PART I: INFILTRATION RATES AND RELATED SOIL PROPERTIES AS INFLUENCED BY SEEDBED PREPARATION AND TIME OF YEAR.

PART 2: INVESTIGATION ON THE SULPHUR STATUS OF SOIL PROFILES FROM KITALE AND KABETE

BY

JEDIDAH ONCHERE

A THESIS SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN THE UNIVERSITY OF NAIROBI

1977

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

J.R.Onchere
Jedidah Onchere
(Candidate)

This thesis has been submitted for examination with our approval as University supervisors.

PART 1

....

Prof. P.M. Ahn
(University Supervisor)

....

Mr. S.M. Kinyali
(University Supervisor)

PART 2

....

Prof. P.M. Ahn
(University Supervisor)

....

Dr. S.O. Keya
(University Supervisor)

ACKNOWLEDGEMENT.

This work has not been done in isolation. The author records her appreciation to many contributors.

The author wishes to thank the University of Nairobi for providing a scholarship to study for a Master of Science degree in Agriculture (Soil Science) in the University of Nairobi.

The author also owes a substantial intellectual debt to the staff members of the Department of Soil Science, of the Faculty of Agriculture, University of Nairobi. Special thanks to go to Professor P.M.Ahn - (first supervisor), Dr.S.O.Keya and Mr. S.M. Kinyali (both second supervisors) and Mr. R.Barber who also beneficially contributed ideas. Many thanks to go to Dr. P.J.M. Cooper and his assistant staff (of National Agricultural Research Station, Kitale); and Mr. Bromfield and his assistant staff (of East African Agricultural and Forestry Research Organisation, Muguga) for providing both academic and physical support for the study.

Thanks to go to Miss S.Okwaro who not only provided accommodation to the author while collecting data at Kitale, but also typed the drafts and final version of this work.

Finally the author wishes to thank members of her family. Her husband Simeon and her son Mogaka who willingfully withstood long hours of the author's absence from home with a steadfast and encouraging response.

PART I

INFILTRATION RATES AND RELATED SOIL PROPERTIES AS INFLUENCED BY SEEDBED PREPARATION AND TIME OF YEAR

Page

CHAPTER ONE:- INTRODUCTION

CHAPTER TWO:- LITERATURE REVIEW

CHAPTER THREE:- MATERIALS AND METHODS

CHAPTER FOUR:- RESULTS AND DISCUSSION

CHAPTER ONE
INTRODUCTION

CHAPTER ONE

INTRODUCTION

CHAPTER I

1.1 INTRODUCTION

Infiltration is of great practical importance, since its rate often determines the amount of runoff which will form over the soil surface during rainstorms. Where the rate of infiltration is limiting, the entire water economy of the rooting zone of plants may be affected. Knowledge of the infiltration process as it relates to soil properties and mode of water supply is needed for efficient soil and water management. It is therefore thought necessary to investigate the factors affecting infiltration rates.

This experiment was conducted at Kitale at the National Agricultural Research Station. It was felt that the results would be of use in the Kitale area. In addition, it was felt that results would also be of relevance in areas where small differences in infiltration rates might be important.

Kenya, as an agricultural country, needs to plan for an extensive agricultural system in the dry areas. While most of the Kenyan population still live in the agricultural sector, the Kenyan land area is mainly of low potential, and the high potential land is very limited. The rainfall in the low potential areas is so low that water becomes a limiting factor. Most of these areas also have soil erosion hazards. An example to be cited is the area around Katumani in Machakos District. While soil conservation methods are necessary and in progress in the area, water conservation is also necessary for the success of crop growth.

Maize, as a major food crop in Kenya, is grown in Kitale area and other dry areas like Katumani. It is therefore possible that with proper tillage methods and management of crop fields, enough moisture can be conserved in the soil to last the crop until the end of the growing season. Since the rainy period is so short, quicker methods of field preparation with maximum conservation of both water and soil would be an advantage to the farmer. To achieve the conservation practice, labour saving methods of farming should be adopted since most farmers in the dry areas depend mainly on family and casual labour.

1.2 OBJECTIVE

The main objective of the study was to find a rapid tillage method that has a high final steady rate of infiltration and a minimum soil erosion hazard in the field throughout the growing season of the annual crop in question.

1.3 REASONS FOR THE STUDY

The study was based on several methods of seedbed preparation. Their effects on soil physical properties as surface bulk density, soil porosity, surface soil roughness and hence infiltration rates were expected to be of importance to the farmer. Since these soil physical properties affect the amount of water entering the soil and hence the amount of water stored in the soil, the final crop yield would probably depend on the method of seedbed preparation. It was felt that if a method of tillage was found to be appropriate to the farmer, then he would be advised to adopt it so that water does not remain his limiting factor in crop growth.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER II

2. LITERATURE REVIEW

2.1 INTRODUCTION

Careful water management is essential, especially in dry areas, to establish a stable and efficient agriculture. In Kenya, a great deal of effort is being directed toward water management and conservation activities, such as irrigation, drainage and erosion control. Examples to be cited are, the rice irrigation schemes at Mwea and Ahero, the drainage work for maize production in the Yala swamps and the soil erosion control programmes in some parts of Machakos District. These activities require a knowledge of the rates at which soils take in water under different conditions. Wide differences can be found within a single soil type, depending upon the soil moisture levels and management practices of the soil in question.

2.2 INFILTRATION RATE

This section deals with definitions of different types of infiltration process and factors affecting infiltration rates. The discussion below is based on readings of relevant sections of Russell (1975), Childs (1967), Hillel (1973), and Baver *et al* (1972) and also Swartzendruber and Hillel (1973).

2.20 DEFINITIONS

Infiltration is simply the entry of water into soil. Various soil physicists have defined infiltration rates in several ways. A few examples could be cited as:-

> "Infiltration may be defined as the process whereby water enters into the soil through its surface."

This was a definition given by Swartzendruber and Hillel (1973) . Hillel also defines infiltration as:

> "... the process of water entry into the soil, generally (but not necessarily) through the soil surface and vertically downwards."

Baver, Gardner and Gardner (1972) simply called infiltration

> "... the downward entry of water into soil."

2.21 SURFACE INFILTRATION

Tillage methods used in this study affected only the 15 cm. of the soil profile. Differences between the results from different treatments can therefore be expected to be due to the differences in the top 15cm. rather than to differences in the subsoil. Sudden flooding of the homogeneously dry soil results in very high infiltration rates. This is due to the steep moisture gradient within a thin surface layer, whose conductivity is high. As the moisture profile develops due to vertical infiltration, the gradient is reduced and hence the rate of infiltration is lowered. The gradient becomes very small with time and the rate of infiltration becomes more or less constant. This has been called "the Final Steady Rate (FSR) of infiltration," by the writer. The FSR has been used mainly because it is thought to reflect the surface soil physical properties as discussed further below.

2.22 THE RATE OF INFILTRATION

Infiltration is easily measured as a function of time. This in effect gives the rate of infiltration a definition of:-

"The rate of entry of water into a soil."

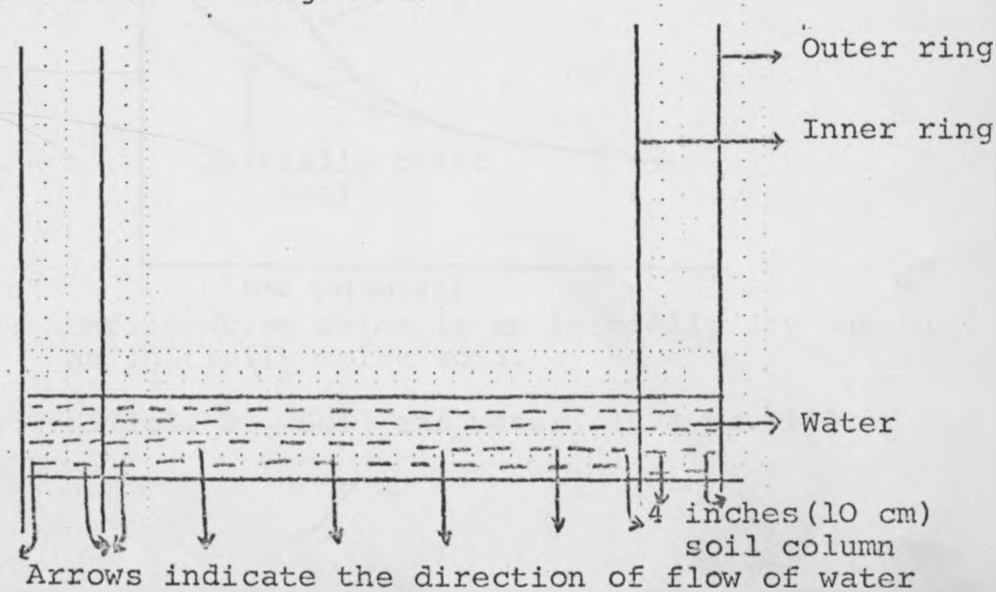
Childs defines it more precisely as:-

> "... the rate at which water crosses the soil surface, insofar as this can be defined and located, and thus enters the profile from outside."

The infiltration rate of a soil profile is a consequence of the hydraulic conductivity and the potential gradient at the soil surface. Low hydraulic conductivity reduces the infiltration rate. Initial soil moisture also affects the infiltration rate. This is especially in the fast initial rate of infiltration which is normally reduced as moisture content increases. Assuming no through flow of infiltrated water down the profile, Childs (1940) postulates that the decrease of infiltration rate to FSR could be related to the rate of increase of the total water stored in the soil profile.

2.23 HORIZONTAL INFILTRATION

This occurs greatly if the gravitational force is reduced with the profile, and water is drawn in mainly by matric suction force only. However, horizontal infiltration can be reduced to near zero by water in the outer ring. As the rings may be hammered into the soil to a depth of about 10 cm., any water moving horizontally out of the inner ring is counterbalanced by the horizontal inward flow of water from the outer ring. This can be diagmatically illustrated as in Diagram I.



Diag. I: Directional flow of water in the top and subsoil.

2.24 VERTICAL INFILTRATION

Under the influence of both suction and gravity gradients, the downward movement of water occurs. This is vertical infiltration which was of great practical importance in the study. It appears that the rates of infiltration measured are related to the vertical infiltration as there was no upward and no appreciable horizontal movement of water within the top 15 cm. of the profile.

There is a high degree of influence of the surface wetness or suction (initial soil moisture content) on the initial rate of infiltration. This can be graphically presented as in Figure I.

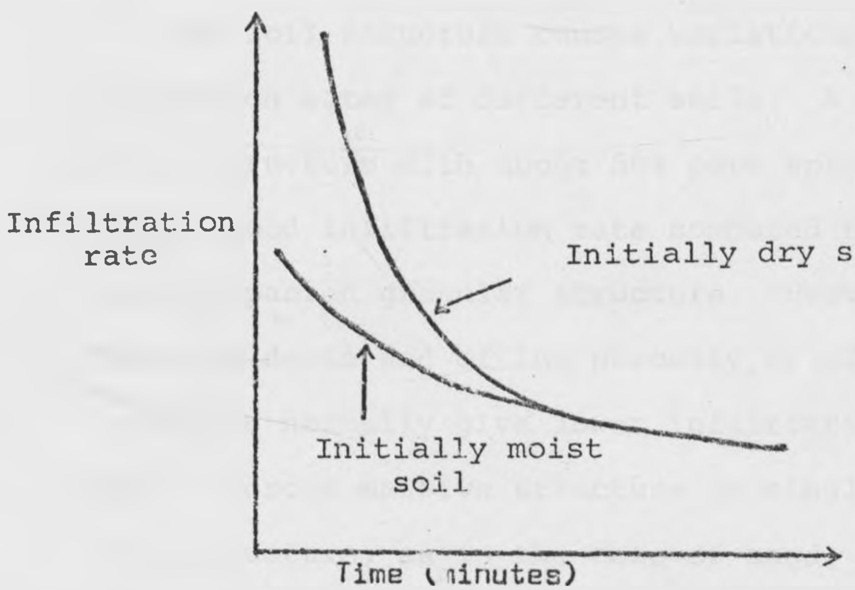


Fig. I: Infiltration rates in an initially dry and in an initially moist soil.

Source: Hillel, D. Soil and water, 1973 pg. 140.

2.25 GENERAL FACTORS AFFECTING INFILTRATION RATES

There are six factors that affect the infiltration rate. These can be listed as:-

(a) the soil structure
(b) the soil porosity
(c) the gradient of the land
(d) the humus content of the soil
(e) the initial moisture content of the soil
(f) soil texture.

These factors are briefly discussed individually.

(a) The soil structure

The soil structure causes variations in the filtration rates of different soils. A good crumb structure with about 50% pore space has a very good infiltration rate compared to a more compacted granular structure. Heavy clays that are dense and of low porosity, or of massive structure normally give lower infiltration rates than a porous massive structure or single grained soil structure, as in the case of sand. The two cases are, however, the extremes.

(b) The soil Porosity

Water enters the soil through cracks and pores. It is therefore important that the soil porosity favours water infiltration. The higher the percentage of macro-pores (non-capillary pores), the higher the infiltration rate of the soil. This is because the macro-pores require less suction to empty them (less than 10 millibars). The coarse pores, therefore, empty down quickly and are refilled with water. On the other hand, the finer pores, needing about 40 millibars or more, to empty them, take much longer to empty and refill than the coarse pores take. Hence low infiltration rates result.

Pore continuity is also very important. Discontinuous pores hinder rapid flow of water down the profile. The pores have to be continuous from the surface of soil for adequate infiltration of water. Pores in a surface crust, if present, are normally fewer and thinner than pores in non-crusted surfaces. This reduces the infiltration of water in the soil.

(c) The Gradient of the land

A steep gradient allows less time for water to infilter through the soil. Gradually graded land, on the other hand, allows more time for water to infiltrate into the soil than the steep graded land. Thus the soils can vary in their infiltration rates even if other factors are equal, due to differences in gradient alone.

(d) <u>The humus content of the soil</u>

The humus content of the soil directly affects the soil structure. The more humous the soil is, the better the crumb structure becomes. A soil with a good crumb structure has a high porosity percentage and infiltration rates are normally high. Humus also acts as a sponge and can absorb moisture many times its weight. When all the pores are filled with water, it drains down the profile. This facilitates the rate of infiltration.

(e) <u>The initial moisture content of the soil</u>

Infiltration rates are initially high in soils that are dry. These rates decrease as soils get wet. Initial moisture content of the soil is an important factor considered in this study as will be seen in the succeeding chapters.

(f) <u>Soil Texture</u>

The texture of the soil also affects the infiltration capacity of the soil in question. This is because texture, to a large extend, affects the type and number of soil pores which take in water.

2.3 SOME ASPECTS ON INFILTRATION RATES

Horton (1933) discussed the role of infiltration in the hydrological cycle. Since then many scientists have been encouraged to work on it under the name "infiltration capacity." Horton (1940) defined infiltration capacity as:-

> "the maximum rate at which a given soil, when in a given condition can absorb rain as it falls."

He showed that infiltration capacity will decrease with rain duration in accordance with the equation:-

$$f = fc + (fo - fc)\, e^{-rft}$$

where:- fo = initial infiltration capacity at the beginning of the rain,

fc = final constant infiltration capacity,

rf = constant which governs the time (t) required under given conditions for infiltration capacity to change from initial value (fo) to near its constant value (fc), rf is dependent on the rate of energy (e) application to the soil surface.

As soil capping occurs due to the hammering effects of rain drops on the soil surface, the rate of energy application becomes constant. The constant energy application results in a decreased effect of rain drop impact at the soil surface. Due to soil capping, the rate of infiltration decreases with time upto the end of the rain, following an inverse exponential law.

A typical infiltration capacity curve will show a high infiltration rate in the first few minutes of rainfall, with a rapid decrease to reach an asymptotic line that gives the constant infiltration capacity.

Horton (1933) stressed the importance of infiltration to rainfall runoff. He also observed that the infiltration rate of soils varied between a maximum value when the soil was dry, and a minimum value when the soil was wet and packed. In the succeeding years, Horton also found that there was a close interrelationship between infiltration rate, moisture content, vegetative growth and ground water levels, i.e. a field with a high moisture content and a high infiltration rate supports vegetative growth best.

According to Horton (1940), three factors influence the infiltration rate:-

(i) Soil type and soil profile characteristics;

(ii) Biological activity and macrostructure within the soil

(iii) Vegetative cover.

While some workers were of the opinion that the infiltration rate depends solely on the whole body of the soil, Horton maintained his idea that the infiltration rate is governed mainly by conditions at or near the soil surface.

Lewis and Powers (1938) found that factors affecting infiltration rate could be divided into two groups:-

(i) Those factors affecting infiltration rate at a given time, such as texture, structure, organic matter and water content.

(ii) Those factors affecting infiltration rates over a considerable area, such as slope, vegetation and surface roughness.

An appreciable amount of work followed to show the effect of soil surface conditions on infiltration rates. When considering crust formation and its influence on infiltration rates, Duley (1939), observed that a rapid reduction of the infiltration rate of a cultivated soil over a short period of time, as rain falls on the surface, was accompanied by the formation of a thin, compact layer at the soil surface. The layer has a reduced coarse pore percentage and allows water to pass through only very slowly. He then postulated that this thin layer was formed as a result of destruction of structure by two processes:-

- beating effect of raindrops.
- a sorting action as water flowed over the surface, and the particles were fitted around the large ones to form a relatively less porous seal.

He later found that this seal had a greater effect on the infiltration rates than had the type of soil, slope, moisture content or profile characteristics.

Musgrave and Free (1939), had earlier found that cultivation of the soil surface and depth of cultivation increased the infiltration rates of soils. This fact was reported earlier by O'Neal (1949), who showed that the condition of the soil surface directly affected the infiltration rates and hence the runoff and soil erosion. This showed that cultivation opened up Duley's thin compact layer and increased the surface porosity while decreasing the runoff and increasing the initial rates of infiltration.

Duley and Russell (1939), worked on the effect of crop residue on infiltration rate. Their findings were that leaving a crop residue at the soil surface increased the infiltration rates, and reduced erosion and evaporation from the soil surface.

Edward (1967), observed that when he compared the cumulative infiltration of crusted and non-crusted soil after two hours, the cumulative infiltration of a non-crusted soil surface was significantly higher than that of a crusted soil surface. The reasons given for this were a high moist bulk density of the crusted soil with decreased porosity and decreasing saturated conductivity with increasing drop impact.

O'Neal (1949), attempted to establish soil structure as the most important factor affecting permeability and hence infiltration rates. However, he found this to be difficult without prior knowledge of percolation rates. His work was more recently updated by Serochkin (1973), who found that infiltration rates depended on the structure of the plough layer, the state of its surface and soil moisture content. However, the plough layer was not a decisive factor in all cases.

Ways and means of improving surface conditions, and of maintaining them, have been investigated by several workers. Structural stability and the ability of the soil to resist capping were the main surface conditions studied. These surface conditions have been known to affect infiltration rates much more than other factors, considered above. Mulching and crop canopy were used for these studies. Peele, Beale and Lesesne (1948), found that infiltration rates of a cultivated soil were improved when a mulch of crimson clover hay was used.

McGeorge (1941), found that vegetative surface cover reduced the raindrop impact, reduced the runoff and increased infiltration rates. His work was supported by Meerwig (1970), who found that vegetation cover and litter cover were both important in maintaining infiltration rates and soil structure stability. Similar work carried on by Wilkinson (1975), using grass fallow rotations, showed that there were improved infiltration rates during fallow periods. This increase was eliminated mainly during the first seedbed preparations and completely at the end of the cropping season.

Miller and Aarstad (1971), found that both straw application and cultivation increased infiltration rates. This was due to an increase of soil organic matter and aggregate stability. This was in agreement with what Duley and Russell (1939), had found when crop residue was left on the ground.

Earlier work had been seen to give similar results on structural stability and infiltration rates. Reitemeier and Christiansen (1946), had found that addition of gypsum at the rate of 5 tons per acre or organic matter in the form of alfalfa at the rate of 5 tons per acre almost doubled the infiltration rates of some soils. This could be mainly due to structural improvement caused by chemicals or organic matter. Reitemeier and Christiansen further observed that prolonged drying periods between irrigation times, were even more effective in increasing infiltration rates than the chemicals and organic matter additions.

Other work on chemical effects on infiltration rates, Pillsburg and Richards (1954), added ammonium sulphate and organic matter to the soil. Moderate applications of sulphate of ammonia resulted in appreciably higher rates of infiltration than did urea mixed with large amounts of organic matter. They also found that, as the amount of surface organic matter increased, so did the rates of infiltration.

The effects of soil moisture content were also extensively studied. Diseker and Joder (1936), found that saturating the soil with water increased the runoff and reduced the inflow of water. O'Neal (1949), also found that a moist soil and a hard crusted surface lost a lot of water through runoff while a cultivated soil did not lose as much water until after a certain period of rainfall. He observed that the soil moisture content at the beginning of the rains had a significant influence on the rate of infiltration during the first twenty minutes. Several calculations gave a relationship that showed that, the rate of infiltration varied appropriately inversely as the square root of moisture content at the beginning of the rain.

After studying the influence of some water properties on infiltration rates, Fletcher (1940) concluded by specifying several interrelationships:-

"(a) Surface tension of soil water increased linearly with infiltration rate.

(b) Viscosity of water decreased hyperbolically with infiltration rates.

(c) Pore size increased infiltration rates parabolically.

(d) Depth of wetting and head of water decreased infiltration rates hyperbolically.

(e) Temperature increased infiltration rates linearly."

Cannell and Stolzy (1962), found that measurements of infiltration rates in soils of different moisture content varied greatly. They suggested that identical soil moisture conditions should be reproduced as near as possible. To reduce the total error, the fields should be wetted at the same hydraulic head for the same number of days before any measurements are made.

Miller and Gardner (1962), using uniformly packed soil tubes in the laboratory found that water movement into the soil surface is reduced as accumulation takes place in the tubes. Bouwer (1960), also studied the final infiltration rates from cylinder infiltrometers and irrigation furrows with an electrical resistance network. He found that as water accumulated in the soil profile, so did the infiltration rates decrease to a low steady rate.

Using 12 inch diameter ring infiltrometers, Tisdall (1951), investigated antecedent soil moisture and its relation to infiltration rate. He found that, in the first few hours of an infiltration run, antecedent soil moisture was a major factor in determining the initial infiltration rate. He also found that the longer the time of water application, the less the effect of antecedent soil moisture.

Dunin (1969), found that variation in infiltration rates during rainfall was related by an inverse exponential function to accumulation of soil moisture.

Ayers and Wikramanayake (1958), investigated the effect of water-storage capacity of soils on mass infiltration. By application of artificial rain to field plots, they found that at various levels of water-storage capacity of the top 15 cm, an equation could be derived to describe the relationship. The equation was:-

$$Y = 0.43 + 0.38x$$

where Y = mass infiltration in inches for 20 minutes

X = available storage - capacity in inches

This equation expressed a linear relationship between the two variables.

Talsma (1975), found in his study of the effect of initial moisture content and infiltration quantity on redistribution of soil water, that while gravity was the dominant factor in sandy soils, initial soil moisture and capillary effects were the dominant factors in loamy soils. He found that an increase in soil moisture led to an increase in capillary effects.

Parlange (1973), had also found with the support of numerical calculations, using results from experiments on absorption of water from cylinders, that diffusion of water in the soil increases exponentially with moisture content of the soil.

