	-0.8014*	0.3040	0.2556	-0.0166	-0.3201	-0.5574	-0.3608	1				
Na	-0.7205*	-0.7046	0.4728	0.2156	-0.5302	0.2153	-0.5212	-0.0850	0.6966	1			
CEC	0.3829	0.3724	0.6577	0.7839*	-0.5420	0.6061	0.4988	-0.0405	-0.3179	-0.2594	1		
BS	-0.4724	-0.4290	-0.5680	-0.7040	0.5028	-0.6158	-0.3393	0.1961	0.3639	0.2602	-0.9437**	1	
ESP	-0.6506	-0.6393	-0.2086	-0.4221	0.1329	-0.3289	-0.6821	-0.0040	0.6329	0.7187*	-0.8520**	0.8127	1

* Significant level less than 0.05, ** Significant level less than 0.01 (2- tailed)

4.4.1 Effect of soil pH (reaction) on soil fertility parameters

In the Alisols, there was a significant positive correlation between Na and pH in H₂O and CaCl₂ ($r = 0.74^*$ and $r = 0.78^*$, Table 4.13, Fig. 4.3 and Fig. 4.4). ESP also had a significant positive correlation with pH both in H₂O and CaCl₂, $r = 0.80^*$ and $r = 0.88^{**}$ (Table 4.13, Fig. 4.5 and Fig. 4.6). The presence of salts especially Ca, Mg and Na carbonates gives preponderance hydroxyl ions over hydrogen ions in the soil solution (Brady, 1974) The high concentration of hydroxyl ions causes a high pH.

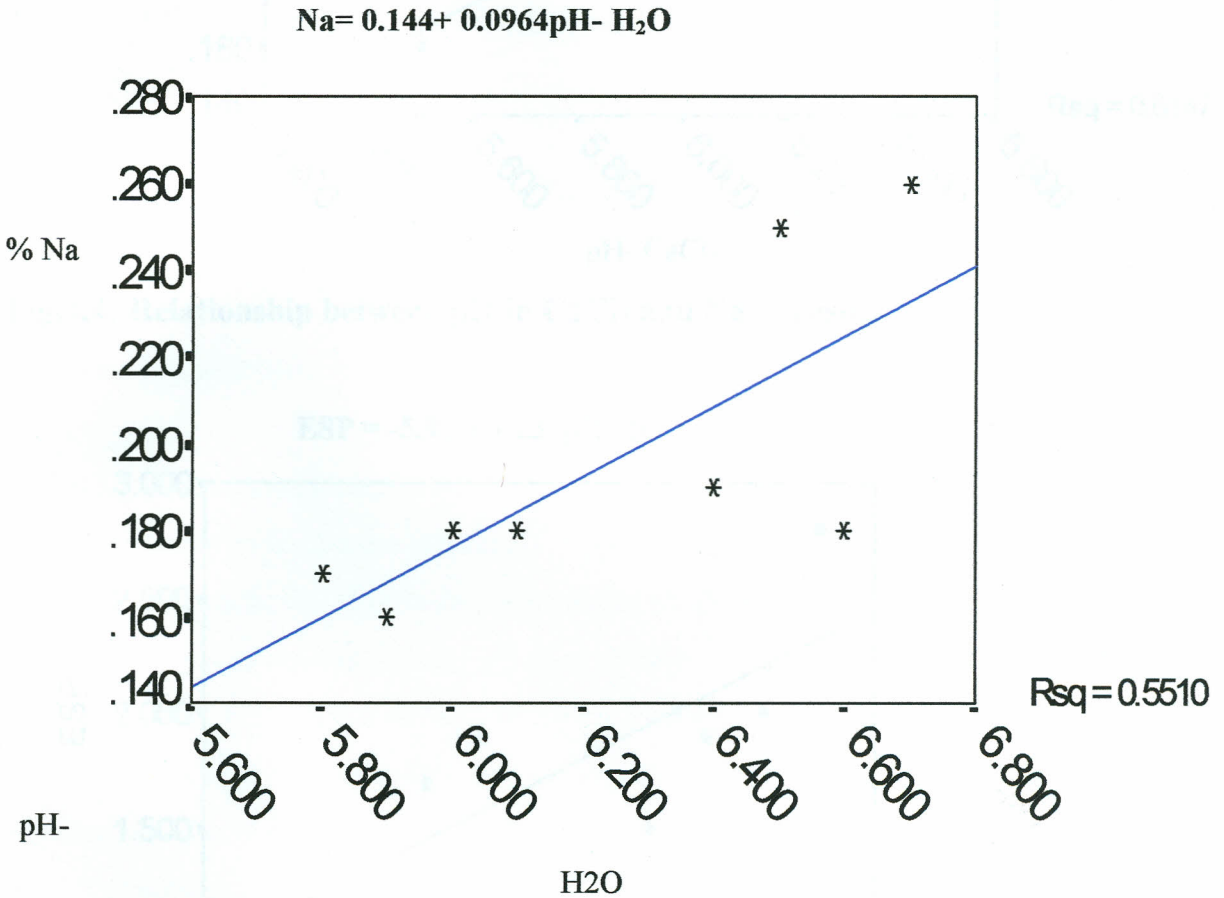


Fig. 4.3: Relationship between pH in H₂O and Na – Alisols

$$\text{Na} = 0.140 + 0.080\text{pH- CaCl}_2$$

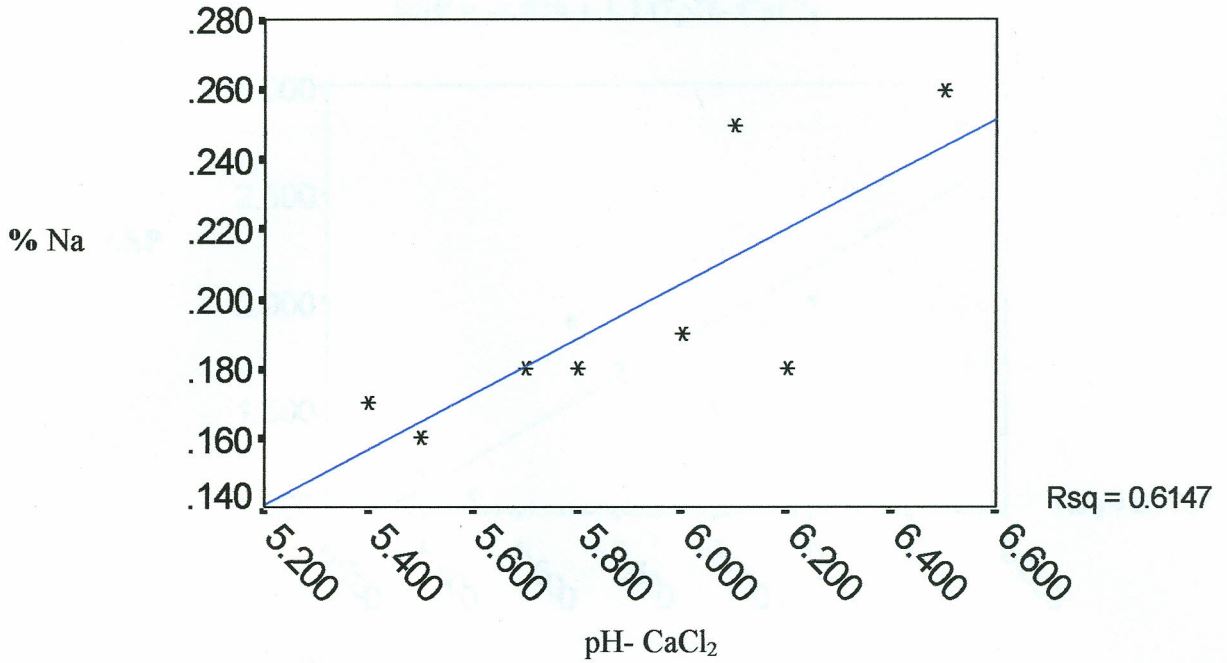


Fig.4.4: Relationship between pH in CaCl₂ and Na – Alisols

$$\text{ESP} = -5.97 + 1.239\text{pH- H}_2\text{O}$$

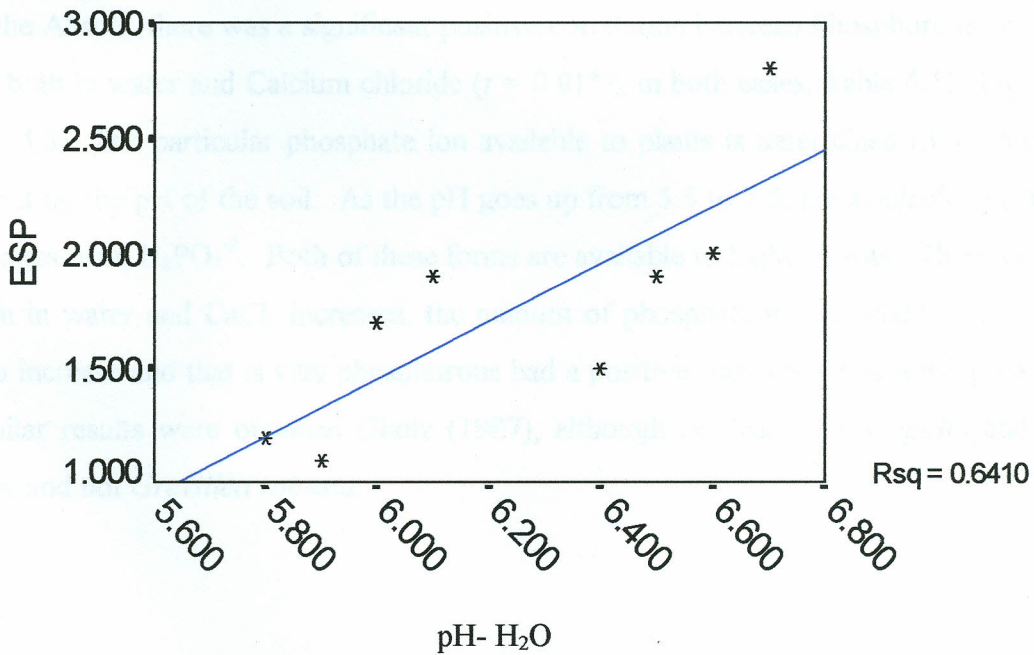


Fig.4.5: Relationship between pH in H₂O and ESP – Alisols

$$\text{ESP} = -4.970 + 1.147\text{pH} - \text{CaCl}_2$$

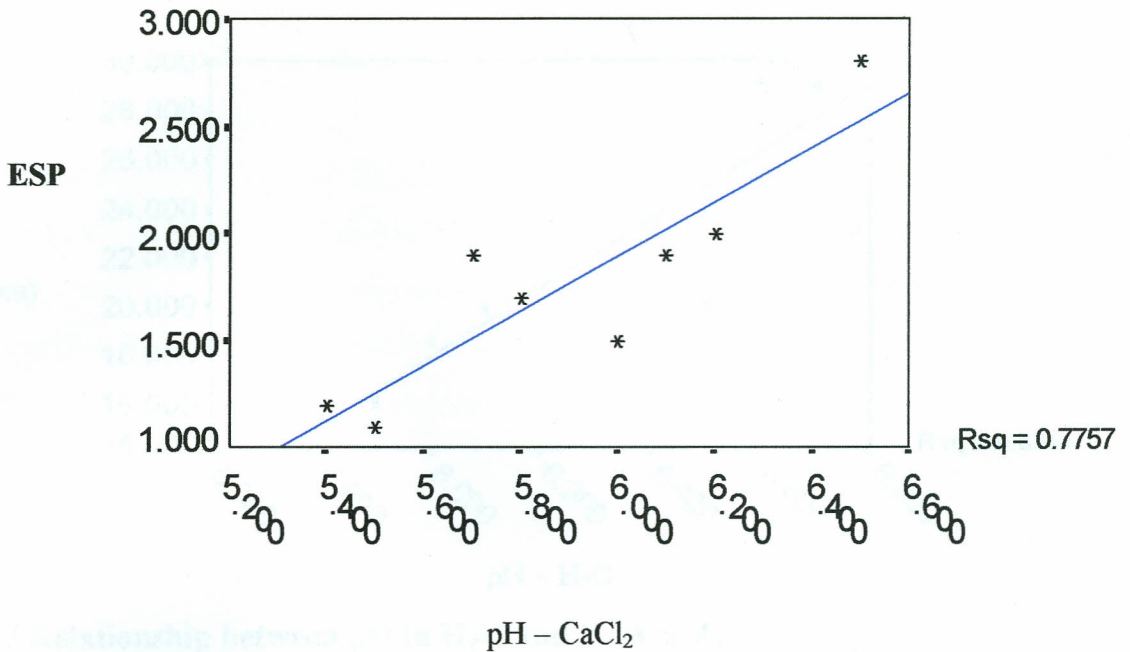


Fig. 4.6: Relationship between pH in CaCl₂ and ESP -Alisols

In the Alisols, there was a significant positive correlation between Phosphorous and the soil pH both in water and Calcium chloride ($r = 0.91^{**}$, in both cases, Table 4.13, Fig. 4.7 and Fig. 4.8). The particular phosphate ion available to plants is determined to a considerable extent by the pH of the soil. As the pH goes up from 5.5 to 7.5, the available phosphorous changes from $\text{H}_2\text{PO}_4^{-2}$. Both of these forms are available to higher plants. Therefore as pH, both in water and CaCl_2 increases, the amount of phosphate ions available for in the soil also increase and that is why phosphorous had a positive significant relationship with a pH. Similar results were obtained Gholz (1987), although he dealt with *Capulin* and *Sabino* trees and not *Grevillea robusta*.

$$P = -66.1500 + 14.0000\text{pH} - \text{H}_2\text{O}$$

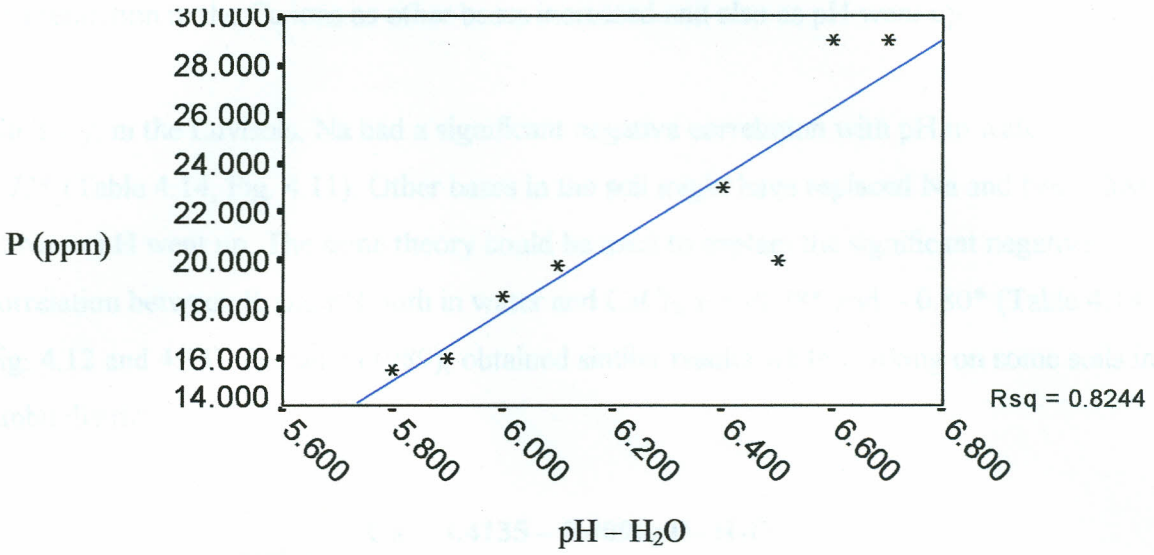


Fig. 4.7 Relationship between pH in H₂O and P –Alisols

$$P = -55.1042 + 12.9583\text{pH} - \text{CaCl}_2$$

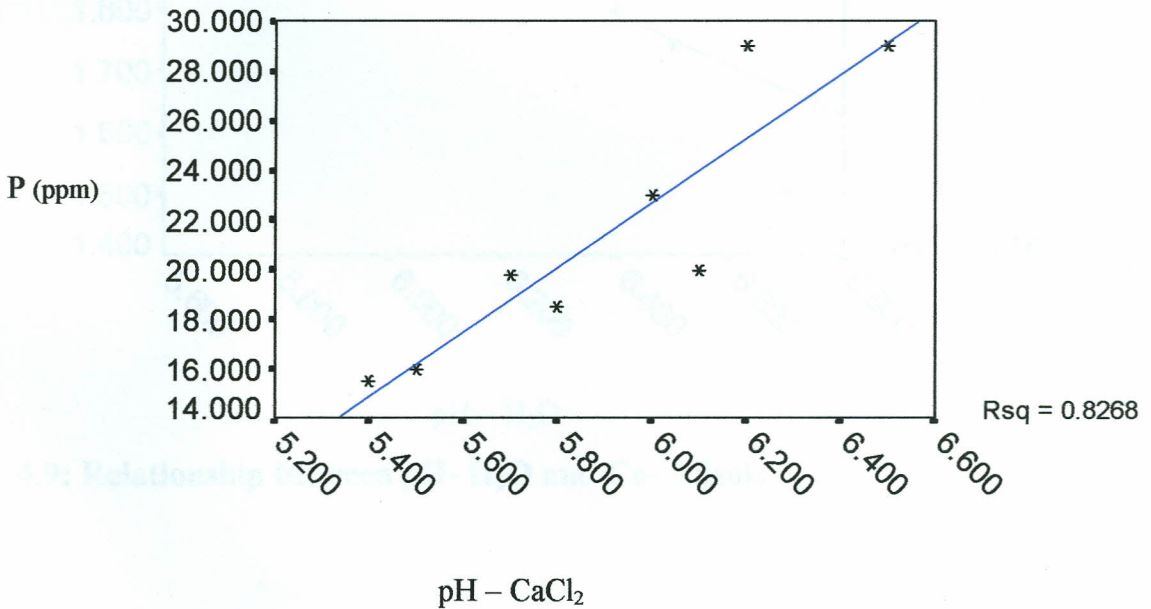


Fig.4.8: Relationship between pH in CaCl₂ and P –Alisols

In the Alisols, there was a significant negative correlation between Ca and pH, both in H₂O and CaCl₂, $r = -0.80^*$ and $r = -0.85^{**}$ (Table 4.13, Fig. 4.9 and fig. 4.10). This could be associated with the increase in the other bases like ESP, as explained earlier. This in turn led to a reduction in the Ca ions as other bases increased and also as pH went up.

Similarly, in the Luvisols, Na had a significant negative correlation with pH in water, $r = -0.72^*$ (Table 4.14, Fig. 4.11). Other bases in the soil might have replaced Na and hence less of Na as pH went up. The same theory could be used to explain the significant negative correlation between K and pH both in water and CaCl₂, $r = -0.78^*$ and -0.80^* (Table 4.14, Fig. 4.12 and 4.13). Getahun (1989), obtained similar results while working on some soils in Embu district.

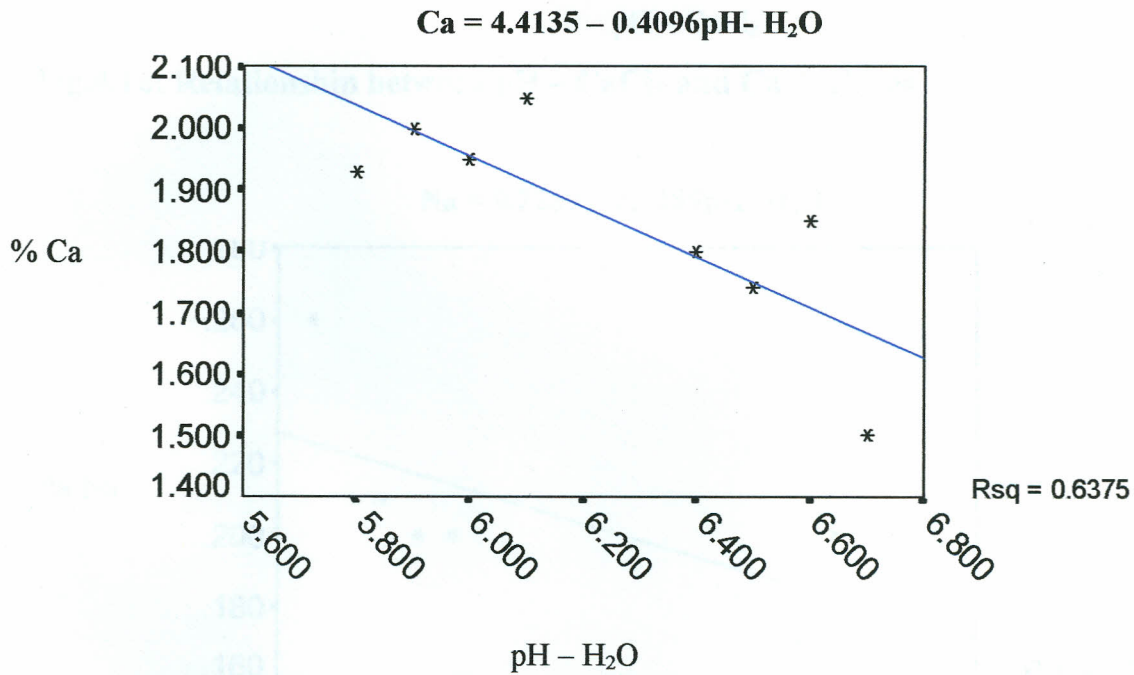


Fig. 4.9: Relationship between pH- H₂O and Ca- Alisols

$$\text{Ca} = 4.2310 - 0.4031\text{pH} - \text{CaCl}_2$$

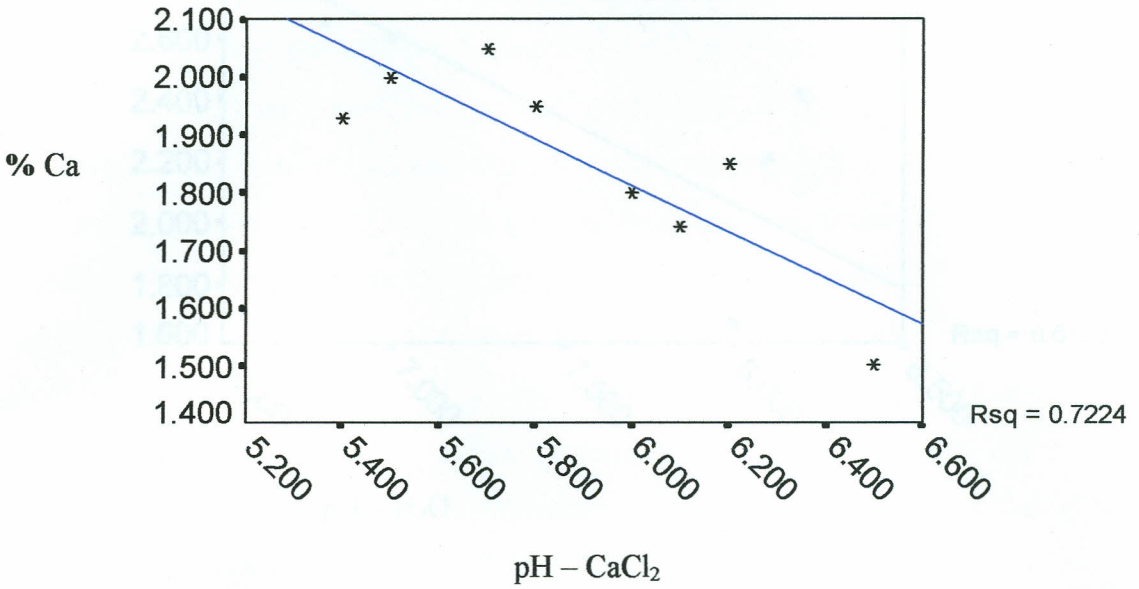


Fig.4.10: Relationship between pH – CaCl₂ and Ca – Alisols

$$\text{Na} = 0.2289 - 0.0289\text{pH} - \text{H}_2\text{O}$$

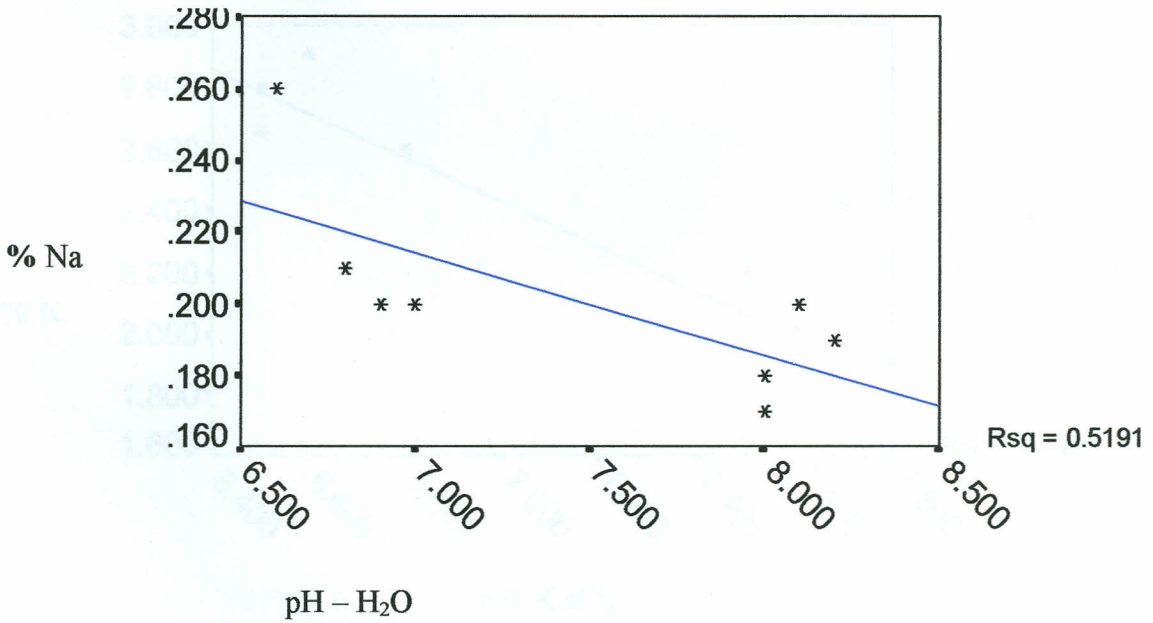


Fig.4.11: Relationship between pH in H₂O and Na – Luvisols

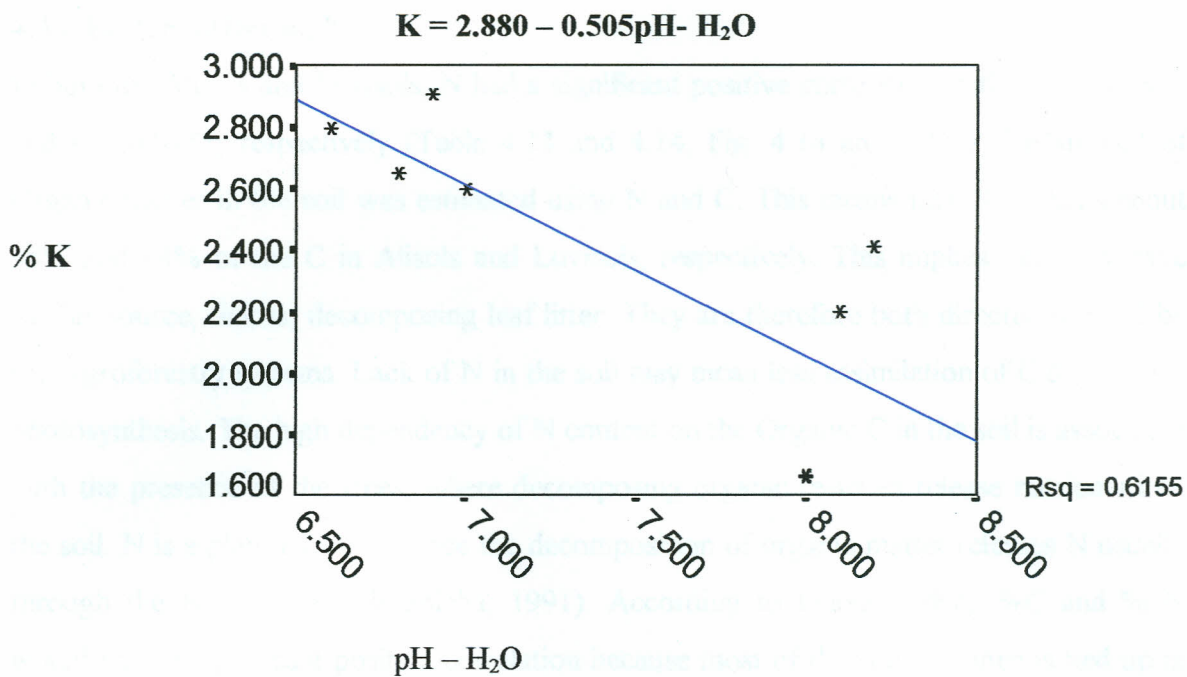


Fig.4.12: Relationship between pH in H₂O and K – Luvisols

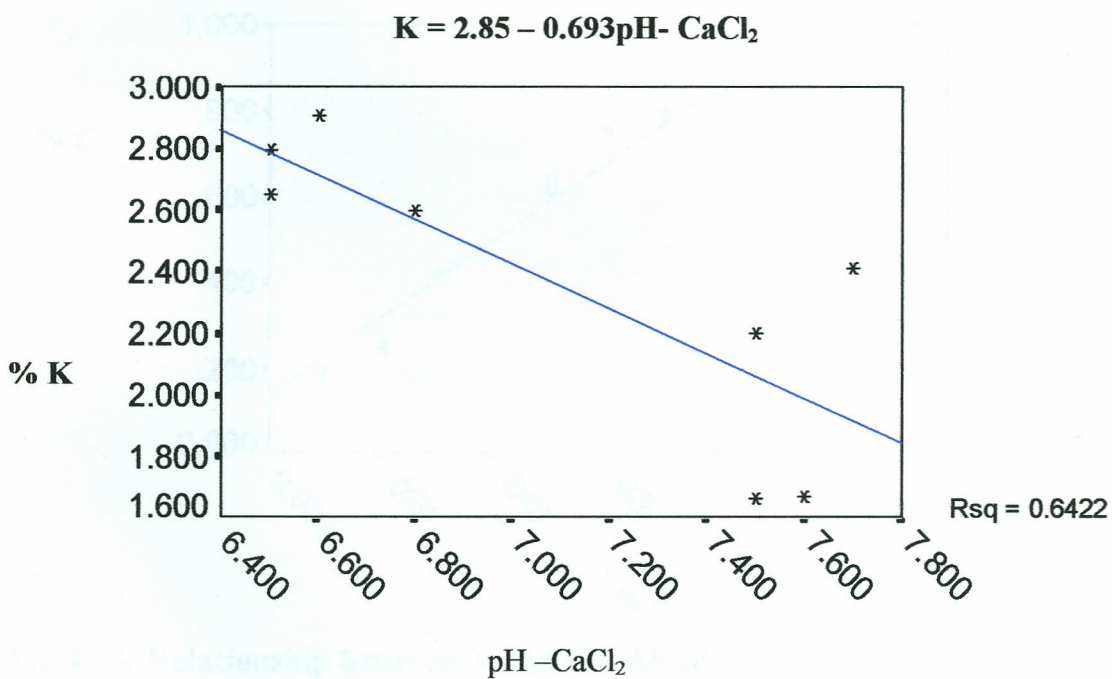


Fig.4.13: Relationship between pH in CaCl₂ and K – Luvisols

4.4.2 Factors affecting N.

In both the Alisols and Luvisols, N had a significant positive correlation with C, $r = 0.98^{**}$ and $r = 0.94^{**}$, respectively (Table 4.13 and 4.14, Fig. 4.14 and 4.15). The amount of Organic matter in the soil was estimated using N and C. This means that N explains about 98% and 94% of the C in Alisols and Luvisols, respectively. This implies that they have similar source, that is, decomposing leaf litter. They are therefore both directly affected by the Agroforestry systems. Lack of N in the soil may mean less assimilation of C by plants – photosynthesis. The high dependency of N content on the Organic C in the soil is associated with the presence of the trees, where decomposing organic residues release nutrients into the soil. N is a plant nutrient, hence the decomposition of organic matter releases N usually through the Batch effect (Wamicha, 1991). According to Gholz (1987), %C and % N would have a significant positive correlation because most of the soil Nitrogen is tied up in organic matter and hence should be higher in the zone of organic matter accumulation.