Previous work on factors that influence infiltration rates shows that, in agreement with Horton, the infiltration rates are influenced by conditions of the soil surface, soil moisture content and to a lesser extent, the soil structure.

2.4 DIRECTIONAL MOVEMENT OF INFILTRATION WATER

Advanced methods of study using gamma rays in soil columns have been developed recently. Hillel and Gardner (1969), found that hydraulic properties of sub-crusts and top-crusts affect infiltration processes. Crust-topped profiles are considered self adjusting systems in which properties of the sub- and top-crusts interact in time to give a steady infiltration rate. Thus, the sub-crust suction that develops creates a gradient through the crust and conductivity in the sub-crust zone which will result into an equal flux through both layers.

Hristov et al (1975), found, using a soil column packed at a bulk density of 1.34 for the study of infiltration rates in three directions (horizontal, vertical and upward directions), that movement in these directions depended on the hydraulic conductivity and water diffusion expressed as a function of volumetric soil water content.

Talsma (1975), found that hydraulic conductivity decreased with depth, decreasing horizontal movement and and increasing vertical movement; therefore deviations from predictions increased with decrease in water supply on the surface.

Parlange (1972) worked mainly on the theory of water movement in soils. He developed analytical equations for the absorption of water in one, two and three directions in porous media.

Read (1959), had earlier on found that in a horizontal radial system, water will move at least 45 cm in soils at moisture tension up to 100 cm of water, and at least 14 cm in soils with moisture tension up to 462 cm.

2.5 EFFECTS OF SEASONAL VARIATIONS ON INFILTRATION RATES

Not much work has been put out on this subject. Recently work on infiltration process has neglected this topic.

Bertoni et al (1958), studied the effect of seasonal variations, during the year, on final infiltration rates in Indiana, U.S.A. His final analyses showed that the rates increased gradually from March to mid June and then increased sharply until late July. The reason offered for this was that the increase in July was due to vegetative cover that protects the surface against sealing. Other reasons could be reduced initial soil moisture which results in cracking of the surface and high soil and water temperatures, which according to Fletcher (1940), increased the rate of filtration linearly. Bertoni _et alli's_ findings were in agreement with observations made by Beutner _et al_ (1940), and Horner and Llyod (1940).

Dunin (1969) also observed the seasonal variation effects on infiltration rates and concluded that, seasonal effects on infiltration characteristics were attributed to the swelling of the colloidal fraction of the soil.

2.6 METHODS OF MEASURING INFILTRATION RATES

Several techniques have been developed to measure the infiltration capacity of soils. Some of these techniques are mentioned briefly below:-

(a) Rainfall - runoff index: the difference between the rainfall and runoff is used as an index. Horton (1933), took into consideration the part of water detained on the ground, after the period of rainfall excess ended, and entered the soil as infiltration. He could then calculate the infiltration capacity of the entire watershed.

(b) Simulation Method: Pearse and Bertelson (1937) used one square foot instead of entire watershed. Water was supplied by overhead system to simulate natural rainfall. This posed a problem of lateral movement of water which resulted in very high infiltration capacities of soils.

(c) Metal cylinder technique: Musgrave (1935) placed a metal cylinder in the soil to a desired depth and water was supplied from a burette so as to maintain a constant head. This method had a problem of entrapped air in the soil pores.

(d) Square frame method: Auten (1934) poured four successive one litre portions of water into a one square foot frame that was sealed to the soil surface with wet clay. The time of infiltration of each water portion was recorded. This method allowed entrapped air to escape and there was little surface disturbance.

The square frame method was later varied by forcing the frames into the soil to a depth of 4-6 cm. and later by introducing buffer compartments in the apparatus. This aimed at compensating for the factor of lateral flow (Kohnke 1938).

2.60 LIMITATIONS OF CYLINDER INFILTROMETERS

Parr and Bertrand (1960),outlined two main limitations of cylinder infiltrometers as being:-

(i) the method of placement
(ii) entrapped air.

(i) The Method of Placement

The method of placement causes a certain degree of disturbance of natural conditions, such as shattering or compaction which may cause a large variation in infiltration rates between replicates.

Furthermore, the interface between the soil and the side of the metal ring may cause unnatural seepage planes which result in abnormally high infiltration rates.

This limitation can be overcome by leaving the cylinders in place over a period of time, during a rainy season before any measurements are made. The soil can then be said to have reverted to its natural conditions.

(ii) Entrapped air

When a constant head of water is applied to the soil surface, as is the case with cylinder infiltrometers, air can be trapped in the soil. The inability of air to escape from the soil results in an impeded downward flow of water. Powers (1934), also found this limitation to be occurring in cylinder infiltrometers.

2.61 EFFECT OF VARIED DESIGNS OF CYLINDER INFILTROMETERS ON INFILTRATION RATES

Many soil physicists have designed methods of determining infiltration rates of soils. Most of these methods are adopted to certain conditions and may not be equally applicable in other areas. Scientists such as Smith *et al* (1937), Auten (1933), Auten (1934) and Lewis (1937) used cylinder infiltrometers. Although most of their results varied considerably within replicates, they also found appreciable differences between different treatments. Musgrave (1935), had the highest variations between replicates. This was due to the use of only one cylinder and failure to account for horizontal movement of water.

Schiff (1953), found in his study of the effect of surface head on infiltration rates, that for all the ring sizes he used, (0.78 to 653 square feet in area), an increase in infiltration rates was directly proportional to an increase in the head used. He found further that equal surface heads in both rings (outer and inner rings) were necessary when the hydraulic head existed at the bottom of the inner ring.

Previous work to Schiff (1953), on infiltration processes had almost similar results to Schiff's which can be summarised as:-

- Infiltration rates are mainly influenced by the conditions of the soil surface, the initial soil moisture, content and to a lesser extent, the soil structure.

- Infiltration rates vary with the season of the year.

- Infiltration rates can be affected by directional movements of water i.e. vertical, horizontal and upward movements.
- Infiltration rates measured by cylinder infiltrometers can vary due to two main limitations; that of entrapped air and that of method of placement of the cylinder infiltrometer.

CHAPTER THREE

MATERIALS AND METHODS

CHAPTER III

3. MATERIALS AND METHODS

3.0 MATERIALS

3.01 GENERAL FEATURES OF THE AREA UNDER STUDY

(a) Location

The National Agricultural Research Station, Kitale, lies south-east of Kitale township, at a distance of about 3.2 km. The Station is bordered by the Kitale/Kisumu road to the east, to the west by Endebbess road and to the north by Kitale Municipality. The station lies at an altitude of about 1860 m. above sea level and occupies an area of about 1232.2 ha. It is at a latitude of about 1°N and longitude of about 35°E.

(b) Geology and Physical Features

The soils of the station are derived from basement system rocks which are composed largely of gneisses and schists. The gneisses and schists were derived from argillaceous and arenaceous sediments which were metamorphised and recrystalized into quartz and feldspar rich rocks with considerable biotite hornblend and garnet.

External and internal geological forces and the nature of the local rocks have to a greater degree influenced the formation of the present landscape.

The land slopes gently from east to west. Major valleys with streams occur at the centre. The southern corners of the station are low lying areas which are seasonally waterlogged.

(c) The soil

The soil is an orthic luvisol which is the equivalent of an alfisol in the 7th Approx. classification.

(d) Vegetation

The area lies in the highlands subtropical area. The natural vegetation is moist woodland with broad leaved trees and large evergreen shrubs.

(d) Climate

Kitale has an annual rainfall of 1130 mm. (1935-1970). Its eight months moist period is centred in the middle of the year. The dry period is normally from November to February. April to August are humid months with moderate rainfall surpluses. August is the wettest month and June has slightly lower rainfall than other wet months. Undue water stress is unlikely to occur even during the dry period unless the year is exceptionally dry. The annual variability of rainfall in Kitale is low and the rain is well distributed.

Little variation in temperature occurs. The mean maximum vary between 23 - 29°C, the minimum varies between 10 - 13°C and the daily range is approximately 12 - 17°C. Single extreme temperature recorded were 31.8°C and 3.9°C. The relative humidity varies between 65 - 35% in the middle of the day and 95-85% in the morning. Cloud cover in the middle of the day expressed in eights varies between 6 and 7.

3.02 GENERAL

An experiment was designed and started off at the National Agricultural Research Station, Kitale by E.K. Wahome. This was for the maize growing season of 1976. This season normally starts in March and ends in early November. The writer took over the experiment and, with several modifications in the design and method, completed it by the end of the rainy season in early November.

3.03 SITE AND MANAGEMENT

An area of land with a gentle (3%) slope was selected for the experiment. Cultivation was carried out to increase the infiltration rate, as this area had been under grass for several years. Maize (Hybrid 613C) was planted to act as a cover i.e. to reduce the rain drop impact on the surface soil that might be subjected to crusting or erosion when left bare.

The crop also provided a natural farm environment in which the infiltration rates were to be taken. All the necessary cultural practices were carried out i.e. weeding, spraying and fertilizer application.

3.04 TREATMENT DESCRIPTIONS

Eight treatments were originally chosen to cover as many variations of seedbed preparation as possible. These treatments were grouped into two main groups:

- the minimum tillage methods of seedbed preparation,

- the"ordinary" seedbed preparation methods.

The minimum tillage methods were attained by use of herbicide while the "ordinary" method was attained by the use of a 'jembe' (hoe). These main groups had several variations and combinations of seedbed preparation. Treatments compared were:-

(i) Fine seedbed versus cloddy seedbed.

(ii) Jembe versus herbicide

(iii) Fine seedbed plus herbicide versus cloddy seedbed plus herbicide.

(iv) Minimum tillage plus mulch versus minimum tillage without mulch.

(v) Grass sward as a control (on similar soil).

(vi) Bare fallow kept clear of weeds versus maize cover.

From the above comparisons, eight defined treatments were chosen:-

(a) Fine Seedbed Jembe (FS(J))

The seedbed was prepared by use of a jembe to a depth of 15 cm. The clods were beaten up to a finer seedbed than the farmer normally makes (2-3 cm. in diameter). Weeds were cleared by jembe.

(b) Coarse Seedbed Jembe (CS(J))

The seedbed was prepared using a jembe to a depth of six inches (15 cm) and the clods left whole without being broken to smaller clods. These clods were larger than the ones found in the usual farmers seedbed (5-15 cm in diameter). Weed control was performed simply by turning over the clods.

(c) Herbicide (H)

This was a complete minimum tillage. No cultivation took place at all. Weeds were killed by the herbicides, Gesaprin Atrazine and Gramaxone. Both seedbed preparation and weed control were by use of herbicide.

(d) Herbide plus Mulch (H + M)

The seedbed was prepared by the use of a herbicide. Weeds were controlled by mulching. The mulch, put in the interrows, was of mixed composition, consisting of the plant material that had been cleared off the area before seedbed preparation.

(e) Bare Fallow (BF)

A seedbed similar to that of an "ordinary" farmer was prepared using a jembe. Weed control was by pulling the weeds out of the ground by hand.

(f) Fine Seedbed Plus Herbicide (FS(H)

The seedbed was prepared as in (a) above but weeds were controlled by herbicide applications.

(g) Coarse Seedbed plus Herbicide (CS(H)

The seedbed preparation was as in (b) but weeds were controlled by herbicides.

(h) Grass Sward (GS)

There was no cultivation on this plot. The grass was kept short. The soil was similar to that of the other plots.

3.05 EXPERIMENTAL LAYOUT

Three blocks were laid out allowing three replicates for each treatment. All plots were 6m. x 6m.

B1	1 FS(J)	2 CS(J)	3 H + M	4 H	5 BF	6 FS + H	7 CS + H
B2	8 CS(H)	9 BF	10 CS(J)	11 H + M	12 FS(J)	13 FS(H)	14 H
B3	15 H	16 FS + H	17 CS(J)	18 BF	19 CS + H	20 H + M	21 FS(J)

GRASS SWARD

KEY

FS - Fine Seedbed

CS - Coarse Seedbed

H - Herbicide

M - Mulch

BF - Bare Fallow

GS - Grass sward

J - Jembe

3.1 METHODS

3.10 GENERAL MANAGEMENT OF THE PLOTS

Maize was planted at the rate of 44,000 plants per hectare, with a spacing of 30 cm x 75 cm. Two seeds were placed in each hole and thinned three weeks after emergence. At planting, 500kg/ha of single superphosphate (11.4 gm/hole) were applied and top dressed at 3 weeks post emergence with

640 kg/ha of A.S.N. (14.5 gm/hole).

Gramaxon was sprayed a day after planting and Atrazine was applied a day later by spraying.

The first hand weeding was carried out three weeks after planting and the second hand weeding four weeks later. The second weeding took place after the beginning of the recording of infiltration rates. At 3 and 7 weeks post emergence, DDT was applied against stalkborer.

3.11 THE APPARATUS

The apparatus used consisted of:-

(i)- Spirit level

(ii)- Hammering equipment (thick pipe).

(iii)- 10.16 x 5.08 x 20.32 cm. timber.

(iv)- Steel metal rings (a) inner ring
6" diam., 12" high.
(b) outer ring,
12" diam., 12" high.

(v) - 9.0 litre plastic aspirator with tap and rubber tube.

(vi)-Metal stand for aspirator.

3.12 METHOD

In every experimental plot, the infiltration rate was measured as the rate of decline in the level of standing water, in the ring, as a function of time. To counteract the edge effect and lateral movement of water, a fairly large area of the soil was covered by the rings. This decreased the lateral movement of water especially in the top 10 cm. of the soil to which depth the rings were hammered down. This works on the principle that, the edge effect from the lateral movement of water increases as the area decreases and the area/perimeter ratio declines.

The apparatus included a ring infiltrometer with two concentric rings i.e. the inner ring, in which the measurements were made and the outer ring which counteracted the edge effects. The inner ring was fed to keep a constant head from a calibrated plastic aspirator that served as a reservoir. A ball-cock was fixed in the inner ring with an inlet valve to regulate the head of water automatically. When the head of water dropped, the valve opened and water filled the ring to the required depth (10 cm.). When the appropriate level was reached, the ball-cock was raised up closing the valve to cut short any more water supply. The outer ring was filled manually from a jerry-can with more care to avoid pounding on the soil surface.

The equipment was set up as in Diag. 2. The level of the water goes down the calibrated reservoir only since the head of water in the inner ring is maintained at a constant level.

In this experiment, the diameter of the reservoir was bigger than that of the inner ring. Hence for every inch in the reservoir there was a corresponding drop in the ring of 1.86 inches i.e.

$$\frac{\text{Drop in water level of inner ring}}{\text{Drop in water level of reservoir}} = 1.86$$

The formula used in calculations of infiltration rates was worked out as:-

Let V be the drop in water-level in the reservoir in units of an inch. Then the drop in the inner ring equals 1.86V.

Hence $I = \frac{1.86V}{T}$

Where I = Infiltration rates

T = Time in minutes

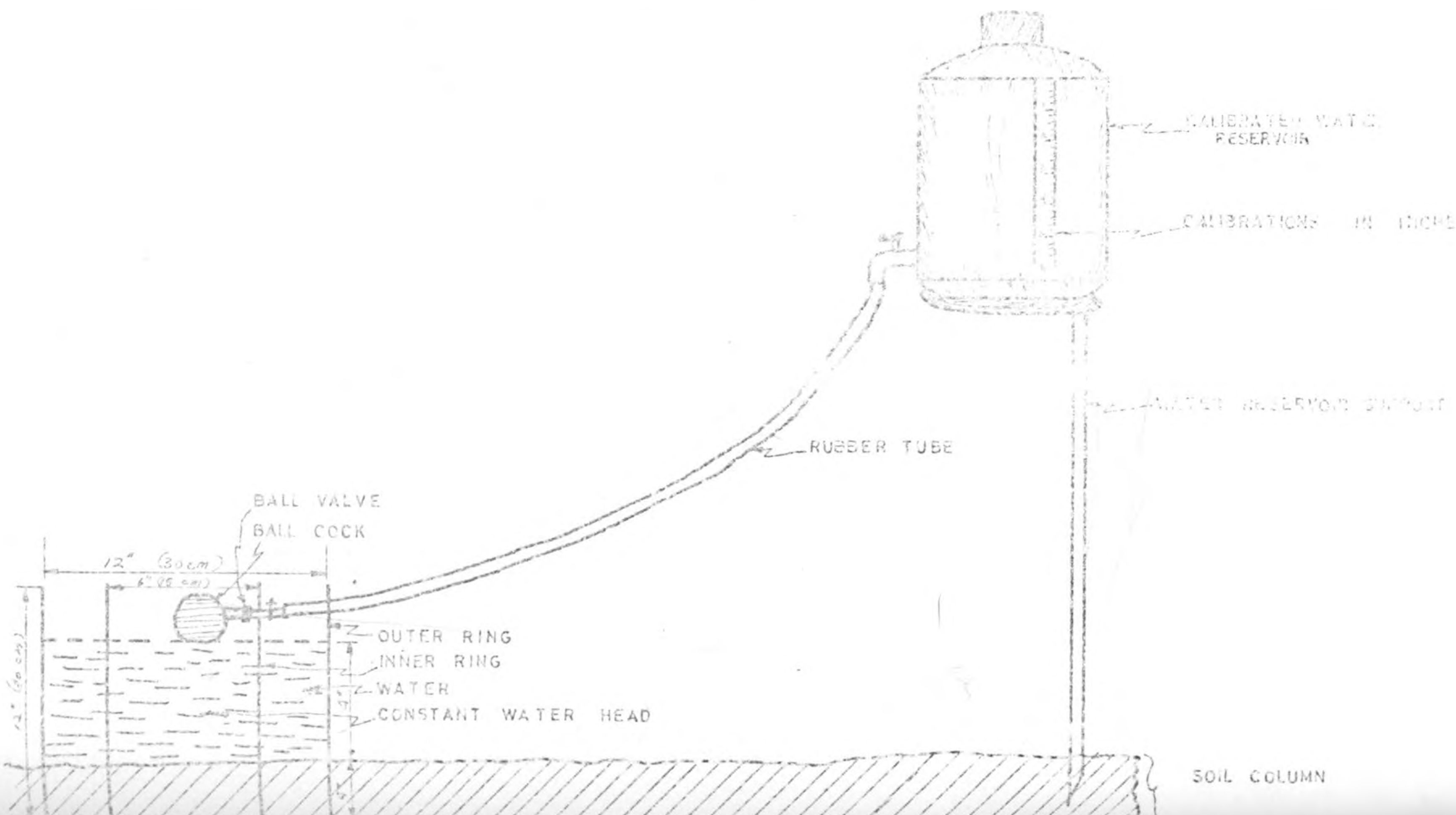
Since 1/10" = 2.54 mm

Then $I = \frac{1.86V \times 2.54}{T}$ mm/minute

$= \frac{4.72V}{T}$ mm/minute

$= \frac{(4.72 \times 60)}{10} \frac{V}{T}$ cm/hr.

$= \frac{28.32V}{T}$ cm/hr.



DIAG. 2 APPARATUS SET UP

3.13 EXPERIMENTAL MODIFICATIONS

The writer decided to modify the method and design of the experiment because of some errors in the former experiment such as:-

(i) The former design had a relatively large number of treatments without sufficient replicates. This posed the problem of accurate statistical analyses of the results.

(ii) The results of the former experiment failed to investigate the correlation between the initial soil moisture and the infiltration rate of plots.

(iii) Although the readings were taken under natural conditions, some readings were taken after it had rained the previous day while others were taken after periods without rain. The new method maintained that same conditions for all the treatments.

(iv) Some readings appeared of doubtful accuracy with an indication that water went back into the aspirators (reservoir) i.e. records of the level of water in the reservoir at a particular time could occasionally be higher than the previous reading after some minutes of allowance for the level to drop (see Appendix I). This is obviously not possible.

(v) As the rainy season for the year 1976 was coming to an end, there was not enough time to repeat the experiment. ~~again~~.

The reduced number of treatments chosen by the writer were:- Fine seedbed jembe, Fine seedbed herbicide, Coarse seedbed jembe and Coarse seedbed herbicide. These four treatments allowed comparisons between the coarse and fine seedbed, and the jembe and herbicide treatments.

Nine replicate readings were recorded for each of the treatments. These were sufficient to make a statistical analysis of the readings possible.

A bare fallow treatment was also included to cover the effect of seasonal variation, as had been previously designed in the experiment.

3.14 THE MODIFIED METHOD

Three sites were chosen at random between the maize rows and watered with about three litres of water. This was to reduce the cracking of the soil surface when the rings were hammered in the soil. It took about 20 minutes for the water to drain sufficiently down the profile.

The rings were hammered gently into the soil to the required level (10 cm into the soil), 4 maize leaves were placed in the outer ring and 2 leaves in the inner ring. This was to reduce the adverse effect, both on the soil surface and on porosity, of pouring the water directly on the soil surface. Water was poured into the rings to a height of about 14 cm. This was done by placing a standard hand at about 10 cm. up the rings, for water to fall on when being poured and reduce its velocity and hence the destruction of the surface soil structure. The hand was steadily raised, with water level increased, to about 15 cm up the rings. The rings were then left in the soil for about 24 hours. This gave the soil and rings enough time to settle into their proper places. It also gave uniform moisture conditions at the start of the tests the following day.

The following day, the rest of the equipment was set up as shown in Diag. 2. The reservoir was filled with water to read a level of zero. Water was poured into the outer ring and then the inner ring. The maize leaves were quickly removed the reservoir tap opened and timing started from this time as t_o. Readings were taken after 1, 3, 5, 10, 20, 30, 45, 60, 90 and 120 minutes.

The rings were left in the soil after the recording was completed. The following day (after about 24 hours), samples were taken in the top 7.5 cm for the determination of bulk density, porosity and the moisture characteristic curve.

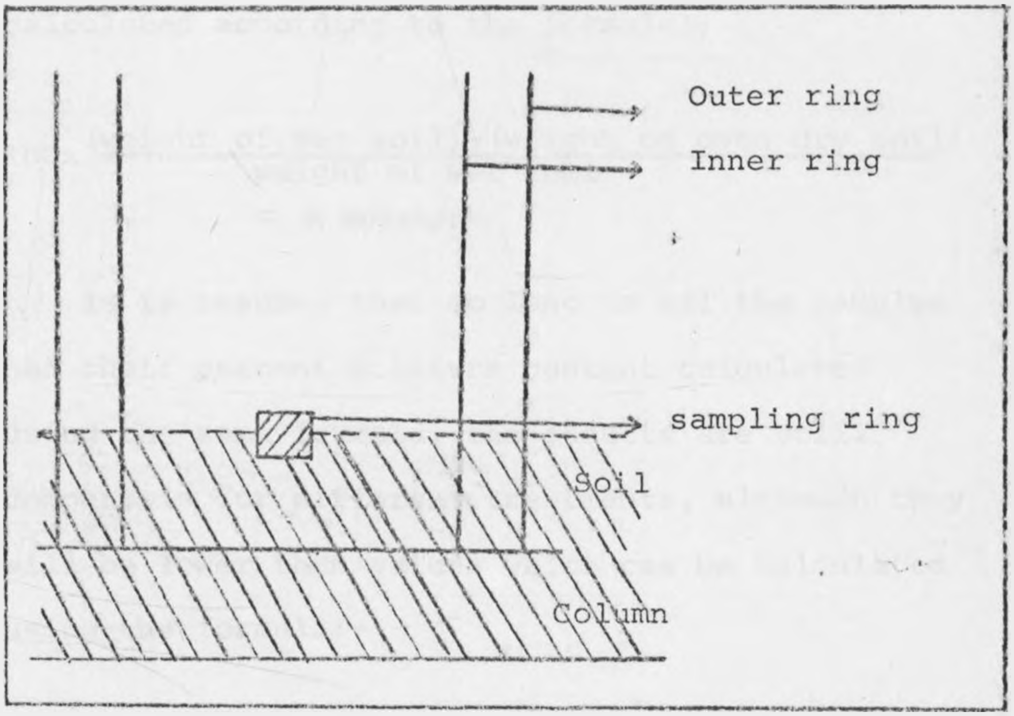
The rings were then removed from the soil, cleared and placed at new sites for further readings.