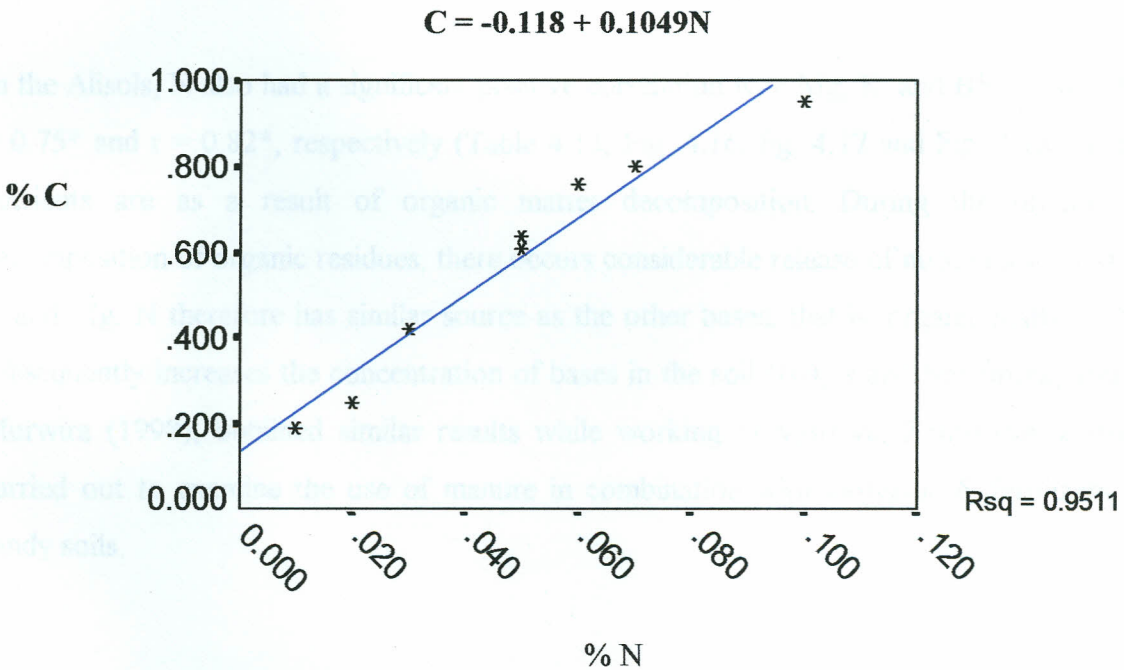


Fig.4.14: Relationship between N and C – Alisols

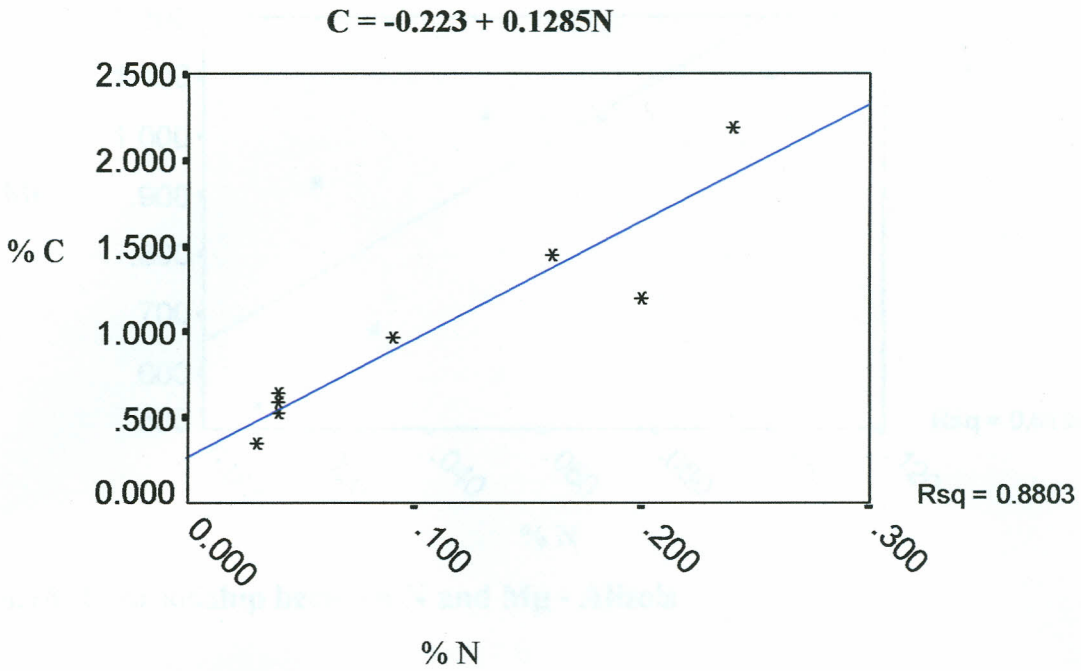


Fig.4.15: Relationship between N and C – Luvisols

In the Alisols, N also had a significant positive correlation with Mg, K, and BS, $r = 0.79^*$, $r = 0.75^*$ and $r = 0.82^*$, respectively (Table 4.13, Fig. 4.16, fig. 4.17 and Fig. 4.18). These nutrients are as a result of organic matter decomposition. During the process of decomposition of organic residues, there occurs considerable release of nutrients such as N, K and Mg. N therefore has similar source as the other bases, that is, organic matter.. This subsequently increases the concentration of bases in the soil (Batjes and Sombroek, 1997). Murwira (1998), obtained similar results while working in Murewa, Zimbabwe, a study carried out to examine the use of manure in combination with inorganic N fertilizers on sandy soils.

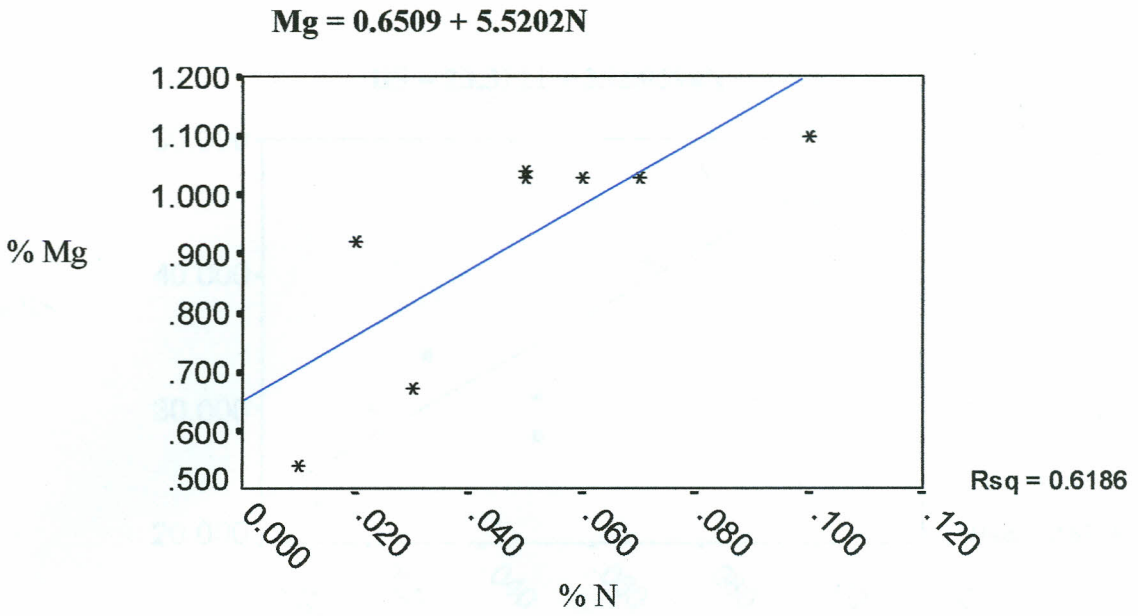


Fig.4.16: Relationship between N and Mg - Alisols

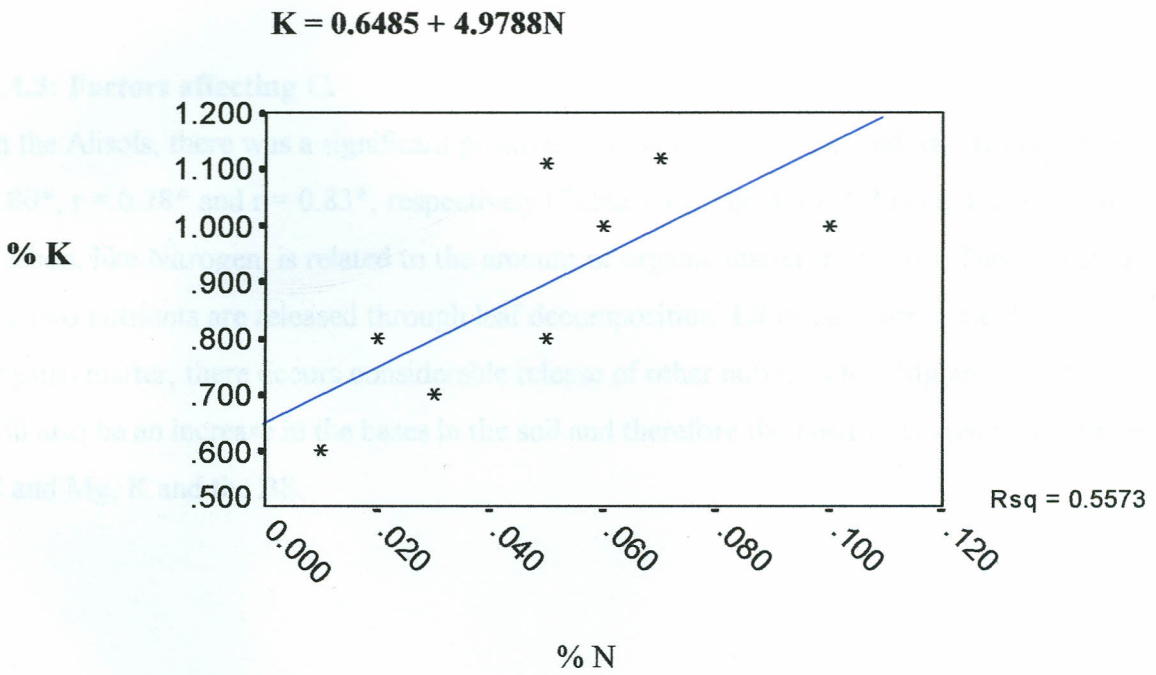


Fig.4.17: Relationship between N and K – Alisols.

$$BS = 23.3121 + 232.0594N$$

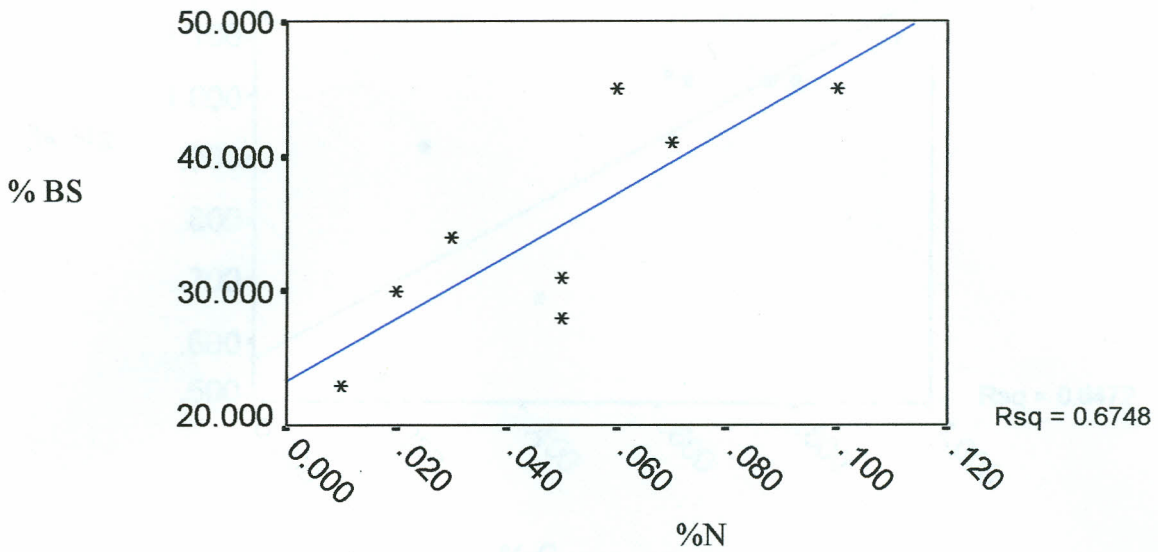


Fig. 4.18: Relationship between N and BS – Alisols

4.4.3: Factors affecting C.

In the Alisols, there was a significant positive correlation between C and Mg, K and BS, $r = 0.80^*$, $r = 0.78^*$ and $r = 0.83^*$, respectively (Table 4.13, Fig. 4.19, 4.20 and 4.21). Organic Carbon, like Nitrogen, is related to the amount of organic matter in the soil. This is because the two nutrients are released through leaf decomposition. Likewise, during the decay of organic matter, there occurs considerable release of other nutrients like Mg and K. There will also be an increase in the bases in the soil and therefore the positive correlation between C and Mg, K and the BS.

$$Mg = 0.5692 + 0.6074C$$

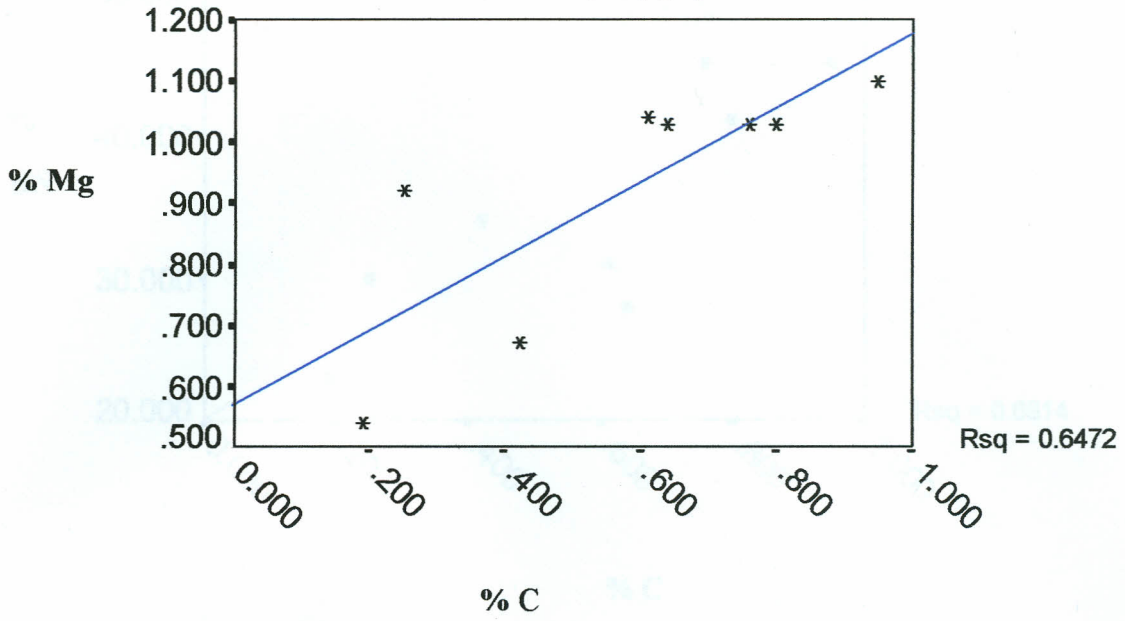


Fig.4.19: Relationship between C and Mg – Alisols

$$K = 0.5671 + 0.5612C$$

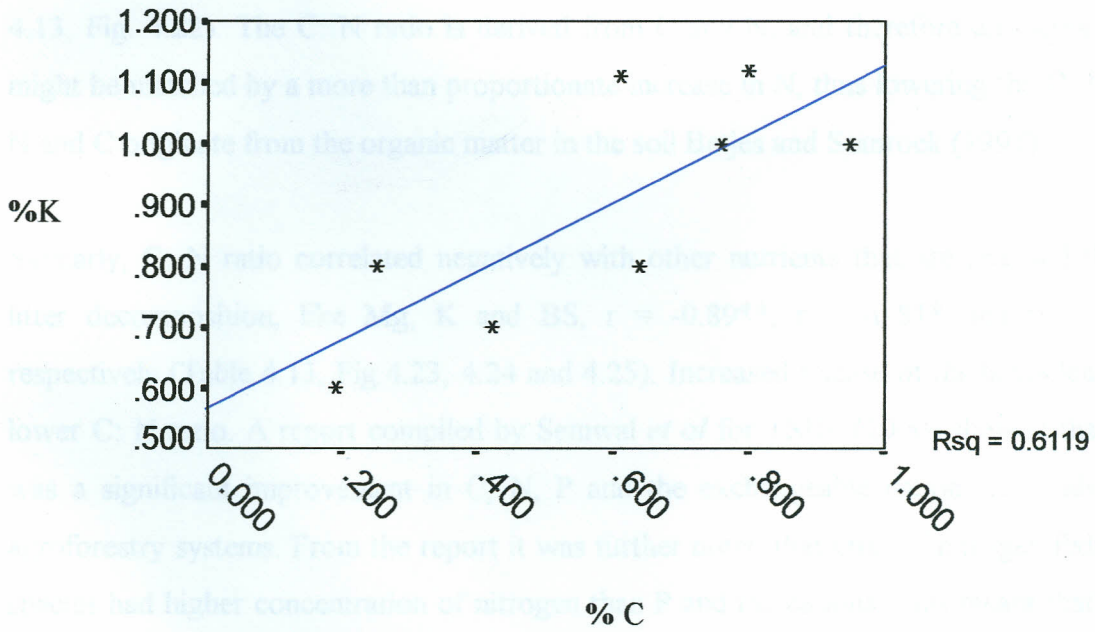


Fig. 4.20: Relationship between C and K – Alisols

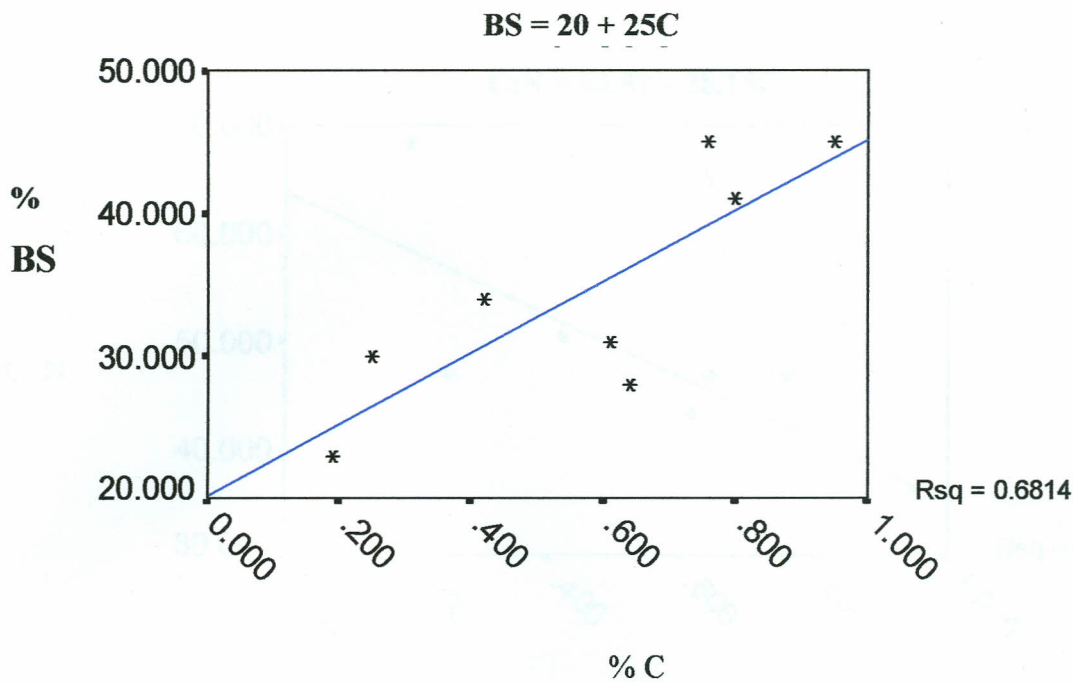


Fig. 4.21: Relationship between C and BS – Alisols

In the Alisols, C had a significant negative correlation with C: N ratio, $r = -0.80^*$ (Table 4.13, Fig. 4.22). The C: N ratio is derived from C and N, and therefore an increase in C might be matched by a more than proportionate increase in N, thus lowering the C: N ratio. N and C originate from the organic matter in the soil Batjes and Somroek (1997)

Similarly, C: N ratio correlated negatively with other nutrients that are released through litter decomposition, like Mg, K and BS, $r = -0.89^{**}$, $r = -0.81^*$ and $r = -0.72^*$, respectively (Table 4.13, Fig.4.23, 4.24 and 4.25). Increased release of the bases leads to a lower C: N ratio. A report compiled by Semwal *et al* for TSBF (2000) showed that there was a significant improvement in C, N, P and the exchangeable cations for soils under agroforestry systems. From the report it was further noted that litter of nitrogen fixing tree species had higher concentration of nitrogen than P and the cations. This meant that the C: N ratio would decrease with increased release of nutrients released through litter decomposition.

$$C:N = 63.57 - 28.15C$$

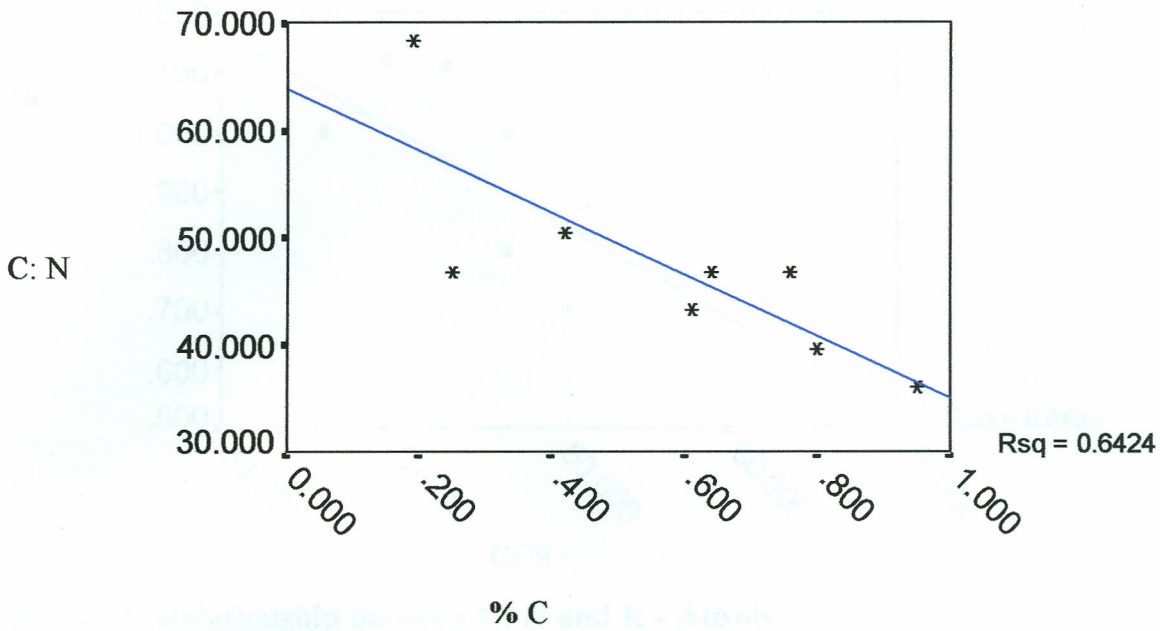


Fig. 4.22: Relationship between C and C: N ratio – Alisols.

$$Mg = 1.8008 - 0.0191C:N$$

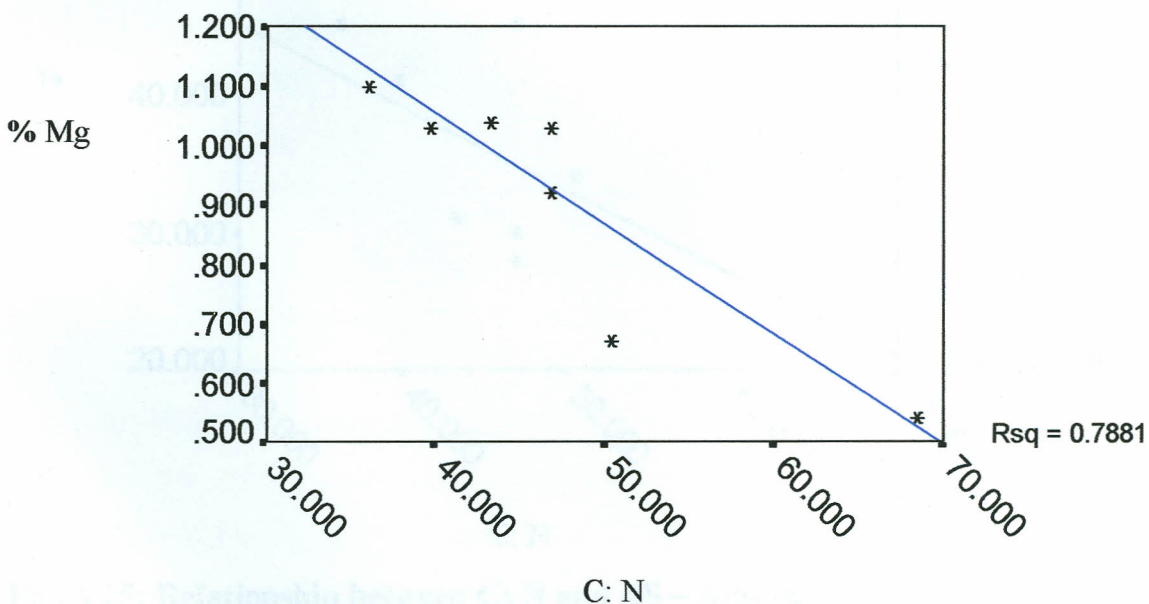


Fig. 4.23: Relationship between C: N ratio and Mg – Alisols.

$$K = 1.16300 - 0.0154C:N$$

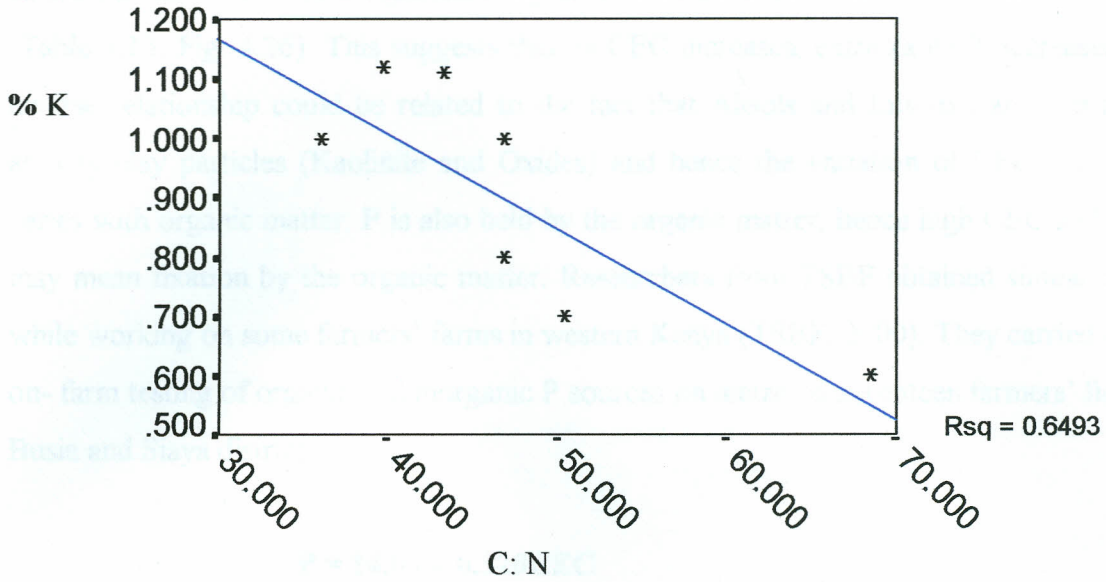


Fig. 4.24: Relationship between C: N and K - Alisols.

$$BS = 45 - 0.583C:N$$

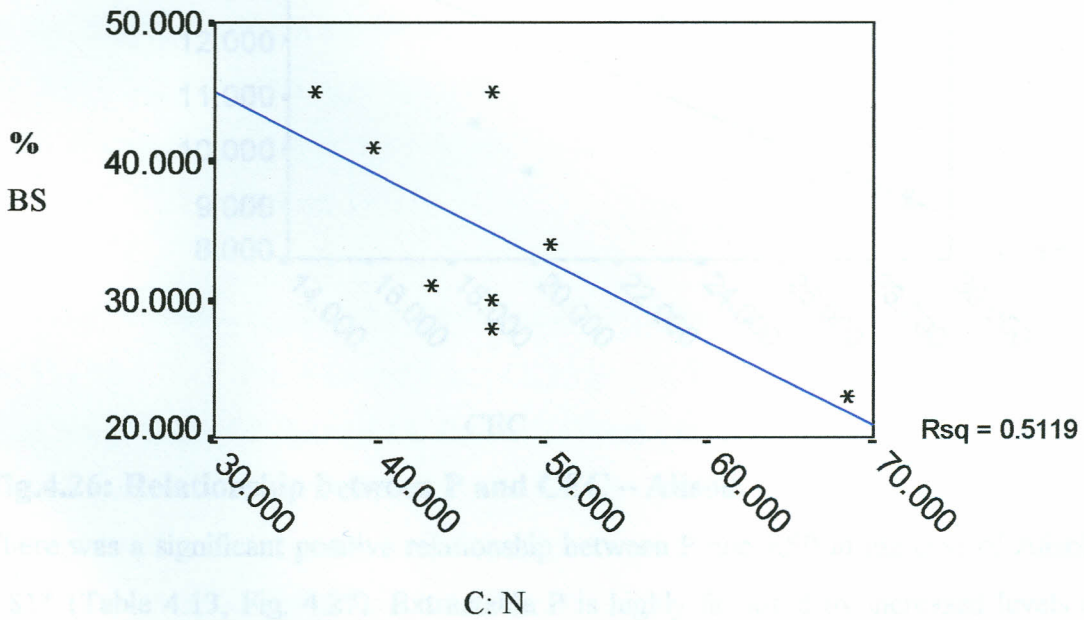


Fig. 4.25: Relationship between C: N and BS - Alisols.

4.4.4: Available P

In the Alisols, there was a significant negative correlation between P and CEC, $r = -0.75^*$ (Table 4.13, Fig. 4.26). This suggests that as CEC increases, extractable P decreases. The inverse relationship could be related to the fact that Alisols and Luvisols are rich in low activity clay particles (Kaolinite and Oxides) and hence the variation of CEC very much varies with organic matter. P is also held by the organic matter, hence high CEC and low P may mean fixation by the organic matter. Researchers from TSBF obtained similar results while working on some farmers' farms in western Kenya (TSBF, 2000). They carried out an on- farm testing of organic and inorganic P sources on maize on seventeen farmers' fields in Busia and Siaya districts.

$$P = 14.00 - 0.320CEC$$

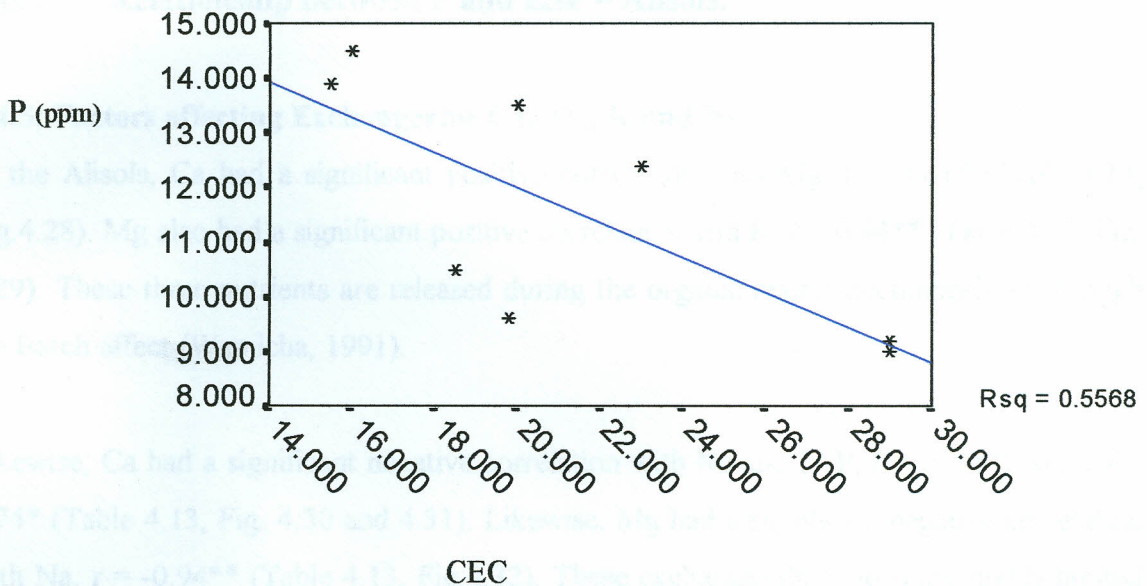


Fig.4.26: Relationship between P and CEC – Alisols.