3.15 THE REFILLING OF THE RESERVOIR

When the level of water in the reservoir dropped below 9 inches, the reservoir was refilled again, to zero level. The time of refilling and the level of water before refilling were both recorded. The tap was turned off and water poured into the reservoir to zero level.

3.16 SAMPLE COLLECTION

One sample was taken from each site where rings were placed in the inner ring at a point which showed the least (or no) soil structure interference. The sampling ring was then gently and steadily pressed into the soil. The inner ring infiltrometer was then pulled out of the soil carefully so that most of the soil remained intact (See Diag. 3). The sampling ring was then removed through the bottom of the inner ring with as much soil around it as possible. The bottom of the sampling ring was carefully trimmed to attain a level surface. All the soil around the sampling ring was cleaned off and the sampling ring put in a polythene bag, labelled and strongly wrapped for packing. The wrapping aided in the soil remaining intact and also hindered the loss of soil moisture. The samples were then packed for laboratory determinations of bulk density, porosity and the moisture characteristic curve.



Diag. 3: Placement of the sampling ring in the inner ring.

3.17 THE SOIL MOISTURE CONTENT DETERMINATION

Soil samples were taken from every plot whose infiltration rate had been measured. A site was randomly chosen and a sample taken. The sample was put in a polythene bag to prevent any moisture loss.

The samples taken to the laboratory were weighed and then put in an oven to dry for 24 hours (at 105°C). From the oven, the samples were immediately re-weighed and the moisture content calculated according to the formula:-

$$100x \frac{(\text{weight of wet soil})-(\text{weight of oven dry soil})}{\text{weight of wet soil}} = \%\ \text{moisture}$$

It is assumed that so long as all the samples had their percent moisture content calculated using the same formula, the results are still comparable for different treatments, although they will be lower than values which can be calculated using the formula:-

$$\frac{(\text{weight of wet soil})-(\text{weight of oven dry soil}) \times 100}{\text{weight of oven dry soil}} = \%\ \text{moisture}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER IV

4. RESULTS AND DISCUSSION

4.0 GENERAL

An attempt was made to interpret the results of the original experiment. However, the expected results were not found in certain cases. Explanations of the differences which occurred in the results were not easy to provide. In some cases, a few probable reasons were given. In general the analysis of the data gave poor results.

Another attempt made to analyse the data of the modified experiment gave better results relative to the original experimental data. It was possible to test statistically the seasonal variation (date effect) and the method of seedbed preparation effect. From the results of the tests made, the effects of method of seedbed preparation on the soil physical properties were discussed using the infiltration rate as an index. The soil properties considered in the discussion were:-

(i) Initial soil moisture in the profile.
(ii) Surface crusting of the top soil
(iii) Bulk density of the soil
(iv) Water holding capacity of the soil
(v) Soil Fauna
(vi) Pore size, density and distribution

4.1 EFFECT OF SEASONAL VARIATIONS ON FSR OF INFILTRATION

The FSR was expected to vary with changes during the season. Early in the season, the FSR values were expected to be higher than later in the season. Diagramatic representation is given in Fig. 2.

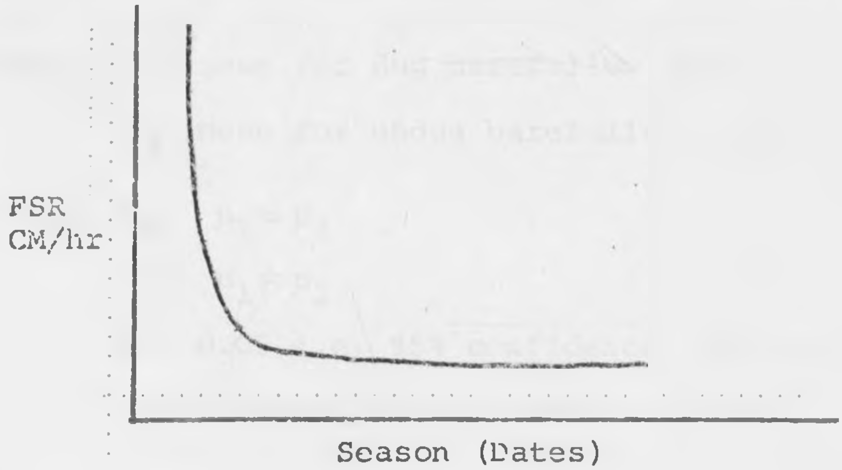


Fig. 2: Expected graphical appearance of the effect of seasonal variation on FSR from field trials.

The variation was expected due to the fact that early in the season, the soil had just been cultivated and opened up. Surface sealing had not occurred and therefore the percentage of coarse pores was still high. The FSR in the early season was therefore expected to behigher than that of later in the season. This was confirmed by the results of the undug and dug fallow plots.

4.11 TESTING FOR DIFFERENCES AMONG MEANS OF DUG AND UNDUG PLOTS

This test is performed using the Student's t-test (unpaired). The Null hypothesis (H_0) to be tested states that:- there is no difference between the two means ($\mu_1 = \mu_2$).

where: μ_1 = mean for dug barefallow plot

μ_2 = mean for undug barefallow plot.

H_0: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

$\alpha = 0.05$ i.e. 95% confidence interval.

t-distribution with (4+4-2) 6 df.

TABLE 1

	dug	undug
Infiltration rates (cm/hr)	3.7	2.0
	5.3	2.4
	4.2	1.8
	4.4	2.6
Total	17.6	8.8
n	4	4
Mean	4.4	2.2
ΣX^2	78.8	19.8
$(\Sigma X)^2$	77.4	19.4
df	3	3
Σx^2	1.4	0.4

$$\text{Pooled } S^2 = \frac{1.4 + 0.4}{3 + 3} = 0.30, \text{ df } 6$$

$$S\bar{x}_1 - \bar{x}_2 = \sqrt{\frac{2(0.3)}{4}} = 0.39 \text{ cm/hr}$$

$$t = (\bar{X}_1 - \bar{X}_2)/S\bar{x}_1 - \bar{x}_2$$

$$= 2.2/0.39$$

$$= 5.64$$

$t_{0.05}$ from table $= 2.447$

Therefore there is enough evidence to reject the Null hypothesis.

CONCLUSION

The effects of the dug and undug condition of the plots on infiltration rates is significant. This is concluded from the analysis which showed significant differences between the means of the two plots. It means that early in the season soon after the seedbed preparation, the infiltration rates are significantly higher than later in the season when the seedbed soil has set to a stable structural condition.

FIXING CONFIDENCE LIMITS

The differences $(\mu_1 - \mu_2)$ have their confidence limits fixed at:

95% confidence limits for $(\mu_1 - \mu_2)$ are given by the formula: $\bar{X}_1 - \bar{X}_2 \pm t\ 0.05\ S\bar{x}_1 - \bar{x}_2$

$$2.2 \pm (2.447)(0.39)$$

$$2.2 \pm 0.954$$

$$1.246 < \mu_1 - \mu_2 < 3.154 \text{ cm/hr.}$$

This test shows that the [illegible] have actually an effect on infiltration rates. This shows that seasonal variation is an [illegible]portant factor affecting rates of infiltration.

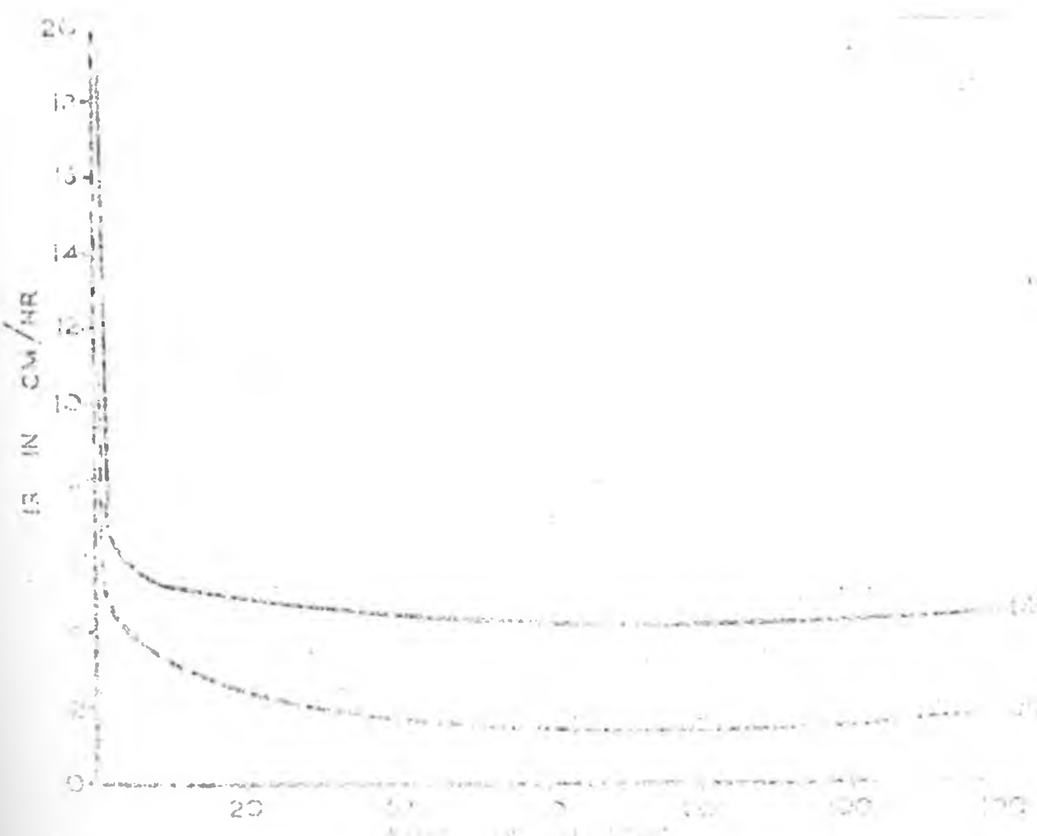


FIG. 8. INFILTRATION RATE [illegible]

4.12 TESTING FOR THE SEEDBED PREPARATION

This is statistically worked out using the Null hypothesis to determine whether the infiltration rates of different plots varied with treatments and dates on which readings were taken. Each treatment had three replicates:-

Ho: $\mu = 0$ (Null hypothesis)

H_1: $\mu \neq 0$ (Alternative hypothesis)

α = 0.05 i.e. the test is carried out at 5% level of significance.

TABLE 2

Anova Table

Source	df	SS	MSS	F
BF vs. Rest	1	5.58	5.58	2.02^{ns}
Min. vs. Conv.	5	63.85	12.77	4.64*
Within FS - J vs H	1	0.49	0.49	0.18^{ns}
Within GS - J vs H	1	10.89	10.89	3.96^{ns}
Within Min. - M vs H	1	11.90	11.90	4.33*
CS vs FS	3	96.04	32.01	11.64*
Treat. differences	6	1.82	0.30	0.11^{ns}
Date	8	38.80	4.85	1.76^{ns}
Error	36	99.16	2.75	
Total	62			

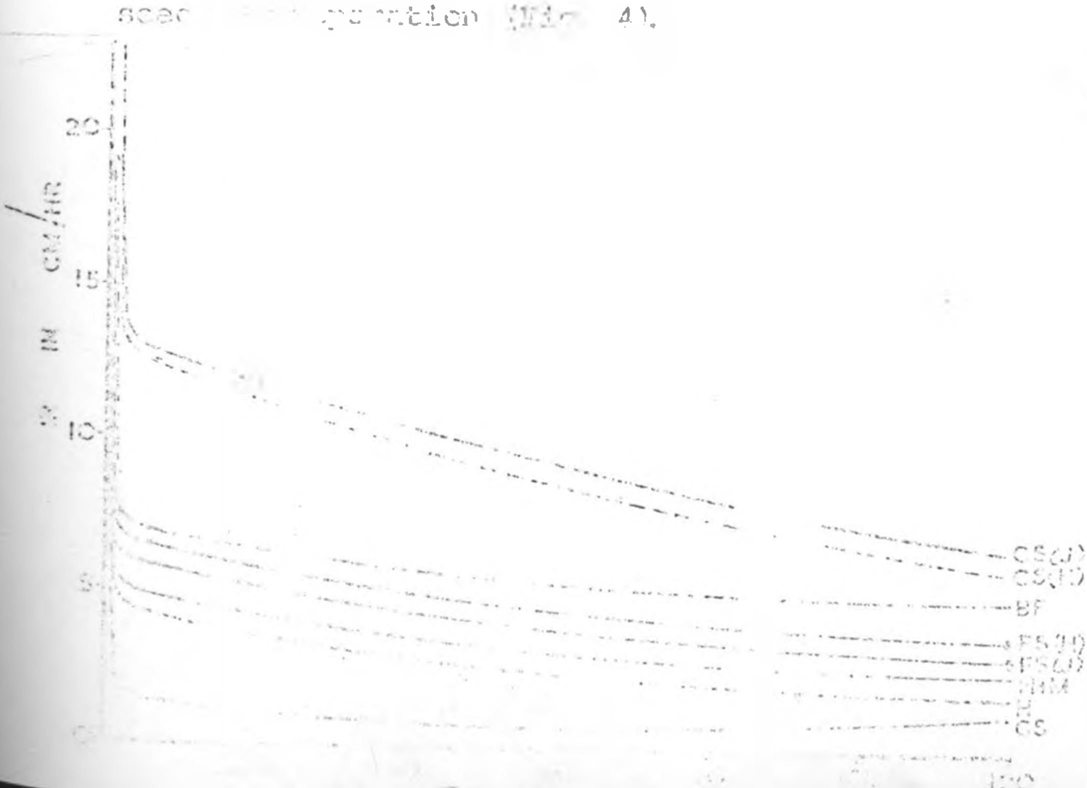
TABLE 3: AVERAGE INFILTRATION RATES

TIME/TREAT. (MIN)	FS(J)	CS(J)	H + M	H	BF	FS(H)	CS(H)	GS
1	12.9	17.9	9.6	6.9	17.5	18.7	22.7	5.0
3	6.0	12.9	5.1	4.7	7.9	6.8	12.3	1.7
5	6.7	12.7	5.5	4.1	9.4	7.5	14.0	1.6
10	5.2	9.8	3.4	2.4	7.2	5.0	9.3	1.1
20	4.7	8.5	3.5	3.1	7.5	4.0	8.1	0.9
30	4.6	7.4	3.1	2.8	7.3	3.8	7.3	1.0
45	4.0	7.5	3.4	3.4	6.1	3.8	7.8	0.5
60	4.7	7.3	3.7	2.4	6.7	3.6	5.9	0.9
90	3.6	6.4	3.3	2.5	5.6	3.3	5.0	1.4
120	3.2	6.3	2.9	2.2	5.1	3.6	5.5	1.3
AVE. FSR	3.6	5.9	3.1	2.3	4.7	3.4	5.3	1.4

CONCLUSION

Almost half the comparisons show significantly different effects on the infiltration rates. There is a highly significant difference between the FS vs C[illegible] and Minimum vs Conventional methods of seedbed [illegible]. This implies that the choice as to [illegible] the farmer is going to use FS or CS is [illegible] and also minimum or conventional methods. [illegible] weeds by jembe or herbicide in a coarse seed[illegible] herbicide and mulch weed control are not [illegible] decisions as these do not show high sig[illegible] differences.

[illegible] for all the eight treatments also sup[illegible] the statistical analysis. There were app[illegible] differences between different methods of see[illegible]paration (Fig. 4).



4.13 EFFECT OF CRUSTED SOIL SURFACE ON INFILTRATION RATES

A crust on the soil surface can develop as a result of the raindrop impact. The beating action of the raindrop detaches the top soil which is transported away from its original position or simply deposited a little distance off by the runoff. The sand is deposited first and the clay particles in suspension may be deposited in sand pores and in pores at places from which the soil has been detached. This soil on drying forms a seal or crust.

The main characteristics of crusted top soil are that the soil has a higher bulk density, finer pores and a lower saturated conductivity than the soil below it. Due to these characteristics, the surface crust influences the infiltration processes of the soil, even though this might be a few millimeters thick.

The crusted top soil has shown an influence on the experimental plots' infiltration rates (Fig. 4). The crust thickness was measured simply by cutting a small triangle, two centimeters deep through the top soil, using a sharp knife. The triangular soil core was then lifted up using the knife and the crust observed. The crust was found to be about one centimeter thick. In some places, it was highly developed, for example on the herbicide without mulch plots. The crust was clearly laminated on these herbicide plots.

Experimental work in the literature has shown the effect of the crust on infiltration rates to be great. This can be graphically presented as in Fig. 5.

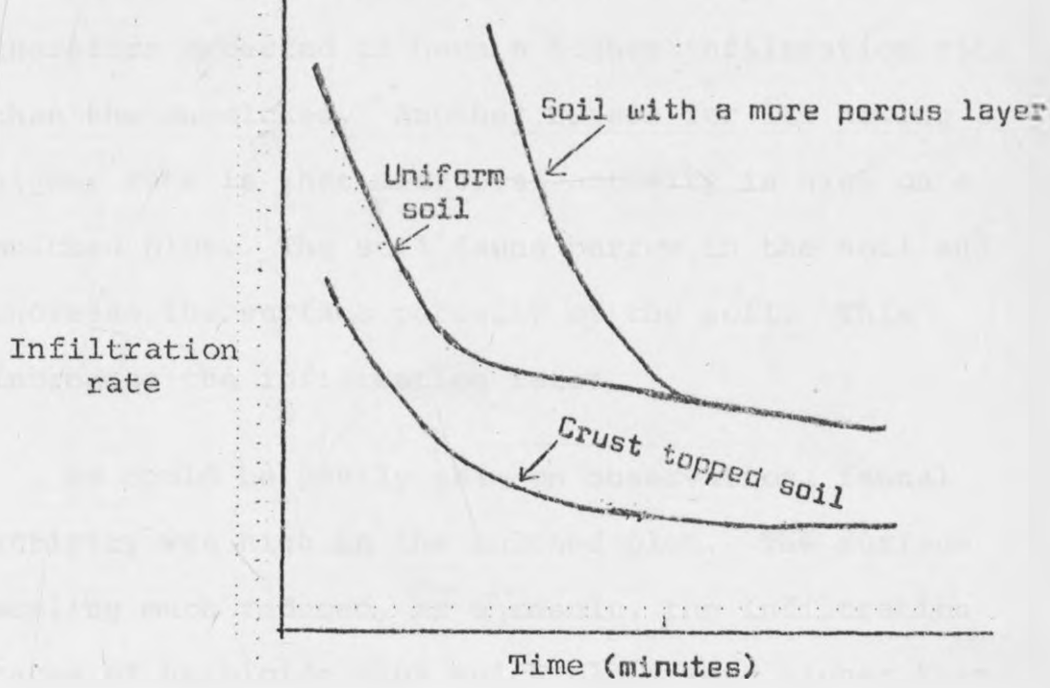


Fig. 5: Infiltration rates of three different soils.
Source: Hillel, D. Soil and Water, Pg. 144.

In this study at Kitale, the experimental plots showed similar trends of infiltration rates. The crusted soils of the fine seedbeds and herbicides had lower FSR than the uncrusted soils of coarse seedbeds.

4.14 EFFECT OF MULCH ON INFILTRATION RATES

Mulch acts as an organic obstacle to the runoff. This increases the time within which water has to move down the soil profile. A mulched plot is therefore expected to have a higher infiltration rate than the unmulched. Another reason for its having a higher rate is that microbial activity is high on a mulched plot. The soil fauna burrow in the soil and increase the surface porosity of the soil. This increases the infiltration rates.

As could be easily seen on observation, faunal activity was high in the mulched plot. The surface sealing much reduced, as a result, the infiltration rates of herbicide plus mulch plots were higher than those of herbicide without mulch (see Fig. 4). This was seen in the graphical representation and the statistical analysis showed that there was significant difference between the two treatments.

4.15 INFILTRATION RATES OF TREATMENTS OF THE MODIFIED EXPERIMENTS

Treatments with coarse seedbed preparation had the highest infiltration rates, especially the FSR. This could be attributed to non-crusting nature of the plots. Even at the end of the season, these plots still had their clods visible and there was complete lack of crusted soil surfaces. The bulk density in the coarse seedbed jembe plots was also lower than other plots i.e. 1.12, (see Table 4).

TABLE 4: BULK DENSITIES OF THE SOIL

Sample No.	CS(J)	FS(J)	CS(H)	FS(H)	BF
1	-	1.24	1.14	1.31	1.11
2	1.02	1.34	1.14	1.23	1.20
333	1.01	1.23	1.24	1.24	1.12
4	1.12	1.14	1.30	1.23	-
5	1.20	1.23	1.31	1.34	-
6	1.14	1.22	1.21	-	-
7	1.20	-	-	-	-
Average	1.12	1.23	1.22	1.27	1.14

This indicated less compaction and a high coarse pore percentage. The infiltration rates were therefore high in these plots.

The barefallow plot crusted due to lack of crop cover. However, the crusting was less severe than other crusted plots. The surface sealing increased the bulk densities of some plots (see table 4) thus reducing their surface porosity. This reduced the infiltration rates of the plots since the quantity of water that enters the soil profile depends on the porosity of the soil surface. It is known from literature that a thin layer of non-porous soil at the surface can reduce the infiltration considerably. The crusted surfaces could have resulted in ponding and as there was no turbulence in the inner ring water, the fine clay particles settled and packed themselves in any open pores. This reduced the porosity even further and consequently the infiltration process.

The grass sward treatment (control) proved of no value. In certain instances the infiltration rate was 0.0 cm/hr., indicating complete stand still of flow of water. This could be due to the high initial moisture content of the plot.

The bulk density as has been shown by previous work on the Kitale Station, has been very high for plots under the grass sward. This can be as high as 1.5. It therefore follows that the percent porosity of soils under grass is greatly reduced. This could also be one of the reasons why the infiltration rates of the grass sward plot was so low.

The fine seedbed treatments had somewhat medium rates because they were opened up. Their bulk densities were reduced to 1.23 (see table 4). Their infiltration rates, as expected, were lower than those of the coarse seedbed ones, the reason being that, the seedbed preparation in the fine seedbeds consisted of beating up the clods by jembe to a very fine seedbed. Since the soil is sandy, any slight runoff redeposited the sand after a particle sorting process. The clay particles in the runoff suspension were then deposited in the sand pores. The next drying period formed a surface seal which reduced their infiltration rates.

Statistical analyses were carried out to see if there was any real significant differences between the FSR means of the eight treatments when treated as contrasts. There were significant differences between:- the fine seed beds and the coarse seedbeds, the minimum tillage and conventional; and the herbicide versus mulch. The rest of the contrasts show no significant differences (see Sect. 4.12). It was then concluded that the method of seedbed preparation had significant effects on the infiltration rates of the soil.