There was a significant positive relationship between P and ESP in the case of Alisols, $r = 0.81^*$ (Table 4.13, Fig. 4.27). Extractable P is highly favoured by increased levels of pH (Brady, 1984). ESP helps in increasing the soil pH and hence in increasing P levels.

$$ESP = 1.154 + 0.0834P$$

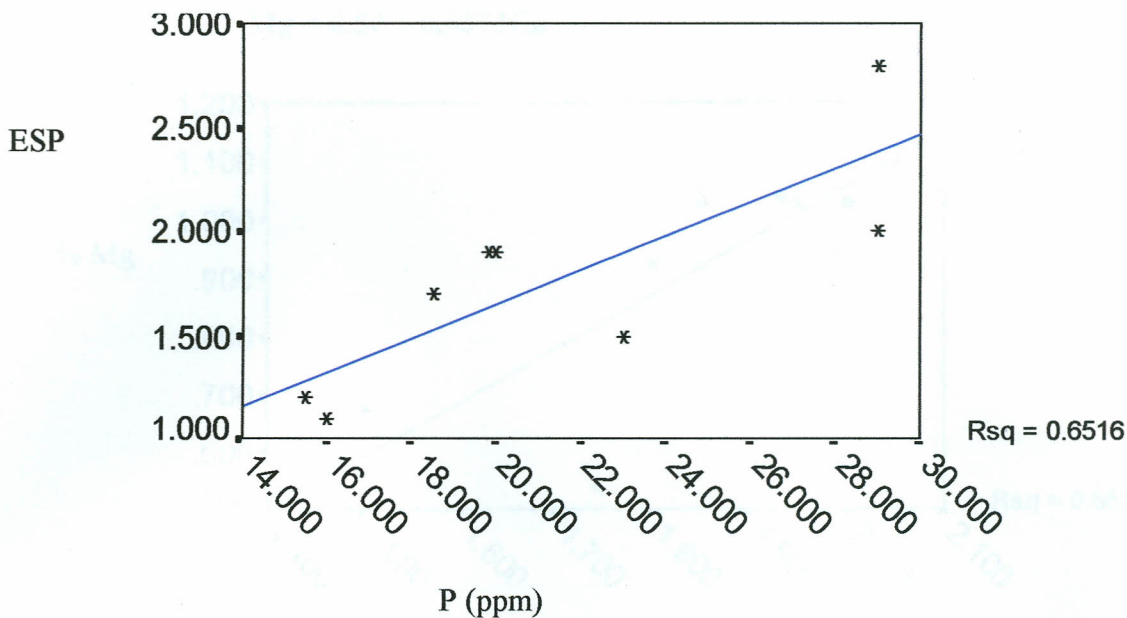


Fig.4.27: Relationship between P and ESP – Alisols.

4.4.5: Factors affecting Exchangeable Ca, Mg, K and Na.

In the Alisols, Ca had a significant positive correlation with Mg, $r = 0.81^*$ (Table 4.13, Fig.4.28). Mg also had a significant positive correlation with K, $r = 0.84^{**}$ (Table 4.13, Fig. 4.29). These three nutrients are released during the organic matter decomposition through the Batch effect (Wamicha, 1991).

Likewise, Ca had a significant negative correlation with Na and ESP, $r = -0.88^{**}$ and $r = -0.74^*$ (Table 4.13, Fig. 4.30 and 4.31). Likewise, Mg had a significant negative correlation with Na, $r = -0.94^{**}$ (Table 4.13, Fig.4.32). These exchangeable cations are highly limited by increased ESP and more formation of Na salts. The high levels of ESP and Na lead to increased pH, which in turn limits the release of these nutrients due to low microbial activities. Availability of cations is influenced by ions held in the soil (Brady, 1984). The same argument could be used to explain the significant negative correlation between K and Na, $r = -0.73^*$ (Table 4.13, Fig. 4.33).

$$\text{Mg} = 0.50 + 0.9373\text{Ca}$$

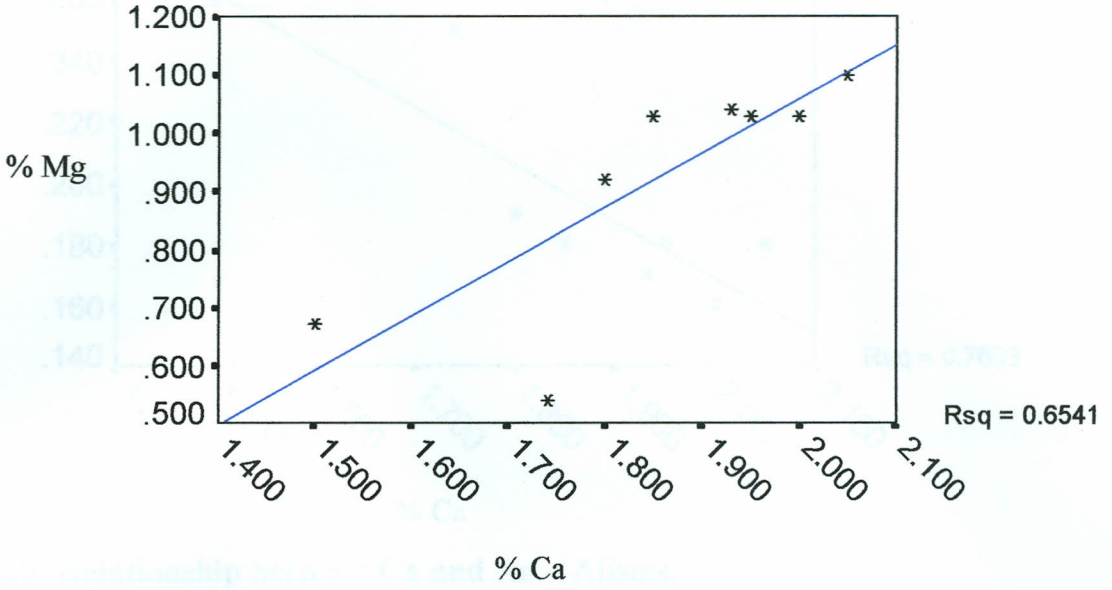


Fig. 4.28: Relationship between Ca and Mg – Alisols.

$$\text{K} = 0.662 + 0.643\text{Mg}$$

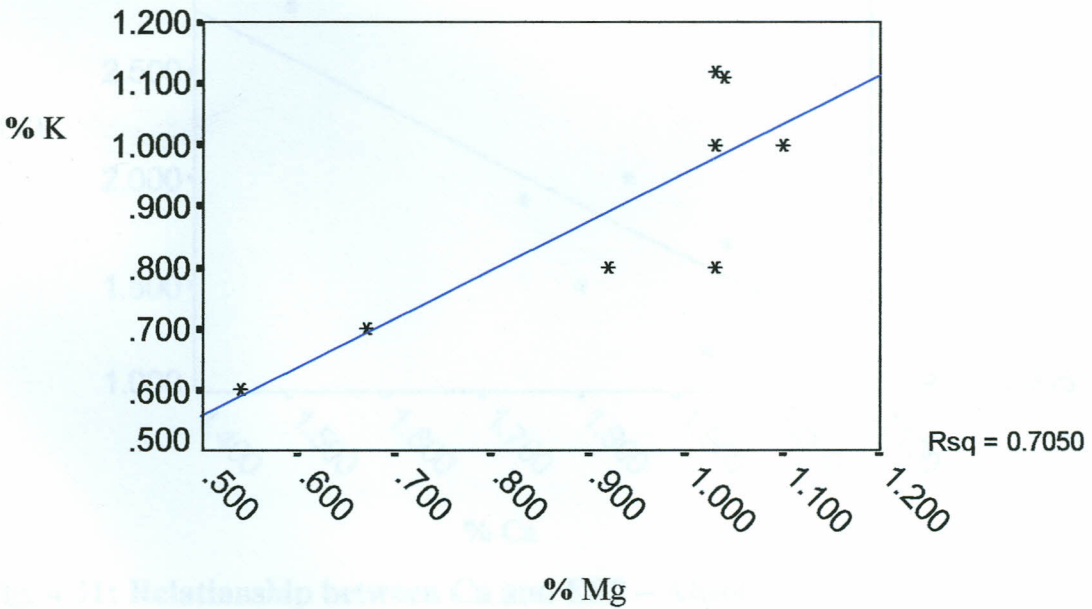


Fig. 4.29: Relationship between Mg and K – Alisols.

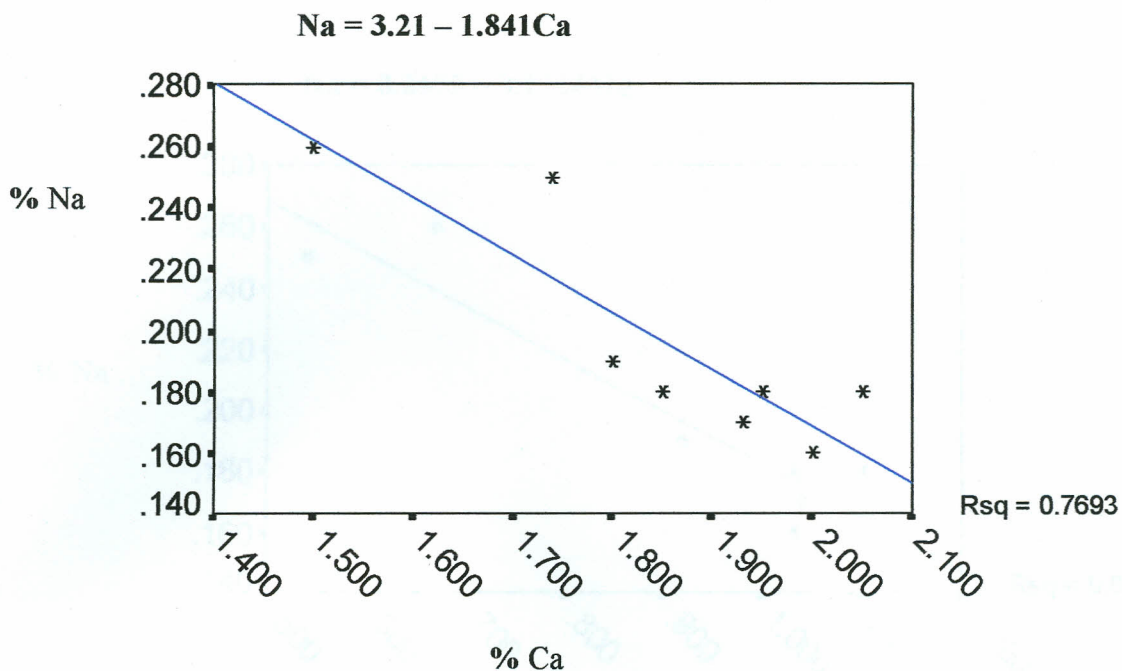


Fig. 4.30: Relationship between Ca and Na – Alisols.

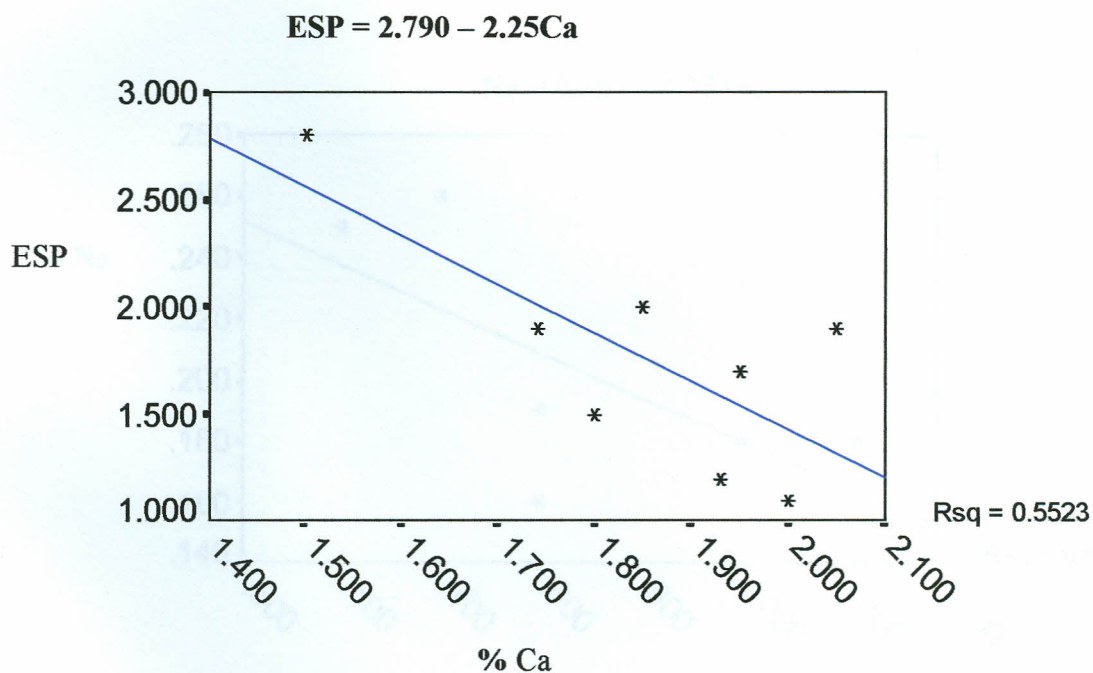


Fig. 4.31: Relationship between Ca and ESP – Alisols.

In both the Luvisols and Luvissols, Na had a negative linear correlation with Ca ($r = 0.77^*$ and $r = 0.72^*$ respectively (Table 4.11) and Fig. 4.30 and 4.31). This is because of the direct Na (FS) and Na (CBC). This is because of the direct reason that Na is directly related to Ca.

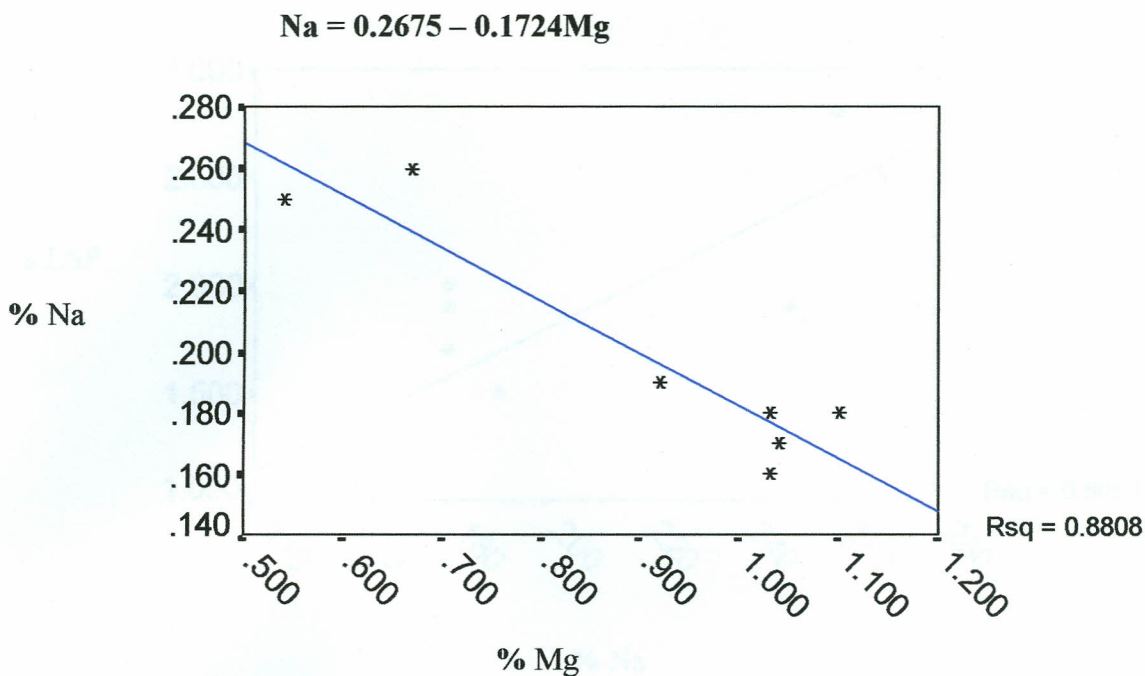


Fig. 4.32: Relationship between Mg and Na – Alisols.

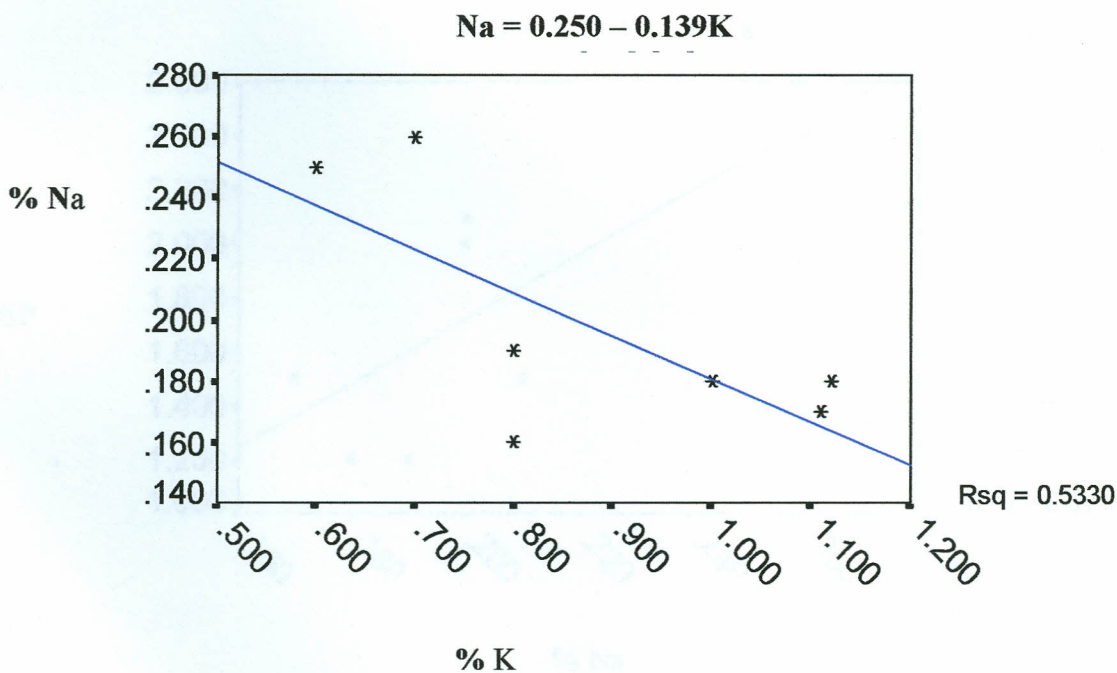


Fig. 4.33: Relationship between K and Na – Alisols.

In both the Alisols and Luvisols, Na had a significant positive correlation with ESP, $r = 0.79^*$ and $r = 0.72^*$ respectively (Table 4.13 and 4.14, Fig. 4.34 and 4.35). ESP is derived from Na ($ESP = Na/CEC$). This is because of the obvious reason that ESP is calculated from Na.

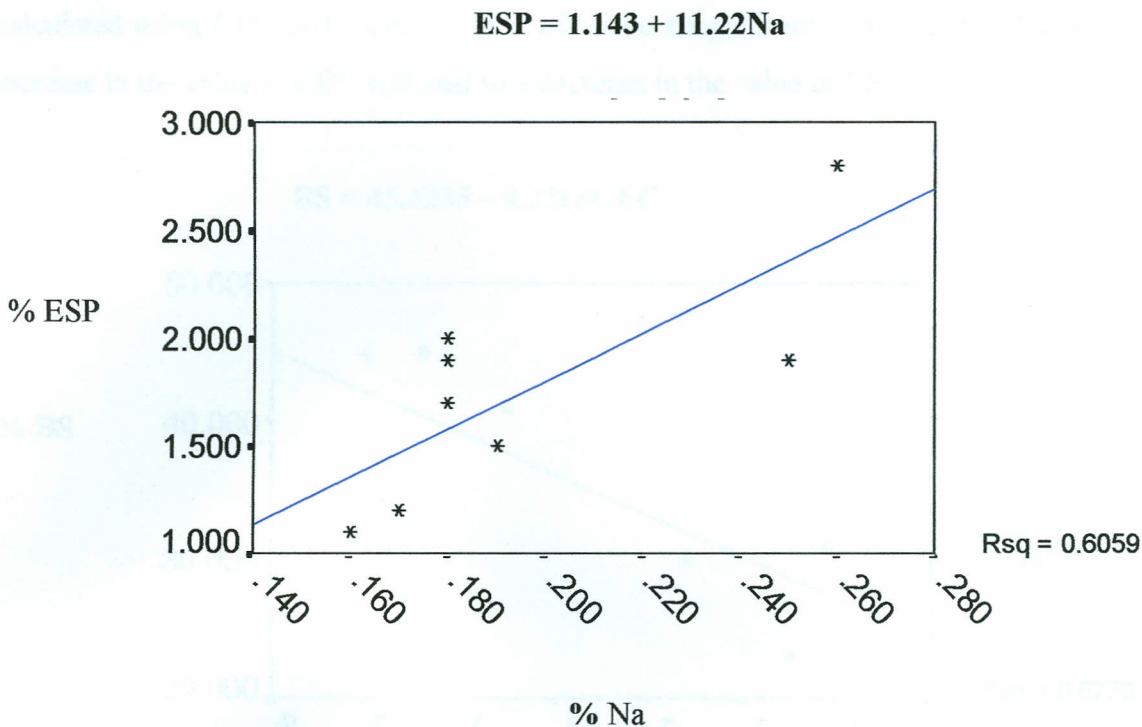


Fig. 4.34: Relationship between Na and ESP – Alisols.

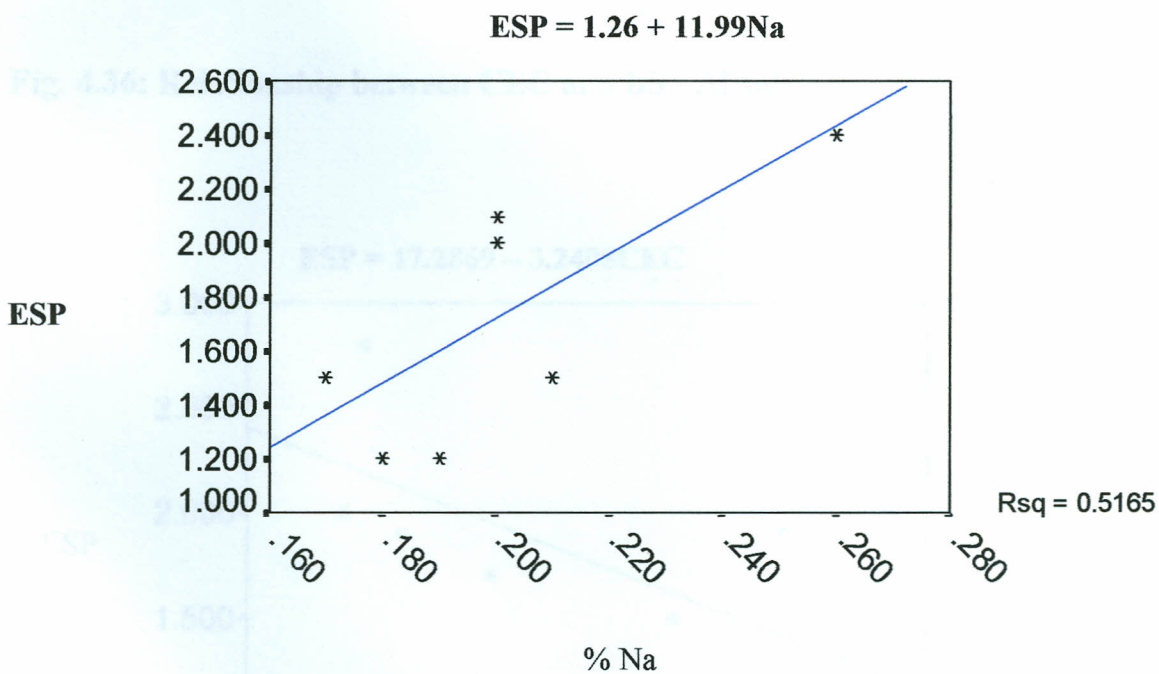


Fig. 4.35: Relationship between Na and ESP – Luvisols.

4.4.6. Factors affecting CEC

In both Alisols and Luvisols, CEC had a significant negative correlation with BS and ESP, $r = -0.82^*$ and $r = -0.77^*$, for the Alisols (Table 4.13, Fig. 4.36 and 4.37); and $r = -0.94^{**}$ and $r = -0.85^{**}$, for the Luvisols (Table 4.14, Fig. 4.38 and 4.39). ESP and BS are

calculated using CEC and therefore they will have a significant relationship. Therefore, an increase in the value of CEC will lead to a decrease in the value of BS.

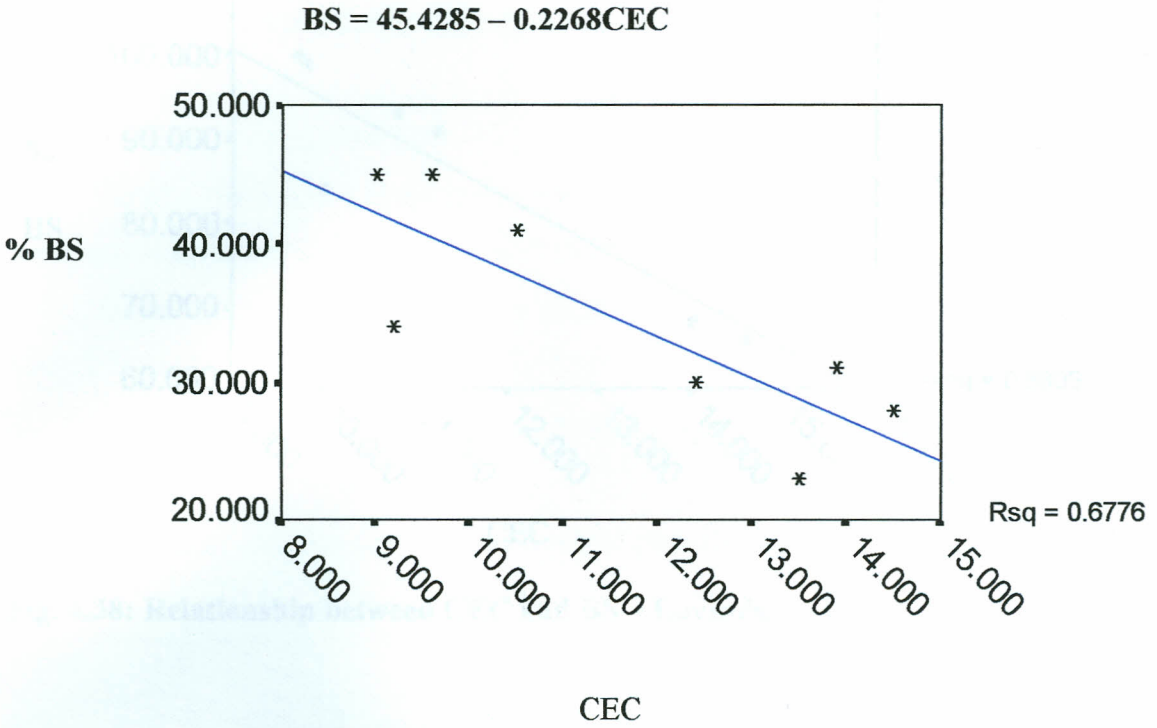


Fig. 4.36: Relationship between CEC and BS - Alisols.

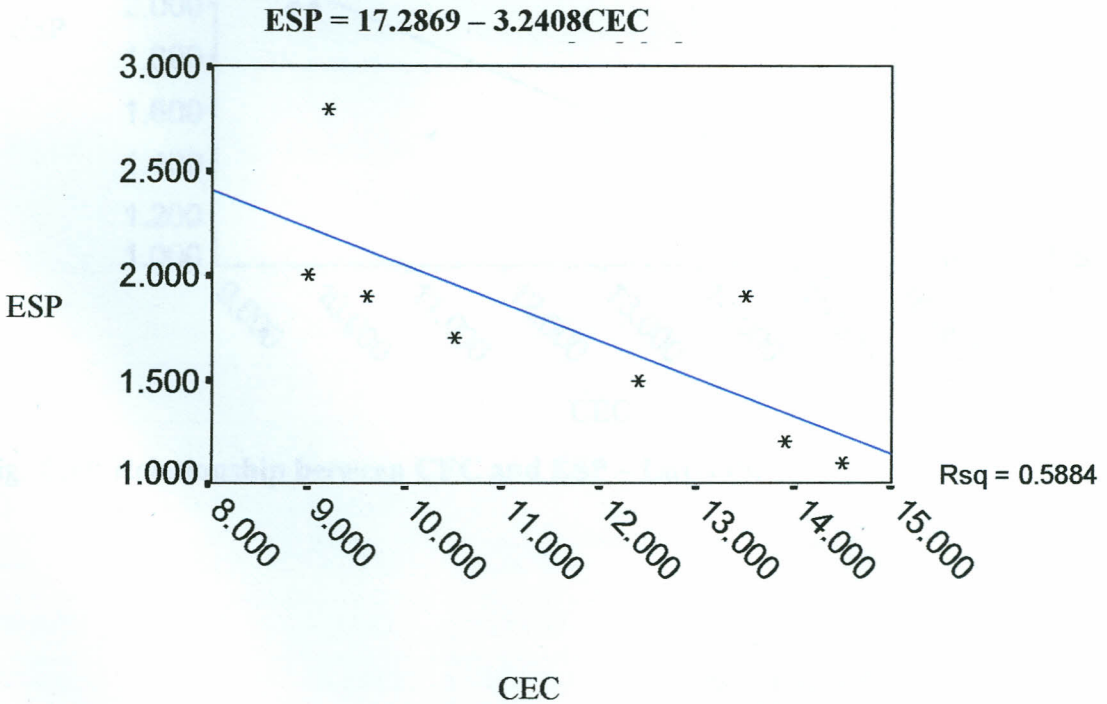


Fig. 4.37: Relationship between CEC and ESP – Alisols.

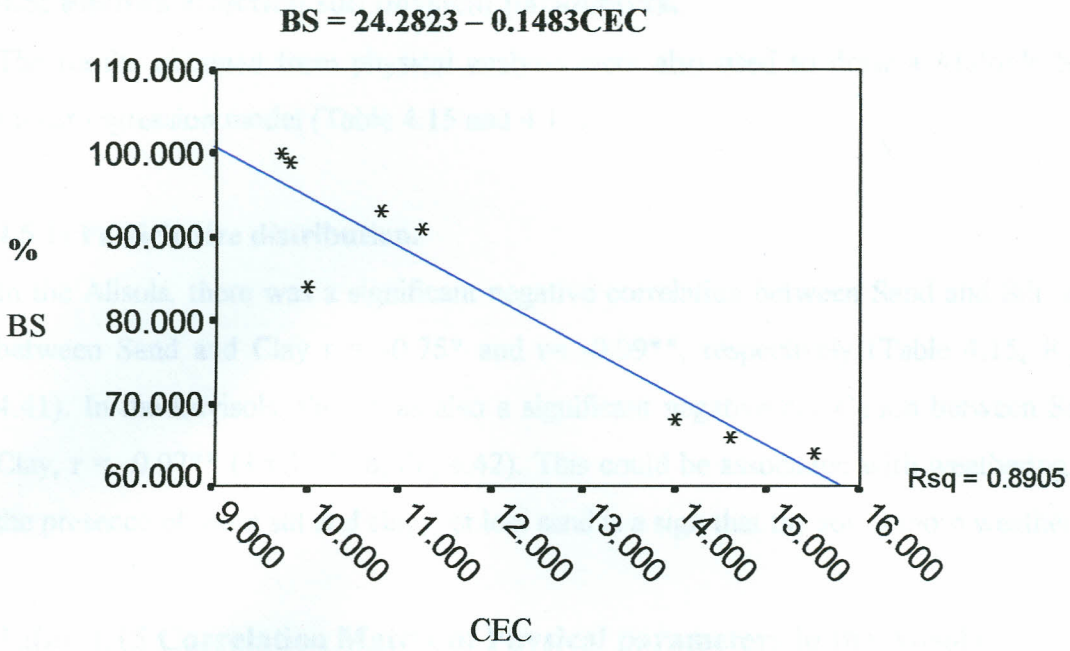


Fig. 4.38: Relationship between CEC and BS – Luvisols.