4.16 TESTING FOR THE TREATMENT AND BLOCK EFFECTS IN THE FOUR PLOTS

The four treatments considered are:-

(a) Coarse seedbed (Jembe) CS(J)

(b) Coarse seedbed (herbicide) CS(H)

(c) Fine seedbed (Jembe) FS(J)

(d) Fine seedbed (Herbicide) FS(H).

These treatments are tested to determine the effects of the three blocks on infiltration rates. The methods of seedbed preparation are also tested for

TABLE 5 FSR OF TREATMENTS IN DIFFERENT EXPERIMENTAL BLOCKS

BLOCKS	TREATMENTS COARSE SEED-BED (JEMBE)	FINE SEED-BED (JEMBE)	COARSE SEED-BED (HERBICIDE)	FINE SEED-BED (HERBICIDE)	TOTAL
I	5.9	1.8	2.6	1.2	11.50
II	4.6	1.1	2.2	1.1	9.0
III	4.8	1.8	2.0	1.7	10.30
MEANS	5.1	1.6	2.3	1.3	3.4
TOTAL	15.3	4.7	6.8	4.0	30.80

their effects.

Null hypothesis is used for testing the means (μ) of treatments and blocks

H_0: $\mu = 0$

H_1: $\mu \neq 0$

X: 0.05 i.e. 95% confidence interval is set for the test.

(See Table 5 for results used in calculations).

<u>CALCULATIONS</u>

Correction factor $= \dfrac{(30.80)^2}{12}$

$= 79.05$

Total sum of squares

$= (5.9^2 + 1.8^2 + \ldots + 6.8^2 + 4^2) - 79.05$

$= 28.79$

Treatment sum of squares

$= \underline{15.3^2 + 4.7^2 + 6.8^2 + 4.0^2} - 79.05$

$= 27.09$

Block sum of squares

$= \underline{11.5^2 + 9^2 + 10.3^2} - 79.05$

$= 0.79$

Error sum of square $= (28.79) - (27.09 + 0.79)$

$= 0.91$

TABLE 6: ANOVA TABLE

Source	df	SS	MSS	F
Treatment	3	27.09	9.03	60.2*
Block	2	0.79	0.40	2.67^{ns}
Error	6	0.91	0.15	
Total	11	28.79		

F from tables = 3.59

Conclusion

The blocks: There were no block effects shown significantly. Therefore any differences in infiltration rates were not mainly due to the blocks.

The Treatments: There were significant effects of different methods of seedbed preparations on the infiltration rates. The very high value of significance shows that differences in infiltration rates were mainly due to the different methods of seedbed preparations.

4.17 TO TEST THE DIFFERENCES IN THE EFFECTS OF METHOD OF SEEDBED PREPARATION

Orthogonal Comparisons

	FS(J)	FS(H)	CS(J)	CS(H)
FS vs CS	+1	+1	-1	-1
H vs J	+1	-1	+1	-1
Interaction	+1	-1	-1	+1
Totals	4.7	4.0	15.3	6.8

Sums of Squares:

(a) FS vs CS SS

$$= \frac{(4.7 + 4) - (15.3 + 6.8)^2}{4(1^2 + 1^2 + 1^2 + 1^2)}$$

11.

$= 11.22$

(b) H vs J SS

$$= \frac{(4.7 - 4 + 15.3 - 6.8)^2}{4(1^2 + 1^2 + 1^2 + 1^2}$$

$= 5.29$

(c) Interaction SS

$$= \frac{(4.7 - 4 - 15.3 + 6.8)^2}{4(1^2 + 1^2 + 1^2 + 1^2)}$$

$= 3.80$

(d) To test for differences within the treatments:

TS = Treatment SS - SS(a + b + c)

$= 27.09 - 20.31$

$= 6.78$

TABLE 7: ANOVA TABLE

Source	df	SS	MSS	F
FS vs Cs	3	11.22	3.74	24.9*
H vs J	3	5.29	1.76	11.73*
Interaction	3	3.80	1.27	8.47*
Treat. differences	3	6.78	2.26	15.07*
Block	2	0.79	0.40	2.67^{ns}
Error	6	0.91	0.15	
Totals	20			

F value from table = 4.76

Conclusion

There is enough evidence to show that all the four treatments have significantly differen. effects on the plots. Therefore to the farmer, the choi.e of which seedbed to use, among the four comparisons, is important as they will affect the infiltration rates of his field. More weight has to be put on the choice between the FS and CS as these appear to affect the infiltration rates more than other methods compared.

Figure 6 also shows graphically a clear difference between the coarse seedbed preparation and the fine seedbed preparation plots. These graphs and statistical results give evidence to support the conclusion that the top 15cm of the soil affect the infiltration rates (FSR) of the different treatments. The lower part of the profile may have little or no part to play, since this is the same in the experimental plots.

CS(J) = Coarse Seedbed (Jembe)

CS(H) = Coarse Seedbed (Herbicide)

FS(J) = Fine Seedbed (Jembe)

FS(H) = Fine Seedbed (Herbicide)

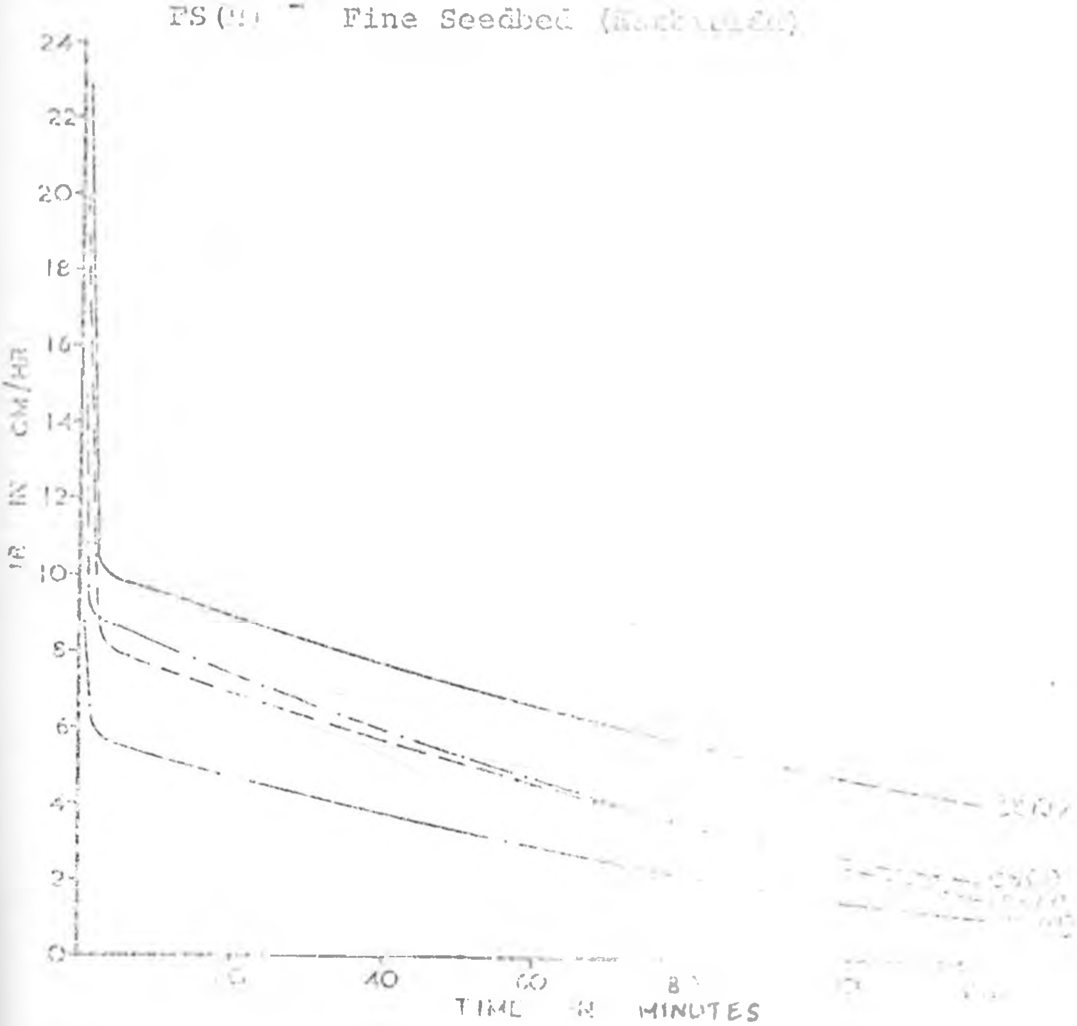


FIG. INFILTRATION RATES IN COARSE AND FINE SEED-BED PLOTS

The uncrusted top soil has somewhat higher infiltration rates than the crusted top soil. Since the crust formation has been the main reason for variations in infiltration rates, the results therefore appear reasonable.

Results all along have shown that the coarse seedbed jembe has the higher rate of infiltration. Before any conclusion is made, that the coarse seedbed jembe is the most suited seedbed preparation method in a dry area like Katumani, two main questions discussed in the next Section have to be answered. These questions are:-

i) Is coarse seedbed preparation suited for germination?

ii) Is it also acceptable to the farmer or does he prefer any other method?

4.2 EFFECT OF SEEDBED PREPARATION ON MOISTURE HOLDING CAPACITY OF THE SOIL

Soil samples taken from five different treatments show that the method of seedbed preparation may have some effects on moisture holding capacity. The moisture characteristics curves (Fig. 7) show that the coarse seedbed (Jembe) absorbs slightly more water than other treatments.Table 8 also shows that coarse seedbed jembe has slightly higher available moisture (9.09%) than others. The differences between other plots does not appear great. The reason for the slightly high values of the coarse seedbed (Jembe) could be probably due to the non-crusting soil surface. The surface had undisturbed coarse pores which allowed more water infiltration than in treatments with crusted soil surfaces. The other treatments had crusted soil surfaces which resulted to surface sealing and a compacted thin layer resulted at the top. The surfaces did not allow in much water and as a result the soil had less available moisture percentages (8.1 to 7.78) than the coarse-seedbed Jembe. The surface soil compaction is also reflected in the bulk densities of the soil (Table 4).

Since the moisture holding capacity of the soil is directly related to the available water capacity, the effect of seedbed preparation is of agricultural

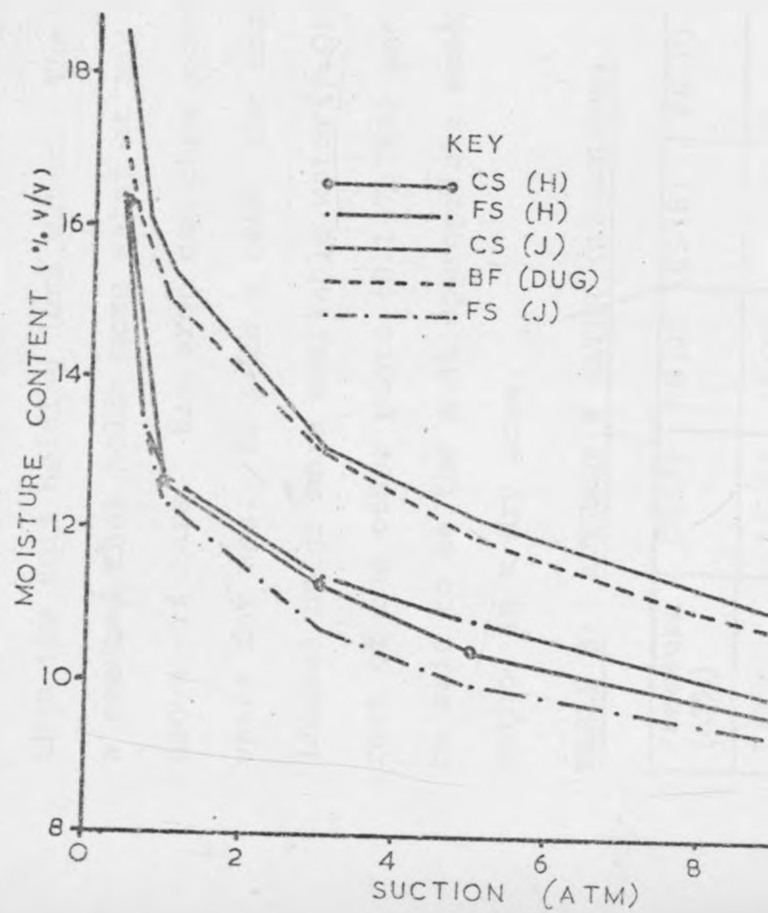
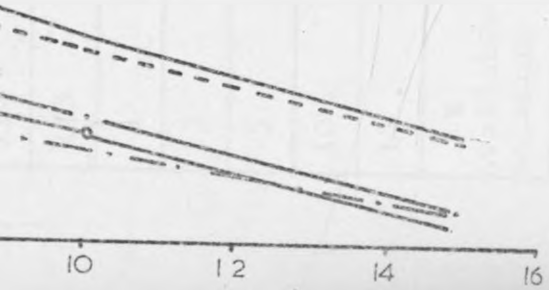


FIG. 7 MOISTURE CHARACTERISTIC CURVES


10
12
14
16

significance. The soil which holds more water in coarse pores also avails more water to the plants than the soil holding less water. The farmer needs a seedbed that holds more water at any given tension above -15 bars. His crop can then extract more water for use. In such a case, the coarse-seedbed (Jembe) holds more available water (9.09%) than the rest of the other plots (8.1-7.78%) and hence can be said to be the most appropriate seedbed preparation method in a dry area.

TABLE 8: AVERAGE % WATER (BY VOLUME)

Pressure (ATM)	CS(J)	FS(J)	CS(H)	FS(H)	BF
1/3	18.50	16.42	16.37	16.24	17.18
2/3	16.06	13.45	14.19	13.63	15.86
1	15.36	12.35	12.38	12.62	15.03
3	13.05	10.76	11.43	11.43	13.07
5	12.26	10.03	10.49	10.85	11.95
10	10.70	9.20	9.50	9.65	10.50
15	9.41	8.43	8.27	8.46	9.39
% Available Moisture	9.09	7.99	8.1	7.78	7.79

CS(J) - Coarse seedbed (Jembe)
FS(J) - Fine seedbed (Jembe)
CS(H) - Coarse seedbed (Herbicide)
BF - Barefallow.

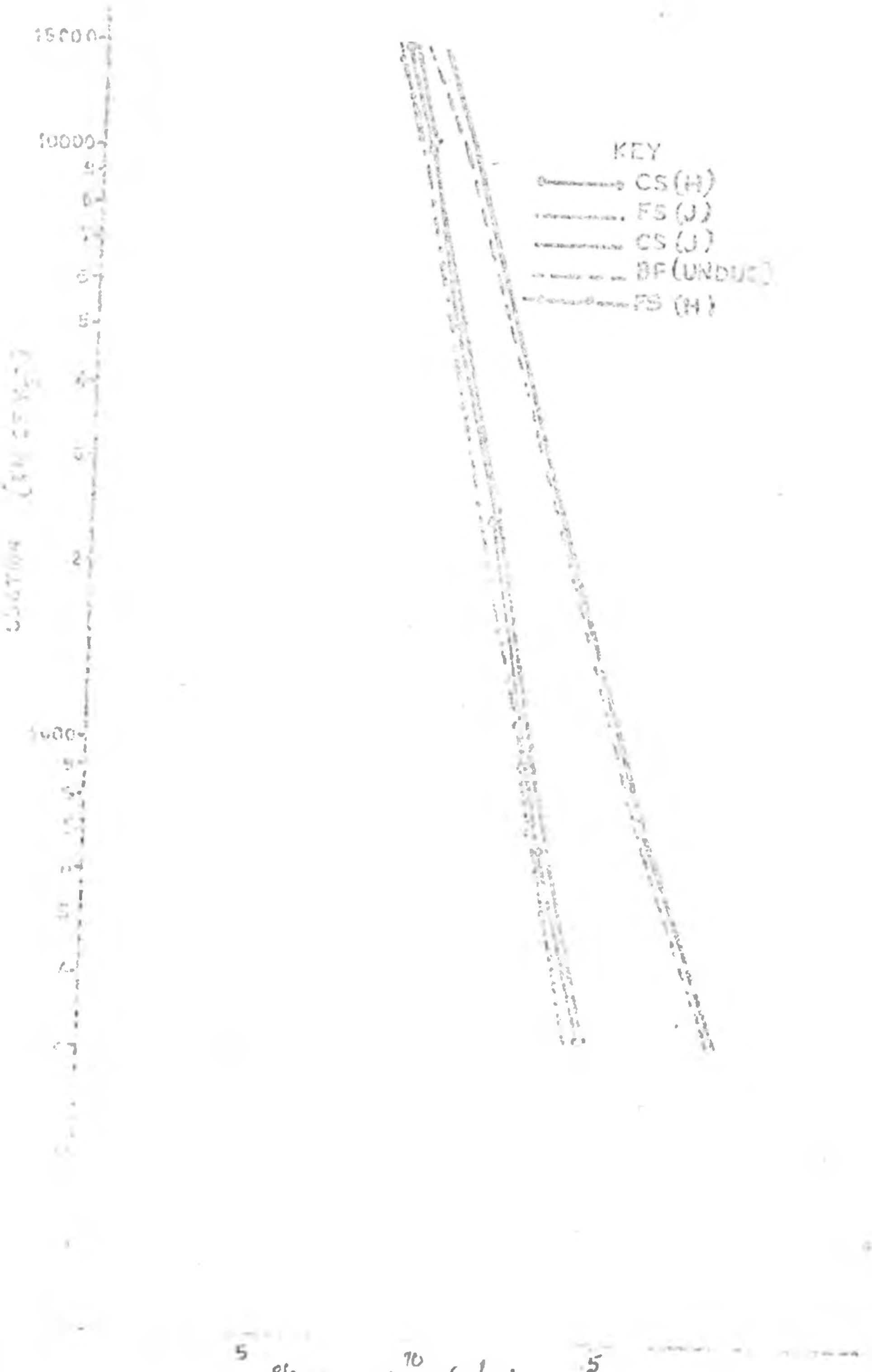


FIG. 8 PF CURVES FOR FIVE SEED-BED P[illegible]

4.3 THE EFFECT OF SEEDBED PREPARATION ON PORE SIZE DISTRIBUTION

The differential soil moisture characteristic curves (Fig. 9) shows the pore size distribution of the plots. Most pores are emptied by a tension -1 atmosphere, and a few others by a tension of atmosphere. Using the formula:-

$$R_{(cm)} = \frac{2T}{\rho g h}$$

where R = radius of pore (cm)

ρ = density

g = gravity

h = suction (cm)

Various pore sizes were calculated. The results showed that at a tension of below 2/3 atm. pore radius of 2.16 μ are emptied. The pore size distribution shown in Fig. 9 shows that in all the plots, pore sizes of above 2.16μ radius are most abundant. These are followed by pore sizes of radius of 2.16 - 0.36 μ. Although these pores are few, they are infact more than the very fine pores emptied by a tension of 4-15 atm which gives pores sizes of .36 μ.

Following the pattern, the seedbed preparation method does not seem to have any marked effects on the pore size distribution. Probably work with tension as small as 0.01 atm. could show some marked

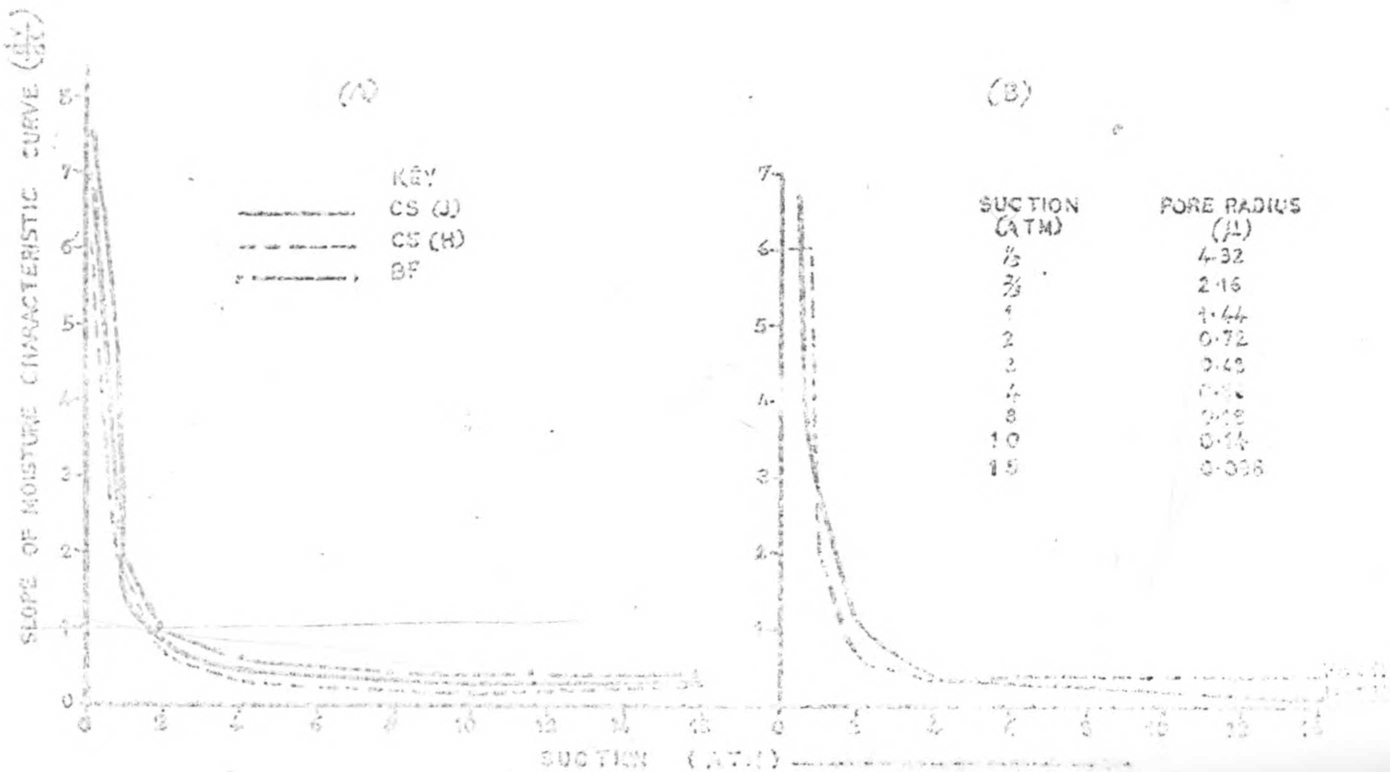


FIG. 9 DIFFERENTIAL CURVES

differences as this could give many values for pore size distribution of coarse pores. Apparently, in all the soils, the pores of a size greater than 2.16 μ are the most abundant.

However, the moisture holding capacity of the soil gives more reliable results than the pore size distribution. This is because, it can be speculated that within the coarse pores above 2.16 μ, there are groups of pore sizes distributed at different radii. The number of the pore sizes is also greater in the CS(J) than in the rest of the plots. This is shown by the highest slope value at 1/3 atm. of the CS(J). The groups of pore sizes as was observed by Childs (1940) can also be seen in pore sizes as between 2.16 μ and 0.36 μ. The graph shows that there is a higher concentration of these pores in CS(J) than in the rest of the plots. FS(J) curve shows that of these pores sizes (0.36 - 2.16 μ), most of them are of size 2.16 - 0.72 μ. Unfortunately these groups cannot be seen in the coarse pore because the water was extracted at a tension which was already too high to show the patterns. For the farmers purposes, the CS(J) still shows favourable pore size distribution because the pores which can be emptied at a tension 4 atm. are visibly more, and even up to 15 atm., they are more than in other plots, other than the bare fallow plot. This indicates that at any one tension exerted by the plant, more water will be drawn out of the CS(J) than in the rest of the plots because there are more pores holding water at the tension in question.

4.4 EFFECT OF SEEDBED PREPARATION ON SEED GERMINATION

Germination in most plots was generally poor. The maize seed had to be replanted in several gaps. However, the fine seedbed prepared plots showed a better germination results than the coarse seedbed ones. The reasons could be that, in a fine seedbed the seed is in a much closer contact with the soil than in the coarse seedbed. The moisture supply is therefore much more efficient for germination in fine seedbeds than in coarse ones. It is also true that in a coarse seedbed, the tilth is much more open and the flow of air is much greater and hence the temperature much lower than in fine seedbeds. These low temperatures may reduce the germination percentages of the maize seed. The coarse seedbed may also tend to loose moisture from the surface soil through evaporation much faster than in fine seedbed. As seedlings are placed in the top soil (about 6cm deep), evaporation of soil water might reduce the available moisture to the seeds and seedlings. Germination in such plots is therefore poor.

4.5 CRITICISMS OF THE MOISTURE ANALYSIS METHOD

The results of moisture analysis do not appear greatly different between treatments. This may be probably due to errors created by the equipment used in moisture analysis. The tensions which could be measured were only as low as 1/3 atmosphere. The available ceramic plate was porous enough to allow only 1/3 atmosphere tension measurement. If any more porous ceramic plate than that of 1/3 atmosphere were available, then probably the differences between treatments could be shown at these low tensions. At higher tensions, the porous paper used dried after three to four days before the soil samples in the pressure pot stabilised. The drying resulted to some papers cracking and hence affecting the values measured for moisture at the high tension.

Another error could have arisen from the use of 'ceramic rings'. The 'ceramic rings' were placed at the bottom of the metal sampling ring to keep the soil, in the rings, in place. The porosity of the 'ceramic rings' was so fine that it could have affected the more porous ceramic plates at low tensions. The 'ceramic rings' also contained different quantities of water at different tensions. Since there was not any correction factor for these 'ceramic rings', there could have been an experimental error created in the analysis. This procedure has been refined by Santababra, California's latest soil moisture procedures.

4.6 PROBLEMS TO BE SOLVED

The problems which remain to be solved are that:-

(i) Are farmers in the dry areas willing to accept the coarse seedbed (Jembe) method as the most suited to their soil conditions?

(ii) Is the extra rain entering the soil all that important in relation to the Kitale rainfall and other areas of high rainfall?

The answer to the first question needs more information in addition to what this study provided. There should be a multi-disciplinary study covering the agronomy, sociology, the economics and farm management of the area. Information from these fields of study will provide a possible answer to the question.

The second question could possibly have an answer. According to the water needs of maize plant in relation to the rainfall patterns at Kitale, the maize plants experience water-shortage for about one and half months in three years out of four. Thus the probability of maize experiencing water shortage, from mid May to end of June, is 0.75 (Fig. 10)

CHAPTER FIVE

CONCLUSION AND SUMMARY

CHAPTER V

CONCLUSION

From the results of the preceeding chapters on results and discussion, several conclusions can be reached. Some soil physical characteristics were seen to be affected by the method of seedbed preparation. Seasonal variations were also demonstrated by two treatments (the undug and dug barefallow plots). The conclusions drawn from the results of the experiment are given in the succeeding paragraphs:-

(i) That the method of seedbed preparation has an effect on the pore size, distribution and density which are the main determinant factors of infiltration rates. The coarse seedbed (Jembe) gave the highest FSR and also the higher density of coarse pores.. For this reason, coarse seedbed preparation method had an advantage over the fine seedbed preparation method.

(ii) That the method of seedbed preparation has an effect on the moisture holding capacity of the soil. The coarse seedbed (Jembe), by implication gave the highest capacity for moisture holding. This means that the coarse seedbed preparation method is most favourable to farmers especially in the dry areas because the soil will tend to hold more moisture in the seedbed than other methods of seedbed preparation.

(iii) That the method of seedbed preparation affects the soil bulk density. Again the coarse seedbed (Jembe) method gave the lowest value for bulk density. This was also true with barefallow. It means that the soil under coarse seedbed (Jembe) and barefallow (BD = 1.1) is less compacted than in other plots with other methods of seedbed preparation. The soil is therefore better aerated and hence more suitable for plant rootgrowth than that of other plots.

(iv) That the method of seedbed preparation has an effect on the surface crusting and sealing of the soil. Most other methods had crusted soil surfaces other than coarse seedbed (Jembe) and coarse seedbed (Herbicide). Barefallow was also less crusted than the fine seedbed preparation method. Since the non-sealed and non-crusted soil surfaces allow more water into the soil and reduced runoff, the coarse-seedbed methods have an advantage over the Fine seedbed methods. For a dry area, coarse seedbed methods are best suited to the conditions.

(v) That the method of seedbed preparation has an effect on the seed germination. The fine seedbed methods had a better germination performance than the coarse seedbed. Reasons for this occurance have been suggested in the preceeding chapter. For this reason, the Fine seedbed methods are more favourable to the farmer than the coarse seedbed. This is because the date of planting has been found to be an important factor in maize yields in Kenya. The poor germination percentage caused by the coarse seedbed necessitates a replanting period. The replanting comes later in the planting period and so the date of planting is late which results to sub-optimal maize yields.

Although it is difficult to grade the method of seedbed preparations, i.e. CS(J), CS(H), FS(J) and FS(H), it is clear that the CS(J) is superior, on balance, to the other methods.

SUMMARY

A study was conducted at National Agricultural Research Station, Kitale to study the effects of different methods of seedbed preparation and the effect of seasonal variation on the physical properties of soil. It was felt that the results obtained, while being useful in the Kitale area, might also be particularly relevant to drier areas of Kenya (such as Katumani).

The main divisions of the methods of seedbed preparation were:-

a) fine seedbed
b) coarse seedbed.

The divisions for weed control method were also two:-

a) control by 'jembe'
b) control by herbicide

Combinations of these four variables were studied in relation to the soil physical properties by measuring the infiltration rates of the seedbeds and thereafter relating the rates to surface crusting and sealing, surface runoff, pore size, density an distribution, moisture holding capacity and bulk density.

The conclusion drawn was that the coarse seedbed (jembe) was the most suited method of seedbed preparation in the dry areas. Reasons for this

conclusion were that the coarse seedbed jembe had the following:-

i) higher steady rate due to more coarse pores than in other plots.

ii) higher moisture holding capacity than other plots.

iii) lower soil bulk density than other plots.

iv) non-crusted soil surface.

However, the coarse seedbed (jembe) had a disadvantage of having a low germination percentage. The conclusion drawn was mainly for drier areas than Kitale because it was thought that the extra rain entering the soil was not all that important in relation to Kitale rainfall and other areas of high rainfall. The question which remained unanswered was the willingness of the farmer in the dry areas to adopt the coarse seedbed preparation method as the most suited one to his environment.

REFERENCES

1. Archer, J.R. and Smith, P.D. (1972) The relationship between bulk density, available water capacity and air capacity of soil.

   J. Soil Sci.,23:475-480.

2. Auten, J.T. (1933) Porosity and water adsorption of forest soils. J. Agric. Res., 46:997-1014.

3. Auten, J.T. (1934) The effects of forest burning and pasturing, in the Ozarks, on the water adsorption of forest soils.

   C.S. Forest Expt. Sta., Sta. Note No. 16.

4. Ayers, H.D. and Wikramanayake, V.E.A. (1958) The effect of water storage capacity of the soils on mass infiltration.

   Cand. J. Soil Sci., 38:44-48.

5. Baver, L.D., Gardner, W.H. and Gardner, W.R. (1972) Soil Physics. 4th Ed. John Wiley and Sons., London. Chap. 10.

6. Bertoni, J., Larson, W.E. and Shrader, W.D. (1958) Determination of infiltration rates on Marshow silt loam from runoff and rainfall records.

   Soil Sci. Soc. Amer. Proc., 22:571-574.

7. Beutner, E.L., Gaebe, R.E. and Horton, R.E. (1940) Sprinkled plot runoff and infiltration experiments on Arizona desert soils.

   Trans. Am. Geophys. Union., 21:550-558.

8. Blake, G.R. and Aldrich, R.J. (1955) Effects of cultivation on some soil physical properties and on potato and corn yields.

   Soil Sci. Soc. Amer. Proc., 19:400-403.

9. Bouwer, H. (1960) A study of final infiltration rates from cylinder infiltrometers and irrigation furrow with an electrical resistance network.

   Trans. 7th Int. Congr. Soil, 1:448-456.

10. Brady, N.C. (1972) The Nature and Properties of Soils. 8th Ed. MacMillan Publishing Co., Inc. New York. p. 50-56.

11. Brown, L.H. and Cocheme, J. (1969) A study of the Agro-climatology of the Highlands of Eastern Africa. FAO, Rome.

12. Cannell, G.H. and Stolzy, L.H. (1962) Hydraulic gradients associated with infiltration in the field studies.

    Soil Sci. Amer. Proc., 26: 112-115.

13. Childs, E.C. (1940) The use of soil moisture characteristics in soil studies. Soil Sci. 50:239-252.

14. Childs, E.C. (1967) Soil Water Phenomena. John Wiley and Sons. Ltd., London. Chap. 12 and 13.

15. Cooper, P.J.M. and Law, R. (1974) An experiment to investigate the effects of soil temperature on the initial growth stages and final yields of maize.

E. Afr. Agr. For. J., 41:189-200.

16. Diseker, E.G. and Yoder, R.E. (1936) Sheet erosion studies on Cecil Clay. Albama Agric. Expt. Sta., Bull. No. 245.

17. Duley, F.L. (1939) Surface factors affecting the rate of intake of water by soils.

Soil Sci. Soc. Amer. Proc., 4:60-64.

18. Duley, F.L. and Russell, J.C. (1939) The use of crop residues for soil and moisture conservation.

J. Am. Soc. Agron., 31:703-709.

19. Dunin, F.X. (1969) The infiltration component of a pastoral experiment catchment. Part I. Hydrographic analysis of the determination of infiltration characteristics.

J. Hydrology, 7:121-146.

20. Edward, W.M. (1967) Infiltration of water into soils as influenced by surface condition.
Thesis of Iowa State University.

21. Fletcher, J.E. (1940) A dielectric method for determining soil moisture.

Soil Sci. Soc. Amer. Proc., 4:84088.

22. Goulden, C.H. (1952) Methods of Statistical Analysis. 2nd Ed. John Wiley. London.

23. Hillel, D. (1973) Soil and Water. 3rd Ed. Academic Press, London, Chap. 4 and 6.

24. Hillel, D.and Gardner, W.R. (1969) Steady infiltration rates into crust-topped profiles.

Soil Sci., 108:137-142 (Quoted from Soils and Fert. Vol. 33:28 (Abst. No. 248).

25. Horner, M.W. and Llyod, L.C. (1940) Infiltration capacity values as determined from the study of an 18 month records at Edwardsville, Illinois.
Trans. Am. Geophys Union, 21:522-541.

26. Horton, R.E. (1933) The role of infiltration in the hydrological cycle.

Trans. Am. Geophys. Union., 14:446-460.

27. Horton, R.E. (1940) An approach towards a physical interpretation of infiltration capacity.

Soil Sci., Soc. Amer. Proc., 5:399-417.

28. Hristov. I.D., Nielsen, D.R., Kirda, C. and Bigger, J.W. (1975) Theoretical and experimental analysis of infiltration into soil columns.

Trans. 10th Int. Congr. Soil Sci. 96:102 (Quoted from Soils and Fert. (Abst. No. 1379).

29. Kohnke, H. (1938) A method for studying infiltration. Soil Sci. Soc. Amer. Proc., 3:296-303.

30. Lewis, M.R. (1937) The rate of infiltration of water in irrigation practice.

Trans. Am. Geophys Union., 18:361-368.

31. Lewis, M.R. and Powers, W.L. (1938) A study of factors affecting infiltration.

Soil Sci. Soc. Amer. Proc., 3:334-339.

32. Linden, D.R. and Dixon, R.M. (1973) Infiltration and water table effects of soil air pressure under border irrigation.

Soil Sci. Soc. Amer. Proc., 37:940-98.

33. Marshall, T.J. (1958) A relation between permeability and size distribution of pores.

J. Soil Sci., 9:1-8.

34. McGeorge, W.T. (1941) Influence of Colorado River silt on some properties of Yumamesa sandy soils. Ariz. Agric. Expt. Sta., Tech. Bull. No. 91.

35. Meerwig, R.O. (1970) Infiltration and soil erosion as influenced by vegetation and soil in Northern Utah.

J. Range Manag. 23:185-188.

36. Michieka, D. and Oswago, O. (1971) Soils of National Agricultural Research Station, Kitale.

Soil Survey Unit., N.A.L., Nairobi, Kenya.

37. Miller, D.E. and Aarstad, J.S. (1971) Furrow infiltration rates as affected by incorporation of straw or furrow cultivation.

Soil Sci. Soc. Amer. Proc., 35:492-495.

38. Miller, D.E. and Gardner, W.H. (1962) Water infiltration in stratified soil.

Soil Sci. Soc. Amer. Proc., 26:115-119.

39. Musgrave, G.W. (1935) Infiltration capacity of soils in relation to the control of surface runoff and erosion. J. Am. Soc. Agron., 27:336-345.

40. Musgrave, G.W. and Free, G.R. (1939) Some factors which modify the rate and total amount of infiltration of field soils.

J. Am. Soc. Agron. 28: 727-739.

41. Nielsen, D.R., Kirkham, D. and van Wijk, W.R. (1961) Diffusion equation calculations of field soil water infiltration profiles.

Soil Sci. Soc. Amer. Proc., 25:165-168.

42. O'Neal, A.M. (1949) Soil characteristics significant in evaluating permeability.

Soil Sci. 67:403-409.

43. Parlange, J.Y. (1971) Theory of water movement in soils. 3. Two and three dimensional adsorption. Soils and Fert., 35:121.

44. Parlange, J.Y. (1972) Theory of water movement in soils. 8. One dimensional infiltration with constant flux at the surface.

Soil Sci., 114: 1-4.

45. Parlange, J.Y. (1973) Horizontal infiltration of water in soils: a theoretical interpretation of recent experiments.

Soil Sci. Soc. Amer. Proc., 37:329-330.

46. Parlange, J.Y. and Aylor, D. (1972) Theory of water movement in soils: 9. The dynamics of capillary rise.

Soil Sci., 114:79-81.

47. Parr, J.F. and Bertrand, A.R. (1960) Water infiltration into soils.

Adv. Agron., 12:311-363.

48. Pearse, C.K. and Bertelson, F.D. (1937) The construction and operation of an apparatus for the measurement of adsorption of surface water by soils.

U.S.A. Dept. Agric. Intermountain Forest and Range Expt. Sta. (mimeographed pamphlet).

49. Peele, T.C., Beale, D.W., (1955). Laboratory determination of infiltration rates of disturbed soil samples.
Soil Sci. Soc. Amer. Proc., 19:429-432.

50. Peele, T.C. and Beele, O.W., Lesesne, F.F. (1948). Irrigation requirements of South Carolina soils.
Agric. Engng., 29:157-158. (Quoted from Soils and Fert., 11:119)

51. Pillsbury, A.F. and Richards, S.J. (1954). Some factors affecting rates of irrigation water entry into Ramona sandy loam soil
Soil Sci., 78:211-227.

52. Powers, W.L. (1939). Soil water movement as affected by confined air.
J. Agric. Res. 49:1125-1134.

53. Read, D.W.L. (1959). Horizontal movement of water in the soil. Canad. J. Soil Sci., 39:27-31.

54. Reitemeier, R.F. and Christiansen, J.E. (1946). The effects of organic matter, gypsum, and drying on the infiltration rate and permeability of a soil irrigated with a high sodium water.
Trans. Am. Geophys. Union., 27:181-186.

55. Russell, E.W. (1975). Soil Conditions and Plant Growth. 10th Ed. ELBS, Chap. 19.

56. Schiff, L. (1953). The effects of surface head on infiltration rates based on the performance of ring infiltrometers and ponds.
Trans. Am. Geophys. Union., 34:257-266.

57. Scott, V.H. (1956). Relative infiltration rates of unburned upland soils.
Trans. Am. Geophys. Union., 37:67-69.

58. Serochkin V.M. (1973): Soil Some characteristics of the infiltration of soil moisture into soils during sprinkling. Pochvovedenie, p. 60-67.

59. Siderius, W. and Muchena, F.N. (1977). Soils and environmental conditions of agricultural research stations in Kenya.
Soil Survey Unit., N.A.L. Miscillaneous paper, No. M.5:23-26.

60. Slatyer, R.O. (1970). Plant and Water Relationships. Academic Press, London. Chap. 4.

61. Smith, F.B., Brown, P.E. and Russell, J.A. (1937) The effects of organic matter on the infiltration capacity of Clarion Loam.

J. Am. Soc. Agron., 29:521-525.

62. Snedecor, G.W. and Cochran, W.G. (1967). Statistical Methods. 6th Ed. The Iowa State University Press; Ames, Iowa, U.S.A.

63. Steel, R.G.D. and Torrie, J.N. (1960). Principles and Procedures in Statistics. McGraw-Hill.

64. Swartzendruber, D., de Boodt, M.F. and Kirkham, D. (1954). Capillary intake rate of water and soil structure.

Soil Sci. Soc. Amer. Proc., 18:1-7.

65. Swartzendruber, D. (1962). Modification of Darcy's law for the flow of water in soils.

Soil Sci., 93:22-29.

66. Swartzendruber, D. and Hillel, D. (1973). Physics of Soil Water and Salts. Ecological Studies 4. Chapman and Hall Ltd., London.

67. Talsma, T. (1975). The effects of initial moisture content and infiltration quantity on redistribution of soil water.

Soils and Fert., 38:856-1252.

68. Tisdall, A.L. (1951). Antecedent soil moisture and its relation to infiltration.

Aust. J. Agric. Res., 2:342-348.

69. Webster, C.C. and Wilson, P.N. (1971). Agriculture in the Tropics. ELBS. Chap. 5.

70. Wilkinson, G.E. (1975). Rainfall characteristics and soil erosion in rainforest areas of Western Nigeria.

Expt. Agric., 11(4): 242-247.

APPENDICES

APPENDIX I: MEAN READING AND CALCULATED INFILTRATION RATES

TREAT. 1: (FINE SEED-BED (JEMBE)

DATE / TIME(MIN)	19-5-76 READING (MEAN)	19-5-76 IR	3-6-76 READING (MEAN)	3-6-76 IR	17-6-76 READING (MEAN)	17-6-76 IR	30-6-76 READING (MEAN)	30-6-76 IR	14-7-76 READING (MEAN)	14-7-76 IR
1	0.4	11.3	1.0	28.3	0.1	2.8	0.2	5.7	0.5	14.2
3	0.6	2.8	1.9	12.7	0.3	2.8	0.4	1.4	0.9	5.7
5	0.9	4.2	2.6	7.9	0.7	5.7	0.8	5.7	1.3	5.7
10	1.5	3.4	3.6	5.7	1.2	2.8	1.7	5.1	2.4	6.2
20	2.8	3.7	5.6	5.7	2.4	3.4	2.8	3.2	4.4	5.7
30	4.3	4.2	7.5	5.4	3.4	2.8	3.8	2.8	6.4	5.7
45	6.1	3.4	11.0	6.6	4.6	2.3	5.6	3.4	8.3	3.6
60	7.6	2.6	13.4	4.5	6.5	3.6	8.5	5.7	10.7	4.5
90	11.4	3.6	18.3	4.6	10.6	3.9	11.9	3.2	12.3	1.5
120	14.6	3.0	24.7	6.0	13.4	2.6	14.8	2.7	17.3	4.7
% Moisture		23.2		13.5		12.6		17.5		17.3

TREAT 1: FINE SEED-BED (JEMBE)

DATE / TIME(MIN)	28-7-76		12-8-76		26-8-76		9-9-76		
	READING	IR	READING	IR	READING	IR	READING	IR	MEAN
1	0.4	11.3	0.5	14.2	0.5	14.2	0.2	14.2	12.9
3	0.8	5.7	1.0	7.1	0.9	5.7	0.4	9.9	6.0
5	1.3	7.1	1.6	8.5	1.6	9.9	0.5	5.7	6.7
10	2.5	6.8	2.7	6.3	2.5	5.1	0.8	5.1	5.2
20	4.2	4.8	4.6	5.4	4.3	5.1	1.2	5.4	4.7
30	6.0	5.1	6.4	5.1	6.0	4.8	1.7	5.7	4.6
45	9.0	5.7	6.7	0.6	8.3	4.3	2.8	6.0	4.0
60	10.9	3.6	11.7	7.6	11.2	5.5	3.4	5.1	4.7
90	15.1	4.0	11.1	-	15.0	3.2	4.9	4.6	3.6
120	18.0	2.7	18.6	-	18.1	2.9	6.8	3.8	3.2
% Moisture		18.3		17.8		12.2		16.2	

TREAT. 2: (COARSE SEED-BED (JEMBE))

DATE / TIME(MIN.)	av.IR	19-5-76 MR	19-5-76 IR	3-6-76 MR	3-6-76 IR	17-6-76 MR	17-6-76 IR	30-6-76 MR	30-6-76 IR
1	17.9	0.5	14.2	0.5	14.2	1.3	36.8	0.7	19.8
3	12.9	1.2	9.9	2.5	28.3	2.3	14.2	1.5	11.3
5	12.7	1.8	5.7	3.7	16.9	4.1	25.5	2.3	11.3
10	9.8	2.8	5.7	5.7	11.3	5.7	9.1	4.4	11.9
20	8.5	4.7	5.3	8.7	8.5	9.2	9.9	7.3	8.2
30	7.4	7.4	7.6	12.3	11.2	11.6	6.8	9.6	6.5
45	7.5	10.5	5.9	18.3	11.3	12.6	1.9	12.7	5.9
60	7.3	12.7	4.2	23.4	9.6	16.6	7.6	17.9	9.8
90	6.4	18.3	5.3	34.1	10.1	23.7	6.7	27.7	9.3
120	6.3	23.2	4.7	45.7	11.0	30.2	6.1	33.4	5.4
% H_2O			20.7		11.1		13.4		15.0

TREAT. 2: (COARSE SEED-BED (JEMBE)) - CONT.