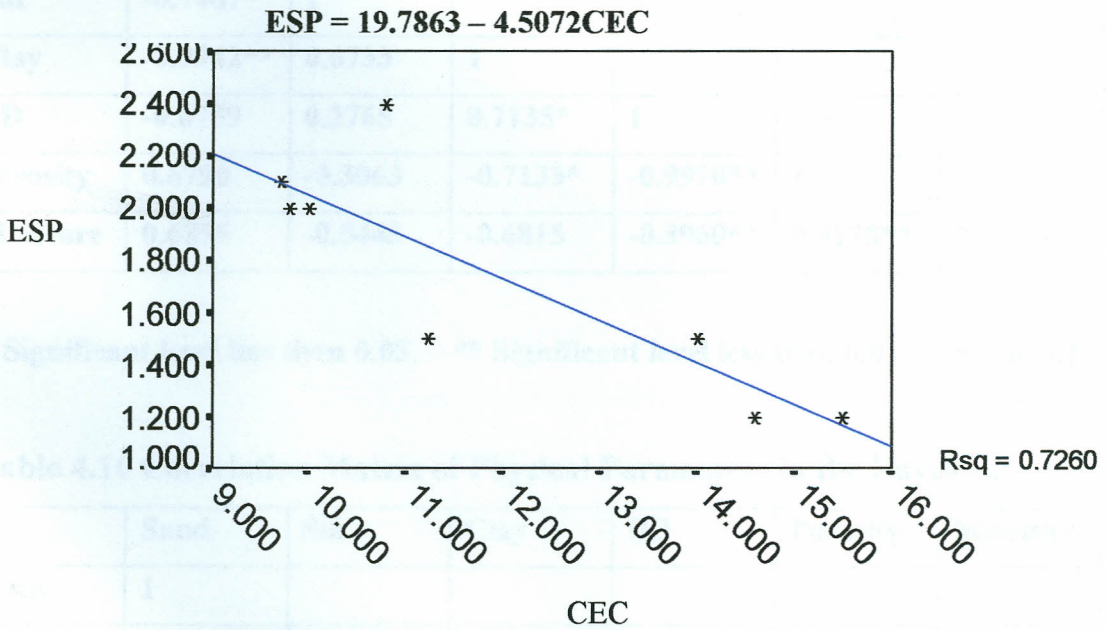


Fig. 4.39: Relationship between CEC and ESP – Luvisols.

4.5: Factors affecting soil physical parameters.

The results obtained from physical analysis were also used to draw a Multiple Stepwise Linear regression model (Table 4.15 and 4.16).

4.5.1: Particle size distribution.

In the Alisols, there was a significant negative correlation between Sand and Silt, and also between Sand and Clay $r = -0.75^*$ and $r = -0.99^{**}$, respectively (Table 4.15, Fig. 4.40, 4.41). In the Luvisols, there was also a significant negative correlation between Sand and Clay, $r = -0.97^{**}$ (Table 4.16, Fig.4.42). This could be associated with weathering, in that the presence of more silt and clay, yet less sand is a sign that the soil is more weathered.

Table 4.15 Correlation Matrix of Physical parameters in the Alisols.

	Sand	Silt	Clay	BD	Porosity	Moisture
Sand	1					
Silt	-0.7467*	1				
Clay	-0.9942**	0.6733	1			
BD	-0.6759	0.2765	0.7135*	1		
Porosity	0.6790	-0.3063	-0.7133*	-0.9970**	1	
Moisture	0.6855	-0.5448	-0.6815	-0.8960**	0.9178**	1

* Significant level less than 0.05, ** Significant level less than 0.01 (2- tailed)

Table 4.16 Correlation Matrix of Physical Parameters in the Luvisols.

	Sand	Silt	Clay	BD	Porosity	Moisture
Sand	1					
Silt	-0.2530	1				
Clay	-0.9653**	0.1111	1			
BD	-0.3819	-0.2609	0.3632	1		
Porosity	0.3829	0.2252	-0.3618	-0.9947**	1	
Moisture	0.6235	-0.1410	-0.5602	-0.2122	0.1699	1

* Significant level less than 0.05, ** Significant level less than 0.01 (2- tailed)

Silt=6.190-0.114 Sand

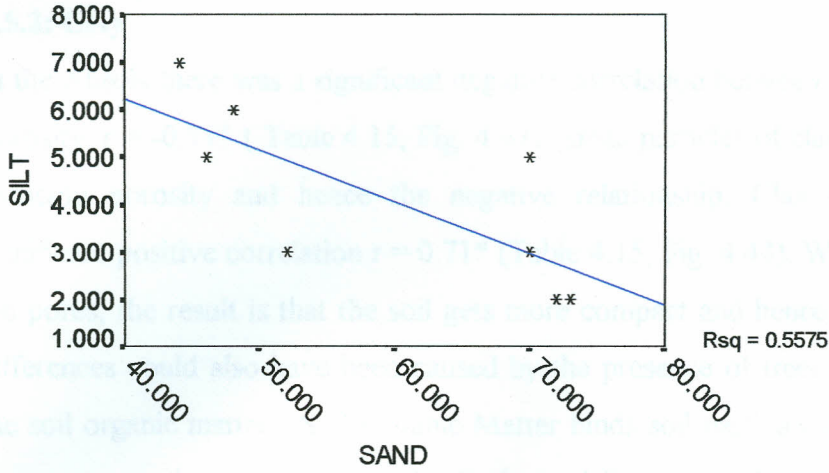


Fig.4.40: Relationship between Sand and Silt – Alisols.

Clay=89.50-0.900 Sand

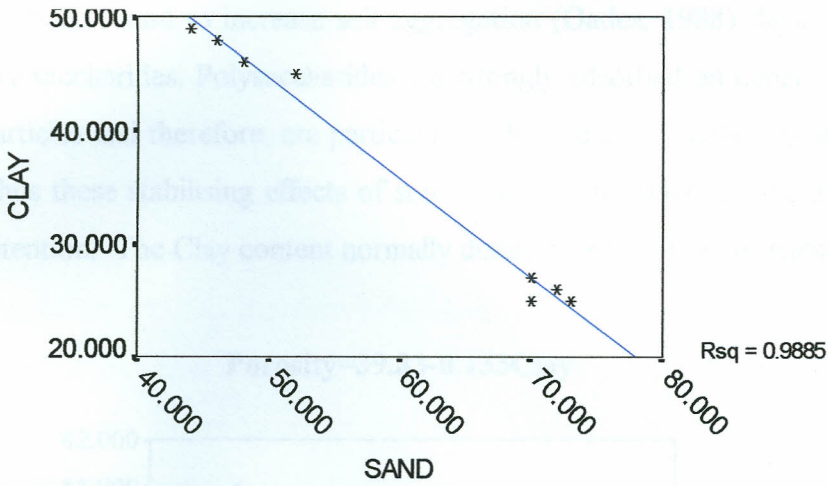


Fig. 4.41: Relationship between Sand and Clay – Alisols

Clay=97.33-1.1444Sand

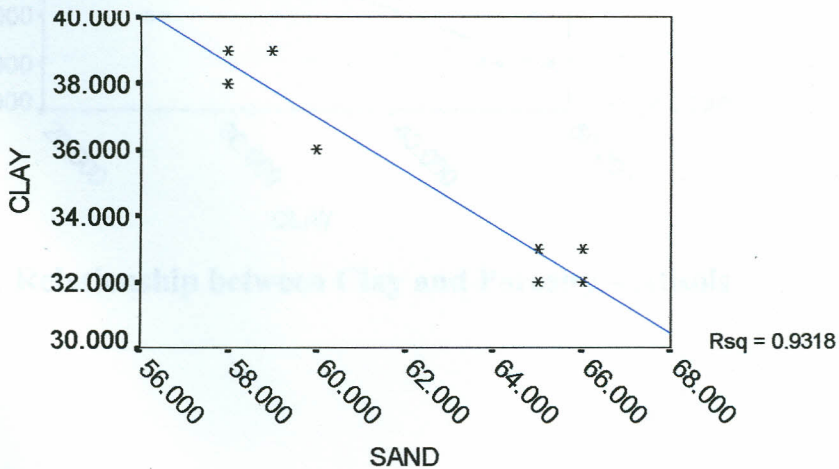


Fig. 4.42: Relationship between Sand and Clay – Luvisols.

4.5.2: Clay

In the Alisols there was a significant negative correlation between soil Clay content and soil Porosity, $r = -0.71^*$ (Table 4.15, Fig. 4.43). Small particles of clay packs in the pores, thus reducing porosity and hence the negative relationship. Clay content and BD had a significant positive correlation $r = 0.71^*$ (Table 4.15, Fig. 4.44). When clay particles pack in the pores, the result is that the soil gets more compact and hence the BD increases. These differences could also have been caused by the presence of trees that helped in increasing the soil organic matter. Soil Organic Matter binds soil particles in microaggregates which increases porosity and reduces BD. (Batjes and Sombroek, 1997). Therefore, while humus increases the porosity and reduces the BD, Clay influences these two factors negatively. Chemical transformations of soil Carbon and its close association with the mineral phase, has been found to increase soil aggregation (Oades, 1988) through binding agents such as polysaccharides. Polysaccharides are strongly adsorbed on mineral materials especially Clay particles and therefore, are particularly effective in strengthening failure zones (Kay, 1997). Thus these stabilising effects of soil organic matter increase the soil Porosity and moisture retention. The Clay content normally determines the effect of stabilisation.

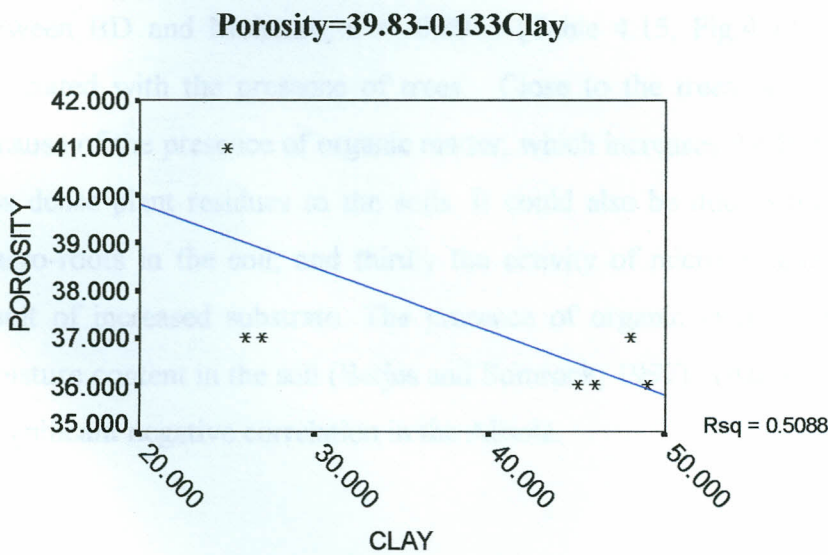


Fig. 4.43: Relationship between Clay and Porosity – Alisols

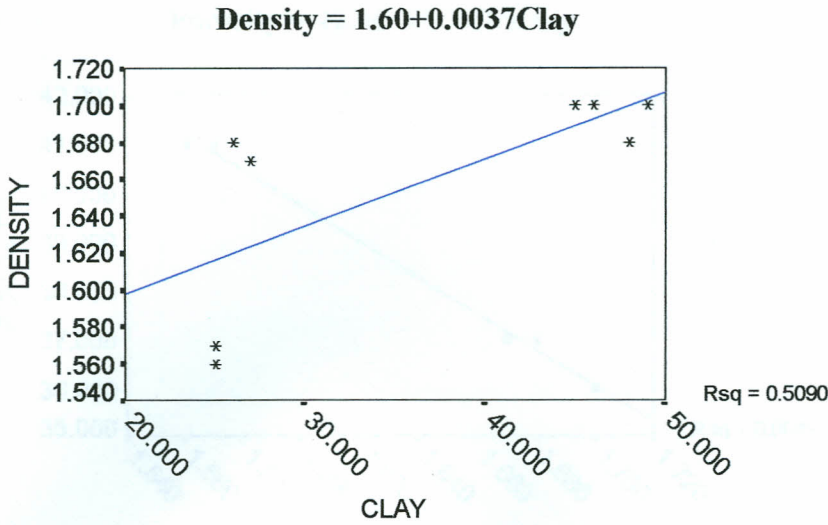


Fig. 4.44: Relationship between Clay and Bulk Density – Alisols.

4.5.3: Bulk density.

In both Alisols and Luvisols, BD correlated negatively with Porosity, $r = -0.99^{**}$ (Table 4.15, Fig. 4.45), for the Alisols, and $r = -0.99^{**}$ also (Table 4.16, Fig. 4.46), for the luvisols. By binding soil particles together, organic matter contributes to increased porosity and lower BD. In the case of Alisols, there was also a significant negative correlation between BD and Moisture, $r = -0.89^{**}$ (Table 4.15, Fig.4.47). These aspects could be associated with the presence of trees. Close to the trees, solid BD is bound to reduce because of the presence of organic matter, which increases the Porosity of the soil and adds less dense plant residues to the soils. It could also be due to the activity of micro – and macro-roots in the soil; and thirdly the activity of micro-organisms which build up as a result of increased substrate. The presence of organic matter reduces BD, yet increases Moisture content in the soil (Batjes and Somroek, 1997). That is why BD and Moisture had a significant negative correlation in the Alisols.

$$\text{Porosity} = 42.00 - 37.06 \text{Density}$$

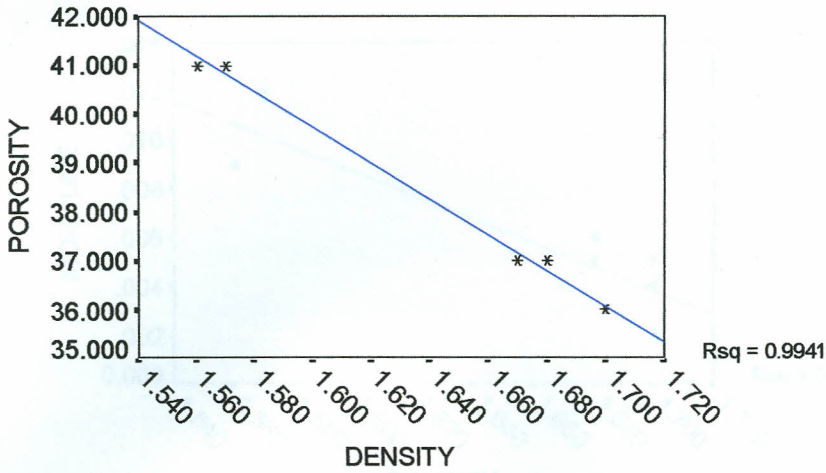


Fig. 4.45: Relationship between Bulk density and Porosity – Alisols.

$$\text{Porosity} = 50.85 - 35.96 \text{Density}$$

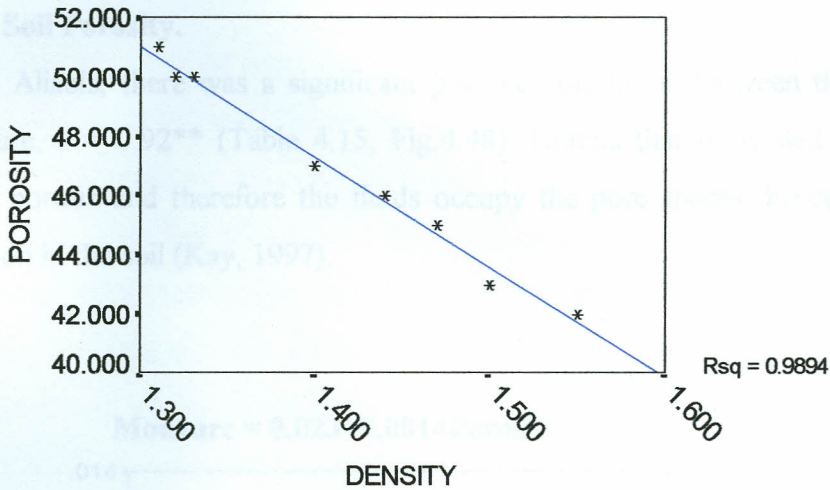


Fig. 4.46: Relationship between Bulk Density and Porosity – Luvisols.

$$\text{Moisture} = 0.0117 - 0.050\text{Density}$$

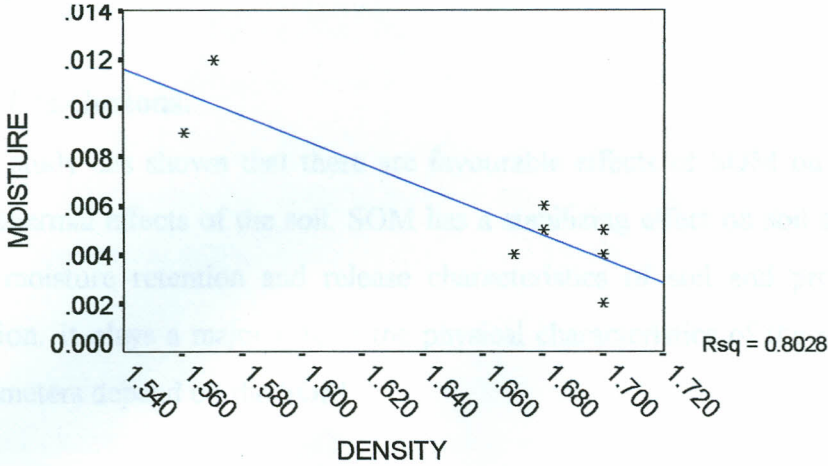


Fig. 4.47: Relationship between Bulk density and Moisture – Alisols.