DATE		14-7-76		28-7-76		12-8-76		26-8-76		9-9-76	
TIME(MIN)	av.IR	MR	IR	MR	IR	MR	IR	MR	IR	MR	IR
1	17.9	0.8	22.7	1.2	34.0	1.0	28.3	0.7	19.8	0.6	17.0
3	12.9	1.4	8.5	1.9	9.9	1.8	11.3	1.7	14.2	1.2	8.5
5	12.7	2.1	9.9	2.6	9.9	2.7	12.7	2.9	17.0	1.6	5.7
10	9.8	4.1	11.3	4.6	11.3	4.5	10.2	4.9	11.3	2.6	5.7
20	8.5	7.5	9.6	8.4	10.8	7.3	7.9	8.6	10.5	4.6	5.7
30	7.4	10.3	7.9	11.3	8.2	9.9	7.4	12.1	9.9	6.3	4.8
45	7.5	15.1	9.1	16.0	10.8	13.5	6.8	16.6	8.5	5.8	-
60	7.3	18.9	7.2	19.5	6.6	16.7	6.0	20.6	7.6	11.6	-
90	6.4	23.7	4.5	24.0	4.2	21.9	4.9	26.7	5.8	15.6	-
120	6.3	33.2	9.0	28.3	4.1	26.8	4.6	32.8	5.8	19.7	-
% H_2O			14.9		17.7		17.8		12.2		

TREAT. 3: (HERBICIDE + MULCH)

DATE		14-7-76		28-7-76		12-8-76		26-8-76		9-9-76	
TIME	(MIN)	MEAN	IR	MEAN	IR	MEAN	IR	MEAN	IR	MEAN	IR
9.6	1	0.2	5.7	0.4	11.3	0.6	17.0	0.4	11.3	0.3	8.5
5.1	3	0.4	2.8	0.4	0.0	1.0	5.7	0.9	7.1	0.4	1.4
5.5	5	0.6	2.8	0.5	1.4	1.5	7.1	1.5	8.5	0.5	1.4
3.4	10	1.2	2.3	0.7	1.1	2.2	4.0	2.6	6.2	0.8	1.7
3.5	20	2.4	3.4	1.0	0.8	3.7	4.2	4.4	5.1	1.3	1.4
3.1	30	3.8	4.0	1.2	0.6	4.6	2.5	5.8	4.0	1.9	1.6
3.4	45	5.4	3.0	1.7	0.8	6.3	3.2	8.6	5.3	2.9	1.9
3.7	60	6.8	2.6	2.1	0.6	5.0	-	11.9	6.2	3.5	1.1
3.3	90	10.0	3.0	2.6	0.3	8.0	-	17.2	5.0	4.2	0.7
2.9	120	12.1	2.0	3.1	0.5	11.0	-	21.6	4.2	6.5	1.2
MEAN IR	$\%H_2O^2$	18.1		17.8		17.6		14.3		16.8	

TREAT. 3: (HERBICIDE + MULCH) - CONT.

DATE	9-5-76		3-6-76		17-6-76		30-6-76	
TIME (MIN)	MEAN	IR	MEAN	IR	MEAN	IR	MEAN	IR
1	0.1	2.8	0.8	22.7	0.4	1.3	0.2	5.7
3	0.4	4.2	1.8	14.2	0.9	7.1	0.3	2.8
5	0.9	7.1	2.4	8.5	1.5	8.5	0.6	4.2
10	1.3	2.3	3.1	4.0	2.5	5.7	1.2	3.4
20	2.4	3.1	4.4	3.7	4.9	6.8	2.4	3.4
30	3.6	3.4	5.8	4.0	6.9	5.7	3.3	2.5
45	5.0	2.6	8.5	5.1	9.7	5.3	4.9	3.0
60	6.4	2.6	11.0	4.7	12.4	5.1	8.3	6.4
90	8.9	2.4	16.1	4.8	17.7	5.0	13.4	4.8
120	12.3	3.2	22.7	6.2	23.3	5.3	14.1	0.7
%H_2O	21.7		17.1		15.9		19.9	

TREAT. 4: (HERBICIDE)

TIME (MIN)	DATE / MEAN %IR	19-5-76		3-6-76		17-6-76		30-6-76	
		MR	IR	MR	IR	MR	IR	MR	IR
1	6.9	0.1	2.8	0.3	8.5	0.2	5.7	0.3	8.5
3	4.7	0.4	4.2	0.6	4.2	0.3	1.4	1.3	14.2
5	4.1	0.6	2.8	0.8	2.8	0.6	4.2	1.6	4.2
10	2.4	0.9	1.7	1.1	1.7	0.9	1.7	2.0	2.3
20	3.1	1.9	2.8	1.9	2.3	1.7	2.3	2.8	2.3
30	2.8	3.0	3.1	3.1	3.4	2.4	2.0	3.5	2.0
45	3.4	4.4	2.6	9.0	11.1	3.6	2.3	4.4	1.7
60	2.4	5.3	1.7	9.9	1.7	4.7	2.1	6.0	3.0
90	2.5	7.4	2.0	15.8	3.7	6.6	1.8	8.3	2.2
120	2.2	9.4	1.9	18.6	4.5	8.4	1.7	10.0	1.6
$\%H_2O$			20.6		12.8		14.2		14.6

TREAT. 4: (HERBICIDE)

DATE		14-7-76		28-7-76		12-8-76		26-8-76		9-9-76	
TIME (MIN)	MEAN IR	MR	IR	MR	IR	MR	IR	MR	IR	MR	IR
1	6.9	0.4	11.3	0.1	2.8	0.3	8.5	0.1	2.8	0.4	11.3
3	4.7	0.5	1.4	0.3	2.8	0.7	5.7	0.3	2.8	0.8	5.7
5	4.1	0.7	2.8	0.5	2.8	1.0	4.2	0.8	7.1	1.2	5.7
10	2.4	1.2	2.8	0.6	0.6	1.7	3.5	1.4	3.4	1.9	4.0
20	3.1	2.2	2.8	1.3	2.0	2.8	3.1	2.5	3.1	3.4	4.2
30	2.8	3.3	3.1	2.0	2.0	3.6	2.7	3.4	2.5	5.0	4.5
45	3.4	4.6	2.5	3.1	2.1	4.9	2.5	4.8	2.6	6.9	3.0
60	2.4	5.8	2.3	4.1	1.9	6.1	2.3	6.1	2.5	8.9	3.8
90	2.5	8.6	2.6	5.9	1.7	8.8	2.5	[illegible].5	2.3	12.4	3.3
120	2.2	10.6	1.9	7.5	1.5	11.0	2.[illegible]	10.6	2.0	15.5	2.9
% H_2O			17.2		18.0		15.8		11.2		16.4

TREAT. 5: (BARE FALLOW)

TIME (MIN)	MEAN IR	19-5-76 MR	19-5-76 IR	3-6-76 MR	3-6-76 IR	17-6-76 MR	17-6-76 IR	30-6-76 MR	30-6-76 IR
1	17.5	0.4	11.3	0.7	19.8	0.8	22.7	0.2	5.7
3	7.9	1.1	8.5	1.5	11.3	2.5	9.9	1.6	8.5
5	9.4	1.8	9.9	2.0	7.1	3.4	12.7	2.6	14.2
10	7.2	2.8	5.7	2.9	5.1	5.6	12.5	4.4	10.2
20	7.5	4.6	5.1	4.8	5.4	10.2	13.0	8.1	10.5
30	7.3	6.4	5.1	6.9	5.9	14.1	11.0	11.7	10.2
45	6.1	8.7	4.3	9.8	3.6	20.2	11.5	15.4	7.0
60	6.7	11.3	4.9	13.5	7.0	25.8	10.6	21.2	11.0
90	5.6	14.8	3.3	19.5	5.7	33.8	7.6	28.4	6.8
120	5.1	21.9	6.7	25.5	5.7	43.6	9.3	33.5	4.3
%H_2O		20.4		14.2		13.7		15.1	

TREAT. 5: (BARE FALLOW) - CONT.

TIME (MIN) \ DATE	MEAN IR	14-7-76 MR	14-7-76 IR	28-7-76 MR	28-7-76 IR	12-8-76 MR	12-8-76 IR	26-8-76 MR	26-8-76 IR	9-9-76 MR	9-9-76 IR
1	17.5	0.6	17.0	0.9	24.1	0.3	25.5	0.5	14.2	0.6	17.0
3	7.9	1.0	5.7	1.5	5.7	1.3	5.7	1.1	8.5	1.1	7.1
5	9.4	1.4	5.7	2.3	11.3	2.0	9.9	1.7	8.5	1.5	5.7
10	7.2	2.4	5.7	3.2	5.1	3.1	6.2	3.1	7.9	2.6	6.2
20	7.5	4.4	5.7	6.3	8.8	5.2	5.9	5.3	6.2	4.9	6.5
30	7.3	6.7	6.5	8.8	7.1	6.6	4.0	7.3	5.7	7.0	10.5
45	6.1	10.1	6.4	12.8	7.6	8.6	3.8	9.9	4.9	10.1	5.9
60	6.7	12.7	4.9	16.1	6.2	10.8	4.2	12.9	5.7	13.0	5.5
90	5.6	18.5	5.5	20.7	4.4	14.8	3.8	17.9	4.7	17.9	4.6
120	5.1	23.9	5.1	24.8	3.9	17.9	2.9	2.0	3.9	22.2	4.1
%H_2O		16.1		15.7		15.5		11.9		16.2	

TREAT. 6: (FINE-SEED-BED (HERBICIDE))

DATE		19-5-76		3-6-76		17-6-76		30-6-76	
TIME (MIN)	MEAN IR	MR	IR	MR	IR	MR	IR	MR	IR
1	18.7	0.5	14.1	0.6	17.0	0.3	8.5	0.1	2.8
3	6.8	1.0	7.1	1.5	12.7	0.8	7.1	0.9	11.3
5	7.5	1.5	7.1	2.0	7.1	1.8	14.2	1.6	9.3
10	5.0	2.6	6.2	2.6	3.4	2.2	2.3	2.5	5.1
20	4.0	4.0	4.0	3.5	2.5	3.0	4.0	3.1	1.7
30	3.8	4.8	2.3	5.4	5.4	5.2	4.5	3.5	1.1
45	3.8	7.0	4.2	6.8	2.3	7.8	4.9	4.1	1.1
60	3.6	8.2	2.3	7.7	1.7	10.6	5.3	7.0	5.5
90	3.3	9.8	1.5	11.4	3.5	13.1	2.4	12.5	5.2
120	3.6	12.1	2.2	14.4	2.8	18.0	4.6	16.2	3.5
%H_2O			20.1		13.5		12.8		17.5

TREAT. 6: (FINE SEED-BED (HERBICIDE) - CONT.

DATE		14-7-76		28-7-76		12-8-76		26-8-76		19-9-76	
TIME (MIN)	MEAN IR	MR	IR	MR	IR	MR	IR	MR	IR	MR	IR
1	18.7	0.8	22.7	0.1	2.8	1.8	51.0	1.9	53.8	0.2	5.7
3	6.8	1.3	7.1	0.2	1.4	2.2	5.7	2.3	5.7	0.4	2.8
5	7.5	2.0	9.9	0.3	1.4	2.6	5.7	2.8	7.1	0.8	5.7
10	5.0	2.9	5.1	1.6	7.4	3.9	7.4	3.7	5.1	1.4	3.4
20	4.0	5.6	7.6	2.7	3.1	5.1	3.4	5.6	5.4	3.0	4.5
30	3.8	7.4	5.1	3.8	3.1	6.6	4.0	7.5	5.4	4.2	3.4
45	3.3	9.9	4.7	5.3	2.8	9.0	6.2	10.0	4.7	5.9	3.2
60	3.6	11.7	3.4	6.8	2.8	10.9	3.6	12.2	4.2	7.7	3.4
90	3.3	15.5	3.6	9.4	2.5	14.4	3.3	16.2	3.8	12.1	4.2
120	3.6	21.2	5.4	13.6	4.0	17.5	2.9	19.4	3.0	15.9	3.6
%H_2O			16.7		17.5		15.9		13.2		16.7

TREAT 7. (COARSE SEED-BED (HERBICIDE))

TIME (MIN) \ DATE	MEAN IR	19-5-76		5-6-76		17-6-76		30-6-76	
		MR	IR	MR	IR	MR	IR	MR	IR
1	22.7	0.2	5.6	1.0	28.3	1.0	28.3	0.9	25.5
3	12.3	0.5	4.2	2.8	25.5	1.7	9.9	2.0	15.6
5	14.0	1.1	8.5	4.3	21.2	2.9	16.9	3.2	17.0
10	9.3	1.8	9.9	6.9	14.7	4.4	8.5	6.4	18.1
20	8.1	3.4	4.5	11.1	11.9	7.4	8.5	9.5	8.8
30	7.8	4.4	2.8	16.0	11.6	10.1	7.6	13.0	9.9
45	7.8	11.7	10.0	23.5	14.2	13.0	5.5	18.1	9.6
60	5.9	13.5	3.4	29.1	10.6	16.1	5.8	21.5	6.4
90	5.0	16.0	2.9	35.3	5.9	21.6	5.1	28.4	6.9
120	5.5	23.2	4.9	42.1	6.4	26.9	5.0	36.0	7.2
% H_2O			22.5		15.0		15.6		16.1

TREAT. 7: (COARSE SEED-BED (HERBICIDE))

DATE		14-7-76		28-7-76		12-8-76		26-8-76		19-9-76	
TIME (MIN)	MEAN IR	MR	IR	MR	IR	MR	IR	MR	IR	MR	IR
1	22.7	0.4	11.3	1.3	36.8	1.1	31.2	0.5	14.2	0.8	22.7
3	12.3	1.0	8.5	2.5	17.0	2.8	17.0	0.8	4.2	1.4	8.5
5	14.0	1.4	5.7	4.0	21.2	3.8	21.2	1.2	5.7	2.0	8.5
10	9.3	2.8	4.0	4.5	2.8	6.1	13.0	2.2	5.7	3.3	7.4
20	8.1	5.3	7.1	7.5	8.5	9.6	9.9	3.9	4.8	6.3	8.5
30	7.8	8.0	7.6	10.2	7.6	13.4	10.8	5.5	4.5	6.1	-
45	7.8	11.4	6.4	14.6	8.3	17.9	8.5	7.3	3.4	10.1	4.2
60	5.9	13.8	4.5	18.5	3.7	21.6	7.0	9.7	4.5	13.6	6.8
90	5.0	17.6	3.6	24.6	5.7	27.3	5.4	13.4	3.5	20.6	6.6
120	5.5	24.3	6.3	29.5	4.6	33.1	5.5	16.8	3.2	27.6	6.6
%H_2O			17.6		18.2		17.6		12.2		18.8

TREAT. 8: (GRASS SWARD)

TIME (MIN) \ DATE	MEAN IR	19-5-76		3-6-76		17-6-76		30-6-76	
		MR	IR	MR	IR	MR	IR	MR	IR
1	5.0	0.1	2.8	0.1	2.8	0.1	2.8	0.1	2.8
3	1.7	0.2	1.4	0.2	1.4	0.1	0.0	0.2	1.4
5	1.6	0.2	0.0	0.3	1.4	0.2	1.4	0.2	0.0
10	1.1	0.3	0.6	0.7	2.3	0.5	1.7	0.3	0.6
20	0.9	0.4	0.3	1.2	1.4	1.4	2.5	0.4	0.3
30	1.0	0.5	0.3	1.6	1.1	2.1	2.0	0.6	0.6
45	0.5	0.6	0.2	2.3	1.3	3.2	2.1	1.0	0.8
60	0.9	0.7	0.2	2.7	0.8	4.2	1.9	1.3	0.7
90	1.4	0.9	0.2	3.3	1.0	6.3	2.0	1.5	0.2
120	1.3	1.0	0.1	4.9	1.0	8.1	1.7	1.6	0.1
$\%H_2O$			21.4		19.8		15.5		-

TREAT. 8: (GRASS SWARD) - CONT.

TIME (MIN)	DATE / MEAN IR	14-7-76		28-7-76		12-8-76		26-8-76		9-9-76	
		MR	IR	MR	IR	MR	IR	MR	IR	MR	IR
1	5.0	0.0	0.0	0.3	8.5	0.1	2.8	0.2	5.7	0.6	17.0
3	1.7	0.1	1.4	0.7	5.7	0.1	0.0	0.4	2.8	0.7	1.4
5	1.6	0.2	1.4	1.0	4.2	0.2	2.8	0.5	1.4	0.9	2.8
10	1.1	0.4	1.1	1.2	1.1	0.2	0.0	0.7	1.7	1.[illegible]	0.6
20	0.9	0.9	1.4	1.8	1.7	0.3	0.3	0.8	0.3	1.1	0.3
30	1.0	1.7	2.3	2.4	1.7	0.4	0.3	0.9	0.3	1.2	0.3
45	0.5	2.9	2.3	3.1	1.3	0.5	0.2	1.0	0.2	1.3	0.2
60	0.9	4.5	3.0	3.6	0.9	0.6	0.2	1.1	0.2	1.3	0.0
90	1.4	13.8	8.8	4.5	0.8	0.6	0.0	1.3	0.2	1.4	0.1
120	1.3	21.8	7.6	5.0	0.5	0.8	0.2	1.5	0.2	1.5	0.1
$\%H_2O$			20.0		20.0		24.7		19.9		17.3

APPENDIX IIa: INITIAL RAPID RATES (IRR) AND FINAL STEADY RATES (FSR) OF INFILTRATION

TREATMENT	FS(J)			CS(J)			H + M			H		
DATE	IRR[a]	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$
19-5-76	5.1	3.3	23.2	10.2	5.0	20.7	5.1	2.8	21.7	3.4	1.9	20.6
3-6-76	14.7	5.3	13.5	21.0	10.5	11.1	13.6	5.5	17.1	4.5	4.1	12.8
17-6-76	4.0	3.3	12.6	23.2	6.4	13.4	8.5	5.1	15.9	3.4	1.7	14.2
30-6-76	4.5	3.0	17.5	13.0	7.3	15.0	3.4	2.7	19.9	9.1	1.9	14.6
14-7-76	7.4	3.1	17.3	11.9	6.7	14.9	3.4	2.5	18.1	4.0	2.3	17.2
28-7-76	7.4	3.4	18.3	14.7	4.2	17.7	2.8	0.5	17.8	2.8	1.6	18.0
12-8-76	9.1	3.3	17.8	15.5	4.8	17.8	8.5	2.8	17.6	5.7	2.3	15.8
26-8-76	9.1	3.3	12.2	16.4	5.8	12.2	8.5	4.6	14.3	6.8	2.1	11.2
9-9-76	9.1	4.2	16.2	9.1	3.8	16.5	2.8	1.4	16.8	6.8	3.1	16.4
r	-0.36			-0.67			-0.40			-0.46		

r = Correlation co-efficient between % moisture and Final steady rate of infiltration.

APPENDIX IIa: CONT.

TREATMENT	BF			FS+ H			CS + H			GS		
DATE	IRR	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$	IRR	FSR	$\%H_2O$
19-5-76	10.2	5.0	20.4	8.5	1.8	20.1	6.2	4.6	22.5	1.1	0.1	21.4
3-6-76	11.3	5.7	14.2	11.3	3.2	13.5	24.4	6.1	15.0	1.7	1.0	19.8
17-6-76	19.3	4.6	13.7	10.2	3.5	12.8	16.4	5.1	15.6	1.1	1.8	15.5
30-6-76	14.7	5.8	15.1	9.1	4.3	17.5	18.1	6.8	16.1	1.1	0.1	-
14-7-76	7.9	5.3	16.1	11.3	4.5	16.7	7.9	5.0	17.6	1.1	8.2	20.0
28-7-76	13.0	4.1	15.7	1.7	3.2	17.5	22.7	5.2	18.2	5.7	0.9	20.0
12-8-76	11.3	3.4	15.5	14.7	3.1	15.9	21.5	5.4	17.6	1.1	0.1	24.7
26-8-76	9.6	4.3	11.9	15.9	3.4	13.2	6.8	3.4	12.2	2.8	0.2	19.9
9-9-76	8.5	4.3	16.2	4.5	3.9	16.7	11.3	6.3	18.8	5.1	0.1	17.3
r		-0.28			-0.50			-0.19				

r = Correlation co-efficient between % moisture and Final steady rate of infiltration.

APPENDIX IIb: AVERAGE % WATER (BY WEIGHT OF OVEN DRY SOIL)

PRESSURE (ATM)	SC(J)	FS(J)	CS(H)	FS(H)	BF
1/3	20.35	19.70	19.64	19.49	18.90
2/3	17.67	16.14	17.03	16.36	17.45
1	16.29	14.85	14.85	15.14	16.53
3	14.36	12.91	13.74	13.71	14.38
5	13.49	12.04	12.59	13.02	13.15
10	11.77	11.04	11.40	10.62	11.55
15	10.35		8.27	8.46	9.39

(FSR) FINAL STEADY RATE OF INFILTRATION OVER THE LAST HOUR

READING NUMBER	BF DUG	BF UNDUG	FS(J)	CS(J)	FS(H)	CS(H)
1	3.7	2.0	0.9	5.6	0.8	1.6
2	5.3	2.4	2.6	6.2	1.1	2.5
3	4.2	1.0	0.9	3.9	1.3	2.8
4	4.4	2.5	1.1	-	1.3	2.4
5	-		1.1	4.6	0.8	2.2
6	-	-	1.3	3.0	1.3	1.9
7	-	-	2.5	-	-	2.4
8	-	-	2.4	3.1	2.3	2.4
9	-	-	1.3	3.9	1.5	2.3
MEAN(FSR)	4.4	1.9	1.6	3.9	1.4	2.3
STD.ERROR	0.33	0.31	0.24	0.46	0.17	0.11

APPENDIX III: CHEMICAL CHARACTERISTICS

HORIZON	0 - 15 cm	30 - 45 cm	60 - 75 cm
CHARACTERISTICS			
PH. (H_2O)	5.4	6.0	6.2
Na me %	0.06	0.04	0.02
K me %	0.5	0.33	0.31
Ca me %	2.0	1.5	0.6
Mg me %	1.45	1.5	1.47
Mn me %	0.51	0.27	0.26
P ppm	22.8	18	19.7
N %	15.3	-	-
C %	1.88	-	-
Hp me %	0.40	0.1	-

TEXTURE AND EXCHANGEABLE BASES

HORIZON	0 - 20	20 - 46	46 - 94
CHARACTERISTICS			
Sand %	69	73	55
Silt %	12	10	12
Clay %	19	17	33
CEC me %	9.7	6.4	3.8
Mg me %	0.7	Trace	0.6
Na me %	0.30	0.20	0.60
K me %	0.2	0.1	0.2

REF: Soils of National Agricultural Research Station, Kitale
by NAL - Michieka and Otieno Oswago
1971

APPENDIX IV

AVERAGE MONTHLY RAINFALL (mm) FOR N.A.R.S., KITALE

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
JAN	2.5	3.0	39.6	32.9	0.0	4.3	7.7	7.5	0.0	83.7	115.4
FEB	68.8	31.5	4.1	159.2	67.3	26.9	57.5	8.6	153.8	117.6	13.9
MAR	178.8	8.0	84.3	126.8	51.8	70.7	127.9	112.1	41.5	74.4	146.7
APR	86.9	114.0	170.7	191.6	153.5	145.4	280.6	164.5	171.2	92.1	144.4
MAY	77.7	122.4	235.2	221.0	127.9	134.6	81.6	251.4	113.1	241.2	104.4
JUN	108.7	135.4	141.2	60.6	125.5	51.6	80.7	127.4	115.9	84.0	102.4
JUL	132.3	223.8	156.7	147.9	155.4	100.1	139.3	162.3	239.1	160.5	141.3
AUG	146.6	197.6	179.3	211.9	222.7	139.8	165.9	148.9	131.9	163.0	222.8
SEP	114.3	129.5	147.1	21.8	177.6	15.8	-	83.6	47.2	147.3	118.3
OCT	48.8	231.6	107.7	16.5	75.5	196.6	47.6	181.4	102.8	100.6	54.2

APPENDIX IV   CONT.

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
NOV	35.6	270.6	64.0	149.0	5.8	101.8	64.3	87.1	46.6	37.8	31.7
DEC	47.0	133.9	44.7	104.0	48.3	30.1	11.7	6.1	29.9	13.3	19.4
TOTAL	1048.0	1711.3	1374.6	1443.2	1212.6	1017.7	-	1340.9	1193.0	1315.4	1214.8

Annual rainfall probability is above 0.90

Source: Michieka, O. and Oswago, C.   1971
Soils of NARS, Kitale
Soil Survey Unit.   N.A.L., Nbi, Kenya

APPENDIX V

$T = 71.97$ at $25^{\circ}C$

$\rho = 1$

$g = 978$

APPENDIX VI : FINAL STEADY RATE

TREAT. SEEDBED	FS(J)	CS(J)	H + M	H	BF	FS(H)	CS(H)	GS	TOTAL	AV.
DATE										
19-5-76	3.3	5.0	2.8	1.9	5.0	1.8	4.6	0.1	24.5	3.1
5-6-76	5.3	10.5	5.5	4.1	5.7	3.2	6.1	1.0	41.4	5.2
17-6-76	3.3	6.4	5.1	1.7	4.6	3.5	5.1	1.8	31.5	3.9
30-6-76	3.0	7.3	2.7	1.9	5.8	4.3	6.8	0.1	31.9	4.0
14-7-76	3.1	6.7	2.5	2.3	5.3	4.5	5.0		37.6	4.7
28-7-76	3.4	4.2	0.5	1.6	4.1	3.2	5.2	0.9	23.1	2.9
12-8-76	3.4	4.8	2.8	2.3	3.4	3.1	5.4	0.1	25.3	3.2
26-8-76	3.3	5.8	4.6	2.1	4.3	3.4	3.4	0.2	27.1	3.4
19-9-76	4.2	3.8	1.4	3.1	4.3	3.9	6.3	0.1	27.1	3.4
TOTAL	32.3	54.5	27.9	21.0	42.5	30.9	47.9	12.5	269.5	
AVERAGE	3.6	6.1	3.1	2.3	4.7	3.4	5.3	1.4		

PART TWO

INVESTIGATION ON THE SULPHUR STATUS OF SOIL PROFILES FROM KITALE AND KABETE.

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

PART 2

CHAPTER I

1. INTRODUCTION

1.0. GENERAL

Sulphur is known to be essential for plant growth. However much is yet to be learned about it's functions in the plant and animal body. Sulphur in the plant is known to be a constituent of amino acids methionine and cystine, vitamins biotin and thiamine and it also determines the structure of protein (Brady 1974).

Until recently, less attention has been given to sulphur recommendation and by many fertilizer manufacturers. The reason could be due to the pre sumed lack of sulphur response or deficiencies which were not recognised in most parts of the world. Lack of sulphur responses in most areas of the world could be attributed to addition of sulphur to the soil without realisation. Phosphatic fertilizers have traditionally contained sulphur as gypsum due to the method of manufacture. Sulphuric acid is added to rock phosphate to dissolve it and therefore many phosphorous responses were partially due to sulphur. When sulphur-free phosphatic fertilizers (MAP and DAP) were introduced, they were first tried in areas having appreciable atmospheric sulphur pollution. It was only when sulphur-free phosphatic fertilizers were tried in 'clean' environments that the full need for sulphur was recognised.

In highly industrialised countries, sulphur dioxide is released into the atmosphere from industrial waste gases and also from burning down of vegetation. The release is in certain cases sufficient or in excess supply to the plants. An example is Britain. It has been estimated that about 10 - 15 kg/ha sulphur is returned in rainfall every year (Russell 1973). The sulphur concentration in dust could also be high. In less industrialised countries, atmospheric sulphur supply is very low. Sulphur deficiencies here therefore appeared in Australia, and Tropical Africa. Sulphur deficiencies have been reported in Tanzania but the deficiencies did not continue due to the use of sulphate of Ammonia and single superphosphate (Le Mare 1969). In Zambia, the law requires that fertilizer companies include sulphur in all fertilizers (Barber 1977). Sulphur supply in the air is related to the distance from the sea. Areas away from the sea show more sulphur responses than areas near the sea.

In Kenya, Kitale is one of the areas which show both sulphur and phosphor us deficiencies. Bromfield (1977) has indicated that these soils in Kitale can be divided in two distinct classes:

a) Volcanic soils; high in sulphur content.

b) Quartzite soils; very low in sulphur content.

Since most high analyses fertilizer, i.e. containing mainly NPK, have no or very little sulphur content, the soil has had its sulphur depleted by crops without anymore replacement. This has speeded up the lowering of sulphur content in the soils and hence sulphur deficiencies may show up in crops. Poultney[1] demonstrated sulphate response by Kenya white clover at Kitale Grassland Experiment Station.

---

[1] Poultney - Mentioned by Mehlich A. (1970)

Maize and wheat, in the same area, showed sulphur deficiency symptoms in 1967 - 68. Songhor area of Nyanza, Kenya also showed sulphur deficiencies. Sugarcane responded to sulphur supply by increase in yeilds in Songhor - East Konyango areas. Hill (1963) showed that sugarcane benefited from addition of gypsum. Gray (1963) working at Kisii and Sotik on experiments with Rhodes grass failed to obtain significant responses with sulphur application. Elgon soils derived from volcanic lava also showed no sulphur deficiency symptoms.

There has not been much work done on sulphur status of Kenyan soils. Kitale being one of the areas which have been found to be sulphur deficient, the author considered that it was an appropriate area for sample collection. To enable sufficient comparisons with areas around Kitale, samples were also taken from the slopes of Mt. Elgon and Kabete, Nairobi. The Kabete area and Mt. Elgon area have not yet been found to be sulphur deficient. This study was therefore hoped to establish laboratory methods of determining the sulphur status of the soil other than plant response in the field. It was hoped that if certain laboratory analyses gave indications of the sulphur status of the soils, and the millet plants in the greenhouse showed a similar trend to that of the laboratory analyses results, then the soils in the field could be ranked in order of the soil sulphur status by laboratory analyses. Thus the objective of the study was to determine whether total sulphur and soluble + absorbed sulphur in the soil, as determined by laboratory techniques give an indication of the sulphur releasing powers of the soil.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER II

2. LITERATURE REVIEW

2.0 GENERAL

Occurence of Sulphur in Plants

Sulphur occurs in two main amino acids found in plant proteins. These are cystine (27% S) and methionine (21% S). Sulphur also occurs in the growth regulators, thiamine and biotine. Different plants have different ranges of sulphur contents. Thomas, Hendricks and Hill (1950) demonstrated this variation by reporting sulphur content of wheat leaves to be 0.19 - 0.72% and lucerne leaves to be 0.18 - 2.11%. Different plant tissues also show varied contents of sulphur (Fox et al 1964).

Importance of sulphur in amino acid balance

Sulphur is required in the synthesis of amino acids, cystine, cysteine and methionine. The biological value of proteins, expressed by "essential amino acid index," has been limited by sulphur containing amino acids (Tisdale et al 1950). Tisdale et al (1950) reported that sulphur-containing amino acids not only determines the biological value of food protein but that it is even more important than the lysine content of these foods.

The sulphur-containing amino acids content of the plant can be altered by sulphur fertilization. Tisdale and Nelson (1966) reported that the methionine, cystine and total-sulphur content of two strains of alfalfa increased with larger inputs of sulphur in the nutrient medium. Deficiency of sulphur can cause an accumulation of non-protein nitrogen in plants. Accumulation of nitrates in plant tissue has been found to be detrimental to non-ruminants. Norwegian workers found that the nitrate accumulation could easily be corrected by addition of sulphur fertilizers. Sulphur addition to the soil narrows the N:S ratio which is important in soil fertility. A wide N:S ratio indicates a nutrient imbalance in the soil and in most cases, the soil appears infertile due to less sulphur available to plants (Tisdale and Nelson 1966).

2.1 Sources of Sulphur

The sulphides of iron, nickel and copper constitute 0.05 - 0.3% S of unweathered igneous rocks. (White-head 1964) The sulphur in the rocks is oxidised during rock weathering and is released as sulphur dioxide or sulphate sulphur. Limestone extractions have given total sulphur contents of 2.5 - 44.5 mg/100g; as shown by Williams and Steinbergs (1962). Many sedimentary rocks also act as a source of sulphur (Rusell 1973). The sulphur found in sedimentary rocks is in the form of sulphides in form of ferrous sulphide or as sulphate in form of calcium sulphate. The sulphur is derived from sea water which distributes sulphur among the alluvial soils along the coasts. Russell (1973) also reports that sulphur occurs as an impurity in some limestones, calcium carbonate concretions and corals.

Clay deposits may contain sulphur in the form of pyrites. Some sulphur contents in clay were reported by the London

Brick Company on Weald, Gault and Oxford clays as ranging from 0.32 - 1.8% S.

2.2. Atmospheric supply of sulphur

Sources of atmospheric sulphur supply are varied. The main one is the industrial release of sulphur gases. Volatile gases released from organic matter also supply sulphur in the atmosphere. The gases are released in a form of sulphides and they are oxidised in the atmosphere to sulphur dioxide. (Eriksson 1959). This sulphur dioxide is either absorbed directly by plants or it dissolves in rain water to form dilute acids such as sulphurous acid. Bromfield (1974a) measured sulphur amounts deposited in dust at 10 sites in Nigeria. He used three different dry seasons and found that the sulphur content varied between sites and seasons due to variations of dust concentrations in the air. The range he found was 0.099 - 0.4_9 kgs/ha deposited in dust quantity ranging from 52 - 226 kg/ha. His work at Muguga, Kenya on atmospheric sulphur showed that there was relatively less sulphur in the air than he found in Nigeria. This sulphur content varied with the rainfall patterns of the year. Thus there was low sulphur content in the atmosphere during the rainy season and this increased as the rains decreased. This was because the sulphur dioxide dissolved in rain water and was removed fast from the atmosphere while in the dry season, the gas took time to settle down to the ground or on vegetation.

Alway, Marsh and Methley (1937) also reported that SO_2 can be absorbed by plants directly from the atmosphere. Work by

Thomas and Hendricks (1943) indicated that SO_2 can be absorbed through plant leaves. Their work was later supported by Johannson (1959) working in Sweden. He found that exposed soil obtained free atmospheric SO_2 much more than SO_2 in precipitation. The proportion obtained by direct absorption depended on the atmospheric SO_2 levels. Olsen and Wanatabe (1957) demonstrated that cotton plants with adequate sulphate solution still obtained 30% of their sulphur from the atmosphere while the sulphur deficient plants obtained 90% of their sulphur from the atmosphere. However, a precise determination of the amounts of SO_2 directly absorbed from the atmosphere by plants is difficult to obtain. This is because accurate methods of SO_2 collection have not been developed yet.

2.3 C:N:S ratio

The plant protein content is affected by the S:N ratio. This is because the sulphur bearing amino acids are important in the synthesis of plant proteins. Stevenson (1956) found that crop with S:N ratio wider than 1:15 had low protein contents. This was later demonstrated by Bardsley and Jordan (1958) who found that clover (*Trifolium repens*) whose ratios were 1:20 to 1:30 and were grown on seven different soils, were sulphur deficient and low in protein contents. The clover which were not sulphur deficient had a ratio of 1:10 to 1:17.

In soils, the C:N:S ratios are very important as they also signify the level of soil fertility and the possibility of sulphur deficiency. High sulphur contents are found in tidal marsh areas where saline soils accumulate sulphides, and sulphur is also found in arid areas in accumulation as inorganic sulphur.

Total sulphur content is closely correlated with organic matter and consequently total sulphur is correlated with total nitrogen. Both sulphur and nitrogen behave in a similar manner to each other in the soil (Whitehead 1964 and Alexander 1961). Their cycles are also of a similar pattern to each other. A number of soil scientists have given C:N:S ratios of different soils. Donald and William (1957) recorded a ratio of 155:10:14 in N.S.W. Australian soils, while Williams, Williams and Scott (1960) recorded 113:10:1.27 on calcareous soils of Minnesota, U.S.A.

It was observed that a wider C:S ratio in soils and plants showed deficiencies (Whitehead 1964). The reason given for this is that since there is high carbon content in relation to sulphur, the microbes take in all the available sulphur, during their activity, and there is not any surplus sulphur released in the soil (Alexander 1961)

2.4 Sulphur Solubility and Leaching

The sulphates of potassium, magnesium and sodium are readily soluble, that of calcium is only sparingly soluble, while those of barium and strontium are completely insoluble. The sulphates of calcium are removed slowly by continuous leaching. Soils of arid regions, without any leaching, have surface accumulations of 'white alkali' which contains Ca, Mg, K, and Na sulphate. However, in most soils, sulphate occurs as anions rather than salts. Soils which are slightly leached have been observed to have calcium sulphate accumulation at a depth of 45 - 90 cm e.g. chestnut soils (Russell 1973). In humid areas, most of the soluble sulphates are removed down the soil profile (Whitehead 1964).

In soils which are well aerated, the inorganic sulphur is in the form of sulphate. Sulphate release by microbial activity is efficiently taken up by plants. In such cases, the excess sulphates are leached down the profile. Lyon and Bizzell (1918) using lysimeter studies at Cornell University found that drainage water removed 3 to 6 times as much sulphate as was taken up by crops.

2.5 Sulphate Retention

Some soil colloids show some sulphate retention properties. Mattson (1927) demonstrated the sulphate adsorption capacity of soil colloids. Using Colloids of Norfolk soils he showed that antecedent capacity increased with decrease in pH. The reason could be that at low pH, SO_4 anion is fully dissociated and can be easily adsorbed by the soil colloids, clays and hydrous oxides which may have a net positive charge at low pH.

Ensminger (1954) working on 12 Alabama soils determined their sulphate content and adsorption capacity and found that in the top horizon, he could not extract any sulphate using an acetate-extractant. The lower horizons (B and C) of most of the soils had appreciable quantity of acetate extractible sulphate. He concluded that these two horizons had a higher sulphur content than the top soil and therefore they possibly have a higher capacity to adsorb sulphate than the top soil, or that it could also be the effect of sulphur leaching down the soil profile. His work was supported by Jordan and Bardsley (1958), and Neller (1959) who reported that very little sulphate seemed to be adsorbed in the top horizon. Their discussion on sulphate retention of different horizons revealed that very little sulphate retention occured in the top soil but a considerable retention occured some depth down the profile. Further work on sulphate retention capacities of soils, by Stanford and Lancaster (1962), Williams and Steinbergs (1962) and Jensen (1963), was in agreement with that of Neller (1959). Neller and the rest also concluded that the lower horizons had higher capacities to retain sulphur than the top horizon. The reason offered for this was that the lower horizons usually had high clay contents and the $SO_4^{=}$ anion was retained on the clay edges.

Lichtenwalner _et al_ (1923) found that iron and aluminium hydrogels adsorb sulphates. Kamprath, Nelson and Fitts (1956), and Berg and Thomas (1959) continued with these studies and found that sulphate retention in soils containing hydrated iron and aluminium oxides and also kaolinitic clay minerals was greater than in 3-layer clay minerals. Ensminger (1954) had also found similar results when he examined the sulphate adsorption capacities of some materials including clay minerals and soil colloids. He concluded that aluminium oxide had a high adsorptive capacity for sulphate. Chao, Harward and Fang (1962[b]) also examined 15 soil samples

Three of the samples had a high content of iron and aluminium oxides as well as exchangeable aluminum. These 3 soils had a higher ability to hold sulphate against leaching than the rest of the soils samples. The ability was appreciably reduced when the iron and aluminum oxides were removed from the soil. Their conclusion was then that iron and aluminum oxides have a high adsorptive capacity for sulphate.

Schell and Jordan (1959), also found that sulphate can be held on silicate clay minerals by attraction due to the positive charges on clay edges, or simply by ligand exchange by substituting for aluminate or silicate ligands within the lattice. Hingston et al (1972) also discussed the sulphate adsorption by positive charges and ligand exchange. Chao, Harward and Fang (1962) found two things in their studies. First, the soils examined did not have definite sulphate adsorption capacities and therefore the mechanism was more complex than simple ligand exchange. Secondly, the removal of organic matter from the soil samples resulted in a marked reduction of sulphate adsorptions. There was no reason offered for this since some soils with equally high organic matter content could not adsorb more sulphate than they did. Furthermore, the adsorption capacities lacked adsorption maxima which meant that other mechanisms in addition to organic matter are involved in sulphate adsorption by the soils in question.

showed that the anion adsorption increased with decrease in soil pH. Kamprath et al (1956) also studied the effects of pH on adsorption of sulphate by three soils. They found that sulphate adsorption decreased with increase in soil pH. The reason given for this observation was the dissociation state of sulphate anions. At low pH values, the $SO_4^=$ ions are fully dissociated and displace most of the -OH groups present.

Overstreet and Dean (1951) also postulated that the mechanisms by which the chlorides, sulphates, and phosphate ions are held in the soil are the similar to each other. Barbier and Chabannes (1944) found that sulphate ions were more strongly held in the soil than chloride ions but less strongly adsorbed than the phosphate ions. This was in agreement with earlier work by Mattson (1931) who had given an order of effectiveness of other anions to display -OH ion as:

phosphate > sulphate > chloride

He concluded that the strength by which these ions are held in the soil are in the same order as that of effectiveness he had given. Recent work by Hingston et al (1972) had findings that $SO_4^=$ ion is adsorbed far more strongly than Cl^- ion. They also noted that there was selectivity in the $SO_4^=/Cl^-$ ions adsorption, i.e. in the presence of $SO_4^=$ ions, Cl^- ions are unlikely to be adsorbed and that $SO_4^=$ adsorbed in presence of Cl^- is equivalent to Cl^- adsorbed in the absence of SO_4^{2-}. This conclusion was based on soils which had Goethite and Gibbsite.

Ensminger (1954) worked on phosphate effects on sulphate adsorption and concluded that application of superphosphate reduced soil's ability to retain sulphates. He also found that dilute phosphate solutions were effective extractants of soil sulphate. His work was supported by Kamprath et al (1956) who demonstrated the reduction of sulphate adsorption of soils, caused by phosphates, in the laboratory. The reason given was that the phosphate ion does not depend on pH for its adsorption. This is because it has got partial dissociation. Therefore at any given pH, the phosphate ion can displace the sulphate ion since it will have some degree of dissociation. Similar work on phosphate/$SO_4^{=}$ retention by Chao et al (1962) was in agreement with previous results of Kamprath et al (1956). This meant that the well-phosphated soils would not retain much sulphate in the top soil. However, the subsurface layers would not be affected since the phosphate ion does not move fast down the profile. The phosphates added to the top soil displace the sulphates and they are leached down the profile. Loses of sulphate through leaching are very variable. Stauffer and Rust (1954) gave a range of values on Illinois soils as 1.44 - 58 kg S/ha/year while Buchner (1958) estimated about 30 kg/ha/year on West Germany soils.

2.6 Sulphur Availability

Plants take in sulphur from the soil mainly as sulphate. Starkey (1950), Fomin and Astokhova (1959) reported that sulphur in form of amino acids is more readily utilized by plants than sulphate sulphur. However, microbial activity renders this form of sulphur insignificant in plant uptake.

Organic matter levels also affect sulphur availability. Barrow (1960), Koter (1965) showed that the rate of mineralisation of sulphur from fresh organic material depended on its C:S ratio. For mineralisation to occur, plant material must have a ratio equal or greater than 250:1.

Due to varied results obtained for rate of mineralisation of sulphur in the soil, it was concluded that the rate depends on the level of freshly added material to the soil other than the bulk of organic matter in the soil (Freney et al, 1962). Barrow (1961) also found that drying of soils increased the soil inorganic sulphate, which he thought was a release from the organic sulphate.

Sulphate adsorbed in subsurface layers of the soil by clay colloids can act as a source of sulphur to deep rooted plants. This was found by Ensminger (1958) when he saw shallow rooted crops showing sulphur deficiency symptoms while the deeper rooted lucerne showed none at all. Lucerne with demands as high as 24 - 27 kg/ha still had enough supply. This was later demonstrated by Neller (1959), and Stanford and Lancaster (1962).

William (1967) studied the release of sulphur in different profiles and concluded that sulphur release appeared to follow 4 patterns during an incubation period.

" a) Immobilisation in the initial stage followed by mineralisation in late stages.

b) Rapid release during the first few days followed by linear release.

c) Steady release over incubation period.

d) Rate of release which decreases probably with time"

These patterns, he said, depended on the nature of the decomposing fraction of soil organic matter and not on any other soil properties.

Jones *et al* (1972) and Barrow (1967) found that some soils mineralised less when under plants than when without plants in a green-house. Barrow (1961 and 1969) found that when soils are incubated, mineralisation is considerably greater for N and S than in soils under field conditions.

2.7 Sulphur deficiency Symptoms

The early stages of sulphur deficiency symptoms, Chlorosis occurs in the younger leaves. The plants resemble the nitrogen deficiency symptoms, except that they are pale green and do not develop leaf patterns. In extreme deficiencies, seedlings may die at an earlier stage (Jordan and Ensminger 1958).

Although sulphur is not a constituent of chlorophyll, sulphur deficient plants are chlorotic. Ergle (1953) found that a reduction of 40% of the chlorophyll content occured when cotton plants which were sulphur deficient were compared with controls.

2.8 Sulphur needs of plants

Sulphur contents of plant tissue vary considerably. Thomas, Hendricks and Hill (1950) have reported wheat leaf content to vary from 0.19 - 0.72% sulphur and lucerne leaf content to vary from 0.18 - 2.11%. However, some crops need greater quantities of sulphur than others e.g. brassicas need more sulphur supply than grasses (Jordan and Ensminger 1958).

Nelson (1956) observed no corn response to sulphur application in U.S.A. while Saalbach (1970) determined the sulphur requirements and sulphur responses from cereals and grasses in Germany. Mehlich (1970) reported that work on 39 soils in Kenya, tomato plants showed response to sulphur supply. He also recorded response of star grass (Cynodon dactylon) to sulphur supply on experiments carried out at National Agricultural Laboratories, Nairobi, Kenya.

Bromfield (1972) found that different plant parts had different sulphur content. Analysing the groundnuts, he found that for 11.6 kg S/ha harvested, 5.4 kg was in haulm, 5.4 kg in kernels and 0.8 kg in shells.

Sulphur is supplied to the plants in the form of fertilizers. Mehring and Bennett (1950) analysed the fertilizers and showed that superphosphate contains about 12% sulphur. Most mixed fertilizers, according to them, could supply enough sulphate to the plants as they contained an average of 7.74% sulphur. The sulphur in mixed fertilizers has no residual effects because most of the fertilizers have phosphates which displace most of the sulphates. The sulphates displaced are then leached away. Crushed elemental sulphur supplied to the soil is more long lasting than other forms of sulphur because it is insoluble in water (Russell, 1973).

2.9 Sulphur Mineralisation

Organic sulphur has not been widely investigated. Trithiobenzaldehyde (Shorey 1930) and cystine (Putman and Schmidt 1959) have been the only sulphur protein compounds extracted from the soil Cysteine and methionine have also been detected (Sowden 1955, Stevenson 1956 and Whitehead 1960).