4.5.4. Soil Porosity.

In the Alisols, there was a significant positive correlation between the Soil Porosity and Moisture, $r = 0.92^{**}$ (Table 4.15, Fig.4.48). Humus that is formed next to the trees is highly porous and therefore the fluids occupy the pore spaces, hence encouraging water retention in the soil (Kay, 1997).

$$\text{Moisture} = 0.023 + 0.0014\text{Porosity}$$

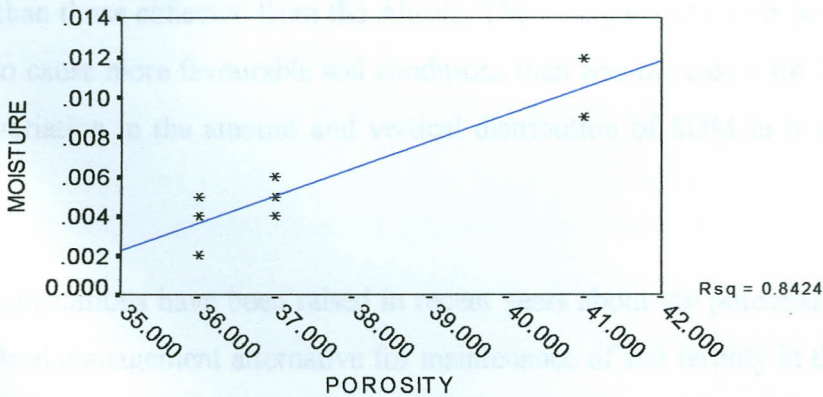


Fig. 4.48: Relationship between Porosity and Moisture – Alisols.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS:

5.1: Conclusions.

This study has shown that there are favourable effects of SOM on the physical, chemical and thermal effects of the soil. SOM has a stabilizing effect on soil structure, improves the soil moisture retention and release characteristics of soil and protects the soil against erosion. It plays a major role in the physical characteristics of the soil. Most soil physical parameters depend on the SOM.

Major environmental controls of organic matter behaviour in soil are moisture status, soil temperature, oxygen supply (drainage), soil acidity, soil nutrient supply, clay content and mineralogy. All other conditions being equal, organic matter accumulates most at low temperatures in acid parent materials and in aerobic conditions.

Biotic controls of SOM formation include the type of flora, through its effect on substrate quality and quantity, and the nature of the fauna that causes litter decomposition. The chemical composition, amount and spatial distribution of fresh organic residues have a varying effect on the content and composition of organic matter in the soil. Horizontal patterns of SOM distribution are related to differences in initial soil organic matter content and to differences between successional tree species, especially in the amounts of woody litter produced. Similarly, the samples collected from the Luvisols seemed to have had more SOM than those collected from the Alisols. The inherent soil properties of the Luvisols also seem to cause more favourable soil conditions than was the case with the Alisols. There is a great variation in the amount and vertical distribution of SOM in tropical and subtropical soils.

High expectations have been raised in recent years about the potential of Agroforestry as a major land management alternative for maintenance of soil fertility in the tropics. These are based on the relatively satisfactory situation with respect to soil conditions in several prominent and promising agroforestry systems and the postulations on the favourable effects of trees on soils

However, Moisture content seems to be the major factor inhibiting the soil fertility in the region of study. The *Grevillea robusta* leaves were identified to be rich in organic matter, that helps in improving the soil Physical and chemical properties. Microbial activities in this region are highly limited by the low moisture content. The region is found in the ASALS of Kenya. The main food crop grown in the region was maize, and the harvests were affected by the SOM in the soil. This is because the farmers in the region did not use inorganic fertilizers, yet the fertility status of their farms was maintained via litter fall from the trees.

5.2: Recommendations.

Farmers from the two research sites need to intensify the planting of *Grevillia robusta*. This is because the trees seem to have contributed positively towards the fertility of the soil. Majority of the Chemical and Physical parameters considered in the research were found to be favourable in sites next to the trees. However, farmers need to get a remedy for the termites in their farms since they eat the stems of the trees, thus affecting their performance.

Previous research carried out by Tefera (2001), showed that 80% of the rural population depend on woodfuel for their cooking. There is need to invest more in researching on the tree species that could help in improving the soil fertility of these farms as well as reduce the problem of shortage of woodfuel in the region.

The government, through the ministry of Agriculture should try to raise peoples' awareness on the importance of integrating tree crops in farming practices. It was established from the pilot survey that most farmers incorporated trees into their farming systems simply because ICRAF had suggested to them to do so. It was not because the farmers appreciated the contribution made by the trees to the fertility of the farms.

Farmers in the region who have tree crops on their farms could be encouraged to continue with the practice by using their farms for further research. Results obtained could be used to advice the farmers accordingly. Seeing improved performance in their farms once the advice is taken will motivate them. The government can administer this through the agricultural extension workers.

In order to increase the understanding of agroforestry in general, and of the various productive and protective roles it plays in existing land use systems in developing economies, there is need for the government to give more attention to such researches and to ensure that results obtained get to help the general public. The natural resource-land, needs to be well managed so that it can meet the demands of the present generation without compromising the ability of the future generations from benefiting.

Goody, N.C. (1984) The Culture and Property of soils. New York, John Wiley & Sons, USA.

Harren, R.J. (1987) Nutrient cycling and nutrient use efficiency in agroecosystems. *Ecology* 68: 1130-1135.

Harrop, A.H. and Zinsmeister, R. (1987) A guide to soil analysis. FAO/ICRAF, Nairobi, Kenya.

Chivanga, P. P., Mwangi, H. K. and Gathumbi, P. (1987) Effects of different soil classification methods on soils of different soil classes in the humid tropics. *Soil Science Society of America* 51: 111-115. Nairobi, Kenya.

FAO (1982) Report on land use and management survey program in Kenya. FAO, Rome, Italy.

FAO (1986) Tree growing by rural people, East Africa.

FAO (1987) Kenya Forest Survey. FAO, Rome, Italy.

FAO (1990) Household food security survey. An analysis of the 1988 survey. FAO, Rome, Italy.

FAO/World Bank (1989) Kenya Forestry Survey. Dis-aggregated report. FAO/World Bank, Rome/Washington D.C.

Fernandes, R. C. M. and F. K. B. (1987) A contribution to the study of structure and function of tropical home gardens. Working paper No. 10. ICRAF, Nairobi, Kenya.

REFERENCES.

Anderson D (1987) *The Economics and Afforestation: A Case Study in Africa*, Occasional Paper No. 1 (New Series), John Hopikins Press, Baltimore, USA.

Batjes, N.H. and W.G. Sombroek (1997) Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology*, Wageningen, The Netherlands.

Brady, N.C. (1984) *The Nature and Property of soils*. Macmillan publishers, Newyork, USA.

Buresh, R.J. (1995) *Nutrient cycling and nutrient supply in agroforestry systems*, Rome, Italy.

Chavangi, A.H. and Zimmermann, R. (1987). *A guide to farm forestry in Kenya*: SIDA/FD. Nairobi, Kenya.

Chivenge. P. P, Murwira. H. K and Giller. K. E (2000) Efficacy of soil organic matter fractionation methods on soils of different texture under similar management. *TSBF*, Nairobi, Kenya.

FAO (1982). *Report on a forestry sub-sector review and programming mission to the Republic of Kenya*. FAO. Rome, Italy.

FAO. (1986) *Tree growing by rural people*, Rome, Italy.

FAO (1987). *Kenya Forestry Sub- sector review*. FAO. Rome, Italy.

FAO (1990). *Household food security Forestry. An analysis of Socio-economic issues*. FAO. Rome, Italy.

FAO/ World Bank (1989). *Kenya Forestry Sub-sector Pre-appraisal report*. FAO/ World Bank. Rome/ Washington D.C.

Fernandes, E. C. M. and P. K. R. Nair (1986) *An evaluation of structure and function of tropical home gardens*. Working paper No. 38, ICRAF, Nairobi, Kenya.

- Getahun, A. and Reshid, K.** (1989) A Field Guide: Agroforestry in Kenya; Ministry of Environment and Natural Resources, Nairobi, Kenya.
- Gholz, H. L.** (1987); Agroforestry; Realities, Possibilities and Potentials; Martinus Nijhoff Publishers and ICRAF, Florida, USA.
- Government of Kenya** (1968). Sessional Paper No. 1. Government Printer. Nairobi, Kenya.
- Government of Kenya** (1986). Sessional Paper No. 1. Government Printer. Nairobi, Kenya.
- Government of Kenya** (1989). Sixth development Plan 1989 – 1994. Government Printer. Nairobi, Kenya.
- Hardwood, C.** (1990). Old friend, new uses. Partners in Research and Development Newsletter. 3: 21-5. ACIAR. Canberra.
- Hardwood, C. and Getahun, A.** (1990). *Grevillea robusta*: Australian tree finds success in Africa. *Agroforestry Today*. (2(1): 8-10.
- Hilhorst, T. and Muchena, F. M.** (2000). Nutrients on the move – Soil fertility dynamics in African farming systems. International Institute for Environment and Development, London, U.K.
- Hinga, G.** (1973) Phosphate sorption capacity in relation to properties of several types of Kenya soils, Nairobi, Kenya.
- Huxley P. A, Pinney A, Akunda E and Muraya P.** (1994) A tree/ crop interface orientation experiment with *Grevillea robusta* hedgerow and maize. *Agroforestry systems*. ICRAF, Nairobi, Kenya.
- Huxley P. A., Rocheleau, D. E. and P. Wood** (1986) Farm Systems and Agroforestry Research in North Zambia, ICRAF, Nairobi, Kenya.

Kay, B.D. (1997) Soil structure and organic carbon: a review. In M.R. Carter, and B.A. Stewart(eds), *Structure and organic matter storage in agricultural soils. Adv. Soil Sci.* CRS Press, Boca Raton, FL.

Kang, B. T. van der Kruijs, A. C. B. M. and Couper, D. C.(1989) Alley Cropping for food crop production in the humid and semi- humid tropics. In *Alley farming in the humid and sub- humid tropics*. Proceedings of an international workshop held at Ibadan. March 10 – 14, 1986. Ibadan: IITA.

KEFRI (1990) *Kenya Forestry Seed Centre* 1989 annual report Nairobi Kenya Forest Research Institute

Kirk, P. L. (1950) Kjeldahl method for total Nitrogen. *Anal. Chem.* 22: 354 – 358. ICRAF, Nairobi, Kenya.

Klute; Haln, H.H, (1994) *Chemical water and Waste water Treatment 2*, Springer- verlag Berlin and Heidelberg GmbH and Company KG: Berlin Germany.

Lundgren. B. (1989). The Potential of Agroforestry. In: Kilewe, A. M, Kealey, K. M and Kebaara, K. K. , eds. *Agroforestry development in Kenya*. Nairobi, Kenya.

Lundgren B.O. and Nair (1985) *Agroforestry for Soil Conservation in S.A*, El-Swarfy, W.C Modlenhower and A. Lo (eds); *Soil Erosion and Conservation* pp. 703-717. Soil Conservation Soc Amer; Ankeny; I.A (Reprinted as ICRAF Reprint 21, 1985).

Mann H.S and Sacena S.K (1980) *Khejri (Prosopis cineraria) in the Indian Desert: Its Role in Agroforestry* CAZRI Monograph II, Central Arid Zone Research Institute, Jodhpur, Rajasthan, India.

Milimo, P.B (1983) *Growth and utilization of Grevillea robusta in Kenya* paper presentation at a workshop on Uses of Australian trees in China, Ghuanguzou, China, October 1- 14, 1988

Murwira, H. K. and Mukamuri, B. B (1998), *Traditional views of soils and soil fertility in Zimbabwe*. *Advances in GeoEcology*, Zimbabwe.

Mwamunga, E T (1989) a keynote speech delivered at a National workshop on strengthening forestry research in Kenya 1- 4 November 1983 Nairobi FD/USAID

Nair, P. K. R. (1984) Soil Productivity Aspects of Agroforestry, ICRAF, Nairobi, Kenya.

Nair, P. K. R. (1990), The Prospects for Agroforestry in the Tropics: World Bank, Washington DC.

Nair, P. K. R. (1993), An Introduction to Agroforestry: Kluwer Academic Publishers in Co-operation with ICRAF, Boston and London.

National Research Council (1982) Ecological Aspects of Development in the Humid Tropics. Washington D. C., USA.

Nyaga, J.J (1989) Opening address In Kilewe, A.M, Kealey K,N. and Kabaara, K.K., eds. Agroforestry Development in Kenya Nairobi ICRAF, 533 pp.

Oades, J.M. (1998) The retention of organic matter in soils. Biogeochemistry **5**, 35-70.

Okalebo, J. R. (1993): Laboratory Methods of soil and plant analysis; Nairobi, Kenya

Page R. M. Cole, Galen E. Timmreck, Thomas C. (1995) Basic Epidemic logical methods and Biostatistics, A prachial Guide book Jones and Barttelt Publishers, Inc.

Peech, M. (1965) Hydrogen- ion activity, IN: C. A. Black (ed), Methods of Soil Analysis, Part 2, Agronomy No. 9. American Society of Agronomy, Madison, WI.

Rao, M. R. (1990). A study of the potential of hedgerow intercropping in semi-arid India using the two-way systematic design, Agroforestry Systems (in press).

Rhodes J.R, George F., Fomby, Thomas. Advances in Econometrics: Economic Iniquality Survey Mothodes and Measurements.JAI Press Ltd.

Rhodes R (1986) and P. Booth (1982) Farmer- back- to- Farmer: a model for generating acceptable agricultural technology Agricadmin 11:127-137.

Rocheleau, D, Weber, F and Field – Juma, A. (1989); Agroforestry in Dryland Africa; ICRAF - Nairobi Kenya.

Sanchez, P. A (1976) Properties and management of Soils in the Tropics. John Willey and Sons, New York, USA.

Sanchez, P. A. (1979) Soil Fertility and Conservation Consideration For agroforestry Systems in the Humid Tropics of Latin America. In: Soils Research in Agroforestry; ed. Mongi, H. O. and P. A. Huxley, ICRAF, Nairobi, Kenya.

Sanchez, P.A. and R.H. Miller (1986) Organic matter and soil fertility management in acid soils of the tropics. Transactions 13th Int. Congress Soil Sci. Hamburg

Semwal, R. L, Maikhuri, R. K and Rao, K. S (2000) Participatory approaches to soil fertility resoration in degraded community forest lands.

Scherr, S. J. (1992) The role of extension in Agroforestry development: evident from western Kenya. ICRAF, Nairobi, Kenya.

Stewart, J. W. B. and H. Tiessen. (1987). Dynamics of soil organics Phosphorus Biogeochemistry 4:41-60.

Tefera, A. T (1996) Final report for on – farm evaluation of agroforestry technologies and their adoption in Machakos, ICRAF, Nairobi, Kenya.

Tefera, A. T. Rao, M. R., Mathuva, M. N. ,Atta-Krah, K. (2001) Farmer – participatory evaluation of *Grevillea robusta* in boundary planting in semi – arid Kenya, ICRAF, Nairobi, Kenya.

TSBF (2000): The biology and fertility of tropical soils Report of the Tropical soil Biology and fertility programme 1997- 1998- Nairobi, Kenya.

Young.A. (1985) The Potential of Agroforestry as a Practical Means of Sustaining Soil Fertility. Working Paper 34, ICRAF, Nairobi, Kenya.

Young .A.(1986) Effects of Trees on Soils; Working Paper; ICRAF, Nairobi, Kenya.

Young, A (1989): Agroforestry for Soil Conservation CAB International, Wallingford, Oxford, UK/ICRAF Nairobi Kenya.

Young, P.A.R. and McDonald, W.J.F. (1987) The distribution, composition and status of the rainforests of southern Queensland (pp. 119- 41) In *the Rainforest Legacy*, Canberra: Australian Government Publishing Service.