Both aerobic and anaerobic decompositions of sulphur proteins occur. Pure cystine is aerobically decomposed to sulphate while hydrogen sulphide is the main product in anaerobic decomposition (Alexander 1961). Fredrick, Starkey and Segal (1957) incubated a moist sand loam soil containing 1% cystine at 28°C. After one week 28% of the sulphur was recovered as sulphate, 57% after 4 weeks and 85% after 21 weeks. Freney (1958) postulated a pathway by which sulphur protein is changed to sulphur as:

Cysteine ⇄ Cystine → Cystine disulphoxide → Cysteine – Sulphinic acid → Cystein acid → SO_4

Organic sulphate is another form of organic sulphur in the soil. There has been evidence that soil organic matter can adsorb sulphate to some extent. Freney (1958, 1961) postulated that a significant proportion of total sulphur in the soil occurs as sulphate that is integrated in organic matter. When organic matter is assimilated by microbes, excess $-SO_4$ is released in the system. However the mechanism by which sulphate is adsorbed onto the organic matter was not discussed.

2.10 Assessment of Sulphur availability in soils

Several methods have been used for assessing sulphur availability in soils. Some of them are briefly discussed below.

The 'a' value method measures the amounts of nutrients absorbed by the soil. McClung et al (1959) assessed the S status of the soil using the 'a' value method. In their experiments, they had millet plants grown in pot cultures in a green-house. S was added as $CaSo_4$ at the rate of .1 kg S/100,000 kg soil (20 Ibs S/2 million Ibs of soil). Top soil of most soils responded while the B horizons of cultivated profiles responded less frequently than the B horizons, of virgin soils. The conclusion reached was that there might have been S movement down the cultivated profiles because the amounts absorbed by plants from B horizons of the cultivated profiles was high.

The "A" value indicates the amounts of nutrient available to the plants both in the soil and in fertilizers. Dean (1954) studied the 'A' value of P when upto 156 kg/ha of P_2O_5 were added. Yield curves were then produced and extrapolated. The extrapolation of ascending straight lines of the curves gave an intersection with the X-axis which approximated the 'A' values. From this approximation, the amounts of P available to plants could be estimated.

Kilmer and Nearpass (1960) used laboratory procedures (colorimetric method) to study the available sulphur in soils as indicated by 'A' values. They used the Johnson - Nishita procedure. The 'A' values and the S determined correlated very well ('r' value of 0.89). Nearpass and Clark (1960) showed that S availablity to the plant can be shown by plant sulphate percentage or by total uptake by plants ('A' values). Using rice plants, they demonstrated the sulphur availability to plants was reduced when the soil was submerged. Algal method was used by Tchan et al (1963). Using Allen and Arnoris basic medium, they grew algae on 24 soils. Plants were also grown on the soils similar to the ones algae was grown on. Percent algal response was plotted against % plant response to sulphur addition on the soils. The two response curves were very well correlated (multiple correlation index of 0.91). Tchan et al concluded that an algal method of bio-assay of soil fertility could be used for agricultural fertilizer recommendation.

Mehlich (1970) also used fungal growth to indicate S deficiencies in soils of Songhor and East Konyango, Kenya. Cunninghamella blakesleeana was used in the study. The growth of this fungus on the soils with added sulphur showed very little growth while those soils without added sulphur showed very good growth. The growth of fungus indicated S deficiencies in the soil. The conclusion reached was that fungal method of bio-assay of sulphur gives a good indication of sulphur status of the soil.

Incubation and Neubauer method of assessing sulphur status of the soil was used by Cairns and Richer (1960). They incubated surface layer soils for 2 weeks and leached the soils with water. They also added plant material and elemental sulphur to the soils during incubation period. Seedlings were grown on soils similar to the incubated ones to extract the available sulphur. The seedling test was according to the Neubauer method of seedling extraction.

The release by incubated soils and extraction by barley seedlings showed good correlation with laboratory determinations of the sulphur content of the soils in question. The conclusion indicated was that the soil incubation or plant extraction can be used to estimate the sulphur status of a soil.

CHAPTER THREE

MATERIALS AND METHODS

CHAPTER III

3. MATERIALS AND METHODS

3.0 Site description

Site in this content refers to the location where the profile was dug. At each site, one or two profiles were dug. Where two profiles were dug, the previous history and present vegetation were different. The description of the sites below is therefore given for each profile and not for each site.

Profile 1

This sample was taken at the National Agricultural Research Station (N.A.R.S.), Kitale. The field was under barefallow cultivation at the time of sampling but had been previously under bush. The soil was sandy loam, (69% sand, 12% silt and 19% clay for the depth of 0 - 20 cm), well drained, dark reddish brown in colour and derived from argillaceous and arenaceous sediments of the basement complex. This profile was in Field 14 at the Research Station.

Profile 2

This profile was also sited at N.A.R.S., Kitale. The soil was similar to that of profile 1 except the field had been under grass for at least six years.

Profile 3

This profile was on the Merrow Down Farm, Endebbes (Kitale). The field was bare immediately following the harvesting of a bean crop. The soil is developed from a volcanic lava on the slopes of Mt. Elgon.

Profile 4

The samples were taken from the Cherengani Hills. The soil was sampled about $3\frac{1}{2}$ km. due east of Makutano near the point where the road divides, going north-east to Cheberaria and east to Kaisubich.

The geology is marked as psammitic quartzite, muscovite quartzite and quartz muscovite gneisses. The vegetation was recently forest. The forest was cleared and burnt down, in order to plant maize, shortly before the samples were taken. The site was at the foot of a slope.

Profile 5

This profile was also in Cherengani Hills near profile 4. The two profiles were similar to each other except profile 5 had vegetation which consisted of poor short grass with some shrubs used as rough grazing.

Profile 6

This profile was at Kabete Field Station , Faculty of Agriculture, University of Nairobi. This was on Field 6 opposite the Field Station buildings. The area on a level site had previously been under a maize crop. The soil was also developed on volcanic lava which gave it some similarities to profile 3 in some respects.

3.1 Horizon description

For all the horizons sampled, their descriptions is given in appendix I.

3.2. Laboratory Analyses

Analyses were carried out to determine the soils exchangeable cations, organic carbon, nitrogen and CEC. The methods used for these analyses were adapted from Ahn (1972).

3.2.0. Total-Sulphur analysis

The determination of total-sulphur was carried out on the soil samples, sample of seed sown and plant materials. The method used for analyses was adapted from Bardsley and Lancaster (1960).

Procedure

About 0.5 gm of sample was weighed out in a labelled crucible. One gramme of $NaHCO_3$ was weighed onto the sample covering it completely. The sample was heated in a hot furnace for three hours (500° C). The sample was then cooled and tapped into a small reducing flask. The flask was connected to the reduction apparatus and 10 ml of reducing agent ran into. The reduced sample sulphur in a form of H_2S was absorbed in 10 ml N NaOH. Reduction process took ten minutes within which the soil sample colour changed indicating the reduction reaction.This indicated that a reduction of soil ferric iron to a ferrous form had taken place.

The absorbate was titrated against 0.0005 M Mercuric chloride, using a few drops of Dithizone in acetone as indicator. A magnetic stirrer was used. At the end point the colour changed from yellow to purple.

Calculation

A multiplication factor of 17.21 was used i.e. for every ml of mercuric chloride used, 17.21 ppm of sulphur reacted. The formulae used were:

a) (Titre - Blank) x 17.21 = μg sulphur in sample.

b) $\frac{\text{(Titre - Blank) x 17.21}}{\text{weight of the soil}}$ = ppm sulphur.

3.2.1. Adsorbed + soluble sulphur analysis

These determinations were carried out on soil sample before and after plant growth and on the nutrient solu ion without sulphur.

Procedure

The method of analyses was adapted from Bardsley and Lancaster (1960) and Barrow (1967). Five grammes of soil were weighed out in duplicates into plastic graduated test-tubes. Twenty five millilitres of 0.01 M $Ca(H_2PO_4)_2$ of pH 4 was added to each of the test-tubes and the samples put on a shaker for 24 hrs. The samples were then centrifuged for 10 minutes at 2000 rpm.

Ten millilitres of supernatant liquid (25 ml in the case of nutrient solution) were pippeted into a distillation flask. This was dried on a hot sand tray until all the liquid evaporated off. The flask was then fixed on the reduction apparatus and five millilitres of the reducing agent let in. The sample was reduced for 10 minutes and H_2S produced absorbed in 10 ml of N NaOH. The absorbate was titrated against 0.0005 M mercuric chloride. The end point was pinkish purple.

Calculation

The following formulae were used:

a) (Titre - Blank) x 17.21 = µg sulphur in sample

b) $\frac{\text{(Titre - Blank)} \times 17.21}{2^{1}}$ = ppm sulphur.

---

1 Ten millilitres were removed from the 25 ml obtained from 5 gm of soil(10/25), therefore 10 ml represent what was obtained from $(\frac{10 \times 5}{25})$ = 2 gm soil. To obtain what was removed from 1 gm of soil in ppm, the result was divided by 2

The composition of the reducing agent was:
4:2:1 by volume mixture of 55% Hydriodic acid, 51% Hypophosphorous acid, 90% Formic acid. The mixture was then heated for 20 minutes in a nitrogen atmosphere to remove the sulphur impurities.

3.2.3. Organic Sulphur

Organic Sulphur content of the soil was calculated from the results of total - sulphur and adsorbed + soluble - sulphur[2] using the formula

TOTAL SULPHUR - (ADSORBED + SOLUBLE SULPHUR) = ORGANIC SULPHUR

The determination of the total-sulphur, organic-sulphur and adsorbed + soluble-sulphur enables the calculation of mineralisation as given by the formula

$$\frac{\text{Total plant sulphur} - \left\{ \begin{array}{l} \text{adsorbed + soluble - sulphur}^{4} \text{ + seed} \\ \text{sulphur + solution sulphur}^{3} \end{array} \right\}}{\text{Organic-sulphur}} \times 100$$

$$= \%\ \text{mineralisation}$$

---

1 Ten ml were removed from the 25 ml obtained from 5 gm soil (10/25), therefore 10 ml represent what was obtained from $(\frac{10 \times 5}{25})=2$ gm soil. To obtain what was removed from 1 gm in ppm, the result is divided by 2

2 Adsorbed + soluble - sulphur is also referred to as sulphate-sulphur or reducible-sulphur in the succeeding chapters.

3 Solution-sulphur = Sulphur impurities in the nutrient solution without added sulphur.

4 Δ adsorbed + soluble-sulphur is determined by the differences between the values of the soil obtained before and after plant growth.

3.3. POT EXPERIMENTS

3.3.0. Washing of sand

The sand was put in plastic basins and washed clean of soil in tap water.
It was then soaked overnight in concentrated hydrochloride acid (36 N.). The sand was then washed several times in tap water to remove the acid and finally rinsed in distilled water. It was then dried in the oven. Sieving was done to discard all the fine sand less than 0.5 mm in diameter. Sand particles of the 0.5 - 2 mm diameter was used in the experiment.

3.3.1. Preparations of the pots for planting

Five holes of 0.5 cm in diameter were made at the bottom of the 200 gm (by weight) plastic cups using a hot nail. The holes were to facilitate the movement of the nutrient solution which was supplied from the bottom. Glass wool was placed at the bottom of the cups to hold the soil in place so that the soil does not come out through the five holes.

3.3.2. Preparation of nutrient solution

Three nutrient stock solutions were prepared. The nutrient solution used in some treatments was prepared free of sulphur (except the sulphur impurities in the chemicals used in preparation). Another nutrient stock solution had sulphur added to it (supplied to plants used as controls). The last nutrient stock solution contained NPK for basal dressing. The composition of the stock solution, prepared free of sulphur was worked out carefully to supply the plants with all the necessary nutrients except sulphur so that any deficiency symptoms could be attributed to the latter (Cooper 1972 and Hewitt 1952). To ensure the antecedent, another stock solution containing NPK was supplied to the plants in additon to the nutrient solution.

Composition of nutrient stock solutions

a) Stock solution A (free of sulphur)

Chemical	Quantity (g/l)	$SO_4^{=}$ impurities
$Ca(NO_3)_2$	328.0	-
KNO_3	202.0	0.02%
$Na_2H_2PO_4.2H_2O$	208.0	-
$Cu(NO_3)_2.3H_2O$	2.5	0.02%
$NH_4MO_3O_{22}.4H_2O$	0.88	0.01%
H_3BO_3	18.6	0.002%
$MgCL_2.6H_2O$	154.0	0.002%
$ZnCl_2$	6.9	-

b) Stock solution B (with added sulphur)

Stock solution B was similar to stock solution A except $MgCl_2.6H_2O$ was replaced by 184.0 g/l of $MgSO_4.7H_2O$.

c) Stock solution C (basal NPK dressing)

KNO_3	30µgN/g soil and 84µgK/g soil
$Na_2H_2PO_4.2H_2O$	17.5 µg P/g soil.

Stock solutions A and B were diluted at a ratio of 1:1000 (Stock solution:Water) before supplying to plants.

Nutrient solutions A and B were kept as stock solutions. Before they were supplied to the plants, they were diluted at a ratio of 1:1000 (solution:water).

The diluted nutrient solutions were added to plants as needed everyday and the amounts recorded.

3.3.3. Experimental set-up

- Two controls with plants were included using solution B (with sulphur) for each soil sample.
- Two wet pots were incubated, for each soil sample, without plants to demonstrate the rhizosphere effects. Analyses of sorbed plus soluble sulphur was done before and after incubation to calculate any sulphur changes.
- Three pots with plants were used for each soil sample to study the sulphate sulphur changes without any sulphur supply.

Since there were 18 soil samples, the total number of pots used was (2 + 2 + 3) x 18 = 126 pots.
The pots were arranged in the greenhouse at random in order to overcome any position effects.

3.3.4. Planting

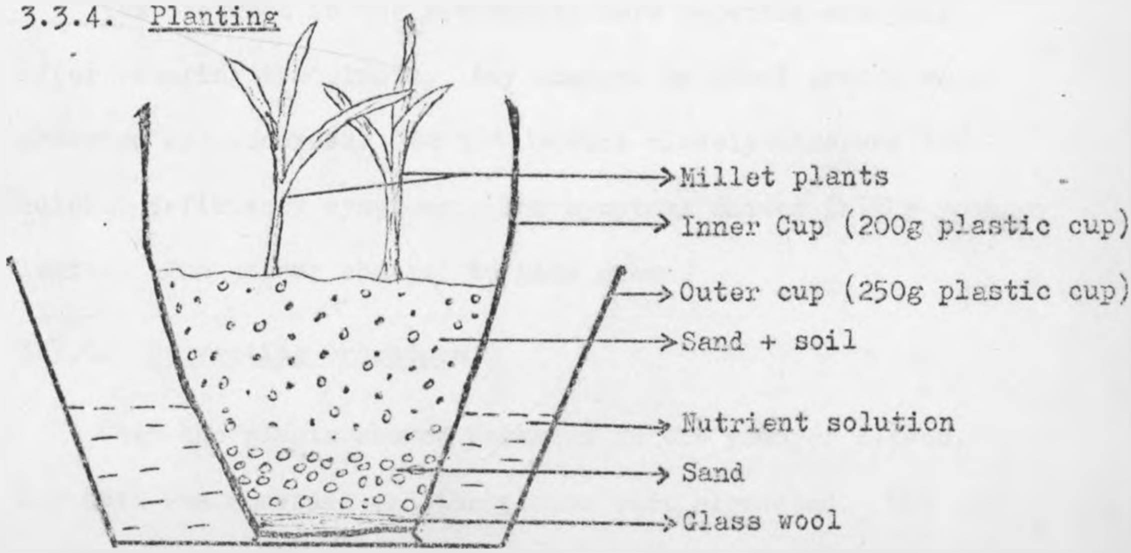


Fig. 1: Apparatus set-up.

25 gm of sand were weighed and put in the inner plastic cup plugged with glass wool at it's bottom. 125 gm of sand were weighed and put in the outer cup and 25 gm of soil sample added to the outer cup. The sand and soil were thoroughly mixed and poured in the inner cup on top of the 25 gm of sand put in earlier. Millet seeds weighing 0.5 gm (approximately 110 seeds) were placed at a depth of about 2 cm in the sand and soil mixture. The inner cup was placed in the outer cup and both cups were labelled. Fifty ml of water were added in the outer cup to soak the soil and provide the moisture necessary for germination. The plants grew on the necessary supply of nutrient solution and distilled water.

3.3.5 General management of pots

Two days after planting, 25 ml of NPK solution were supplied to the plants and pots without plants and thereafter every three days. Other nutrient solutions (after dilution) were supplied to the pots as needed and the amounts recorded. Distilled water was also supplied to plants to keep the soil moist and avoid oversupply of nutrients.

Temperatures in the greenhouse were recorded everyday after watering the plants. Any changes in plant growth were observed and recorded. The plants were closely observed for sulphur deficiency symptoms. The symptoms showed in the younger leaves. The colour changed to pale green.

3.3.6. Harvesting procedure

When the plants showed paleness in the younger leaves, the date was recorded and the plants were harvested. The pot contents were tapped out on to a tray. The soil and sand were shaken off the plant roots. The millet roots were then washed clean into the tray using distilled water. The plants were weighed, root, stem and leaf length were measured and plants were oven dried. The measurements were carried out on ten plants picked at random and the third leaf was used for taking the leaf length measurements. The oven dry weight was taken.

To recover the 25 gm of solid from the sand, the tray contents were oven dried, the soil was rubbed off the sand and passed through 0.5 mm seive into another tray. The sand was then washed with distilled water to remove all the soil. This water was then put in the oven to recover any remaining soil.

The soil was then collected in flat bottomed flasks ready for analysis of the adsorbed + soluble sulphur.

3.3.7. Preparation of plant samples.

The dried plant material was ground to a fine sample into a labelled bottle. This was stored for analyses of 'sulphate'-sulphur and total - sulphur.

Both the soil and the plant samples were analysed for sorbed + soluble or reducible sulphur to calculate the changes of sulpur content in the soil and the plant uptake.

3.3.8. Plant sorbed + soluble-sulphur analysis.

Zero point one gm. of plant material were weighed into a reduction flask. This was directly connected to the reduction plant. Five mls of the reduction agent were ran into the flask. The sample was then distilled into 10 mls N NaOH and titrated against 0.0005M Mercuric chloride. The calculation was similar to that of the soil sorbed + soluble - sulphur already

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER IV

4. RESULTS AND DISCUSSION

4.0. Soil analytical results

The six soil profiles gave varied results. Table I illustrates variations in contents of different forms of sulphur. However, the results had some relationship with other soil properties such as clay content and organic carbon content. Soils which were sampled from Profiles 1, 2, 3 and 5 had a general increase down the profile for sulphate-sulphur. The soils sampled at Kabete Field Station (6a - 6c) showed a sulphate-sulphur bulge in the middle horizon. The soils from Cherengani Hills (formerly under forest), 4a - 4c, gave contrasting results. The top horizon had about ten-times more sulphate-sulphur than the lower horizon (23.2 ppm for top soil compared to 2.6 ppm for subsoil). The pattern of organic-sulphur followed that of the total-sulphur because organic-sulphur forms the bulk of total-sulphur. These results too, had no general trend down the soil profiles. The soil Profile 1 (from NARS, Kitale) had an odd rise in the second horizon (1b), while Profile 2 from the same area but under grass had moderate low fall with depth for total-sulphur.

Total sulphur of soil from Endebbes (3a-3c) were uniform down the profile while the soils from Cherengani Hills formerly under forest (4a - 4c) had an exceptionally high total-S content, decreasing with depth. Soil sample 5a - 5c had fairly low total-S content and uniform down the profile. These results indicate that

TABLE 1: FORMS OF SULPHUR (ppm)

SAMPLE NUMBER	TOTAL-SULPHUR	SULPHATE-SULPHUR	ORGANIC-S
N.A.R.S., Kitale			
1a	122.2	12.1	110.1
1b	158.0	13.9	144.1
1c	116.7	39.1	77.6
N.A.R.S, Kitale (grass)			
2a	192.8	7.1	185.7
2b	106.4	16.7	89.7
2c	136.9	50.2	86.7
Endebbes			
3a	277.9	18.5	259.4
3b	280.0	17.4	262.6
3c	237.8	40.2	197.6
Cherengani, Forest			
4a	780.0	23.2	756.8
4b	399.0	2.4	387.6
4c	374.7	2.6	272.1
Cherengani, Grass			
5a	64.4	1.9	62.5
5b	54.0	2.2	51.8
5c	67.3	1.6	65.7
Field Station, Kabete			
6a	383.8	16.6	367.2
6b	416.6	40.5	376.1
6c	182.4	13.1	169.3
S.E.	±0.13%	±0.7ppm	

the sulphur content of the soil depends on several soil properties other than the soil depth. However earlier work has shown that sulphate-sulphur is mainly found in the subsoil. (Russell 1973)

4.0.2. Relationship between organic carbon and soil total-sulphur

Using values of total-S from table I and values of carbon from table II, it can be seen that the trend of % carbon follows that of total-Sulphur. Taking the soils of Cherangani Hills as an example (Profile 4 and 5), it is clear that sample 4 which was formerly under forest has the highest value of %C (4.08-3.86) and also the highest value of total-S (779-375 ppm). Sample 5 which was under poor grazing and was very gravelly gave the lowest total sulphur values as well as the lowest carbon values (67.27 - 54 ppm S and 1.3 - 1.03 %C)

The trend of % carbon in the soils is mostly followed by the organic-sulphur content. This is best demonstrated by the soil samples 1 and 2 from the N.A.R.S., Kitale. Organic-sulphur bulge in sample 1 is also reflected in the %C bulge, while the general decrease of the organic-sulphur in sample 2 is also reflected in general decrease of %C down the soil profile. This pattern is not true with the sulphate-sulphur values.

These results show that there is a close relationship between organic-sulphur and % carbon and therefore total-sulphur and % carbon. A ratio of %C:Organic S can therefore be calculated and be of use in the determination of sulphur release (See Section 4.0.4).

TABLE II: ANALYTICAL RESULTS

SAMPLE NUMBER	% CLAY	% C	% N	pH (H_2O)
N.A.R.S., Kitale				
1a	19	1.69	0.15	5.0
1b	24	1.77	0.13	5.3
1c	17	1.17	0.08	5.3
N.A.R.S., Kitale				
2a	21	1.75	0.19	6.1
2b	20	1.42	0.12	6.0
2c	19	1.05	0.08	5.7
Endebbes				
3a	69	2.70	0.28	6.0
3b	68	2.80	0.26	6.0
3c	65	1.960	0.22	5.8
Cherengani, Forest				
4a	69	4.08	0.69	7.7
4b	10	3.12	0.39	6.5
4c	13	3.86	0.29	5.8
Cherengani, Grass				
5a	3	1.03	0.08	5.5
5b	2	1.14	0.07-	5.6
5c	2	1.30	0.06	5.5
Field Station, Kabete				
6a	80	2.79	0.33	5.6
6b	81	2.60	0.28	5.7
6c	78	2.21	0.19	6.0
Std. dev.	-	± 0.11	± 0.02	± 0.04

4.0.3. Relationship between Nitrogen and the soil Sulphur

Soil sulphur and soil nitrogen behave in almost a similar manner and the proteinaceous tissues contain both of these elements. Soils low in nitrogen will also be low in organic sulphur. This is shown by soils of Cherengani Hills (Profile 4 and 5). Profile 4 which was formerly under forest gave the highest organic sulphur values (756.8 ppm) and also the highest %N values (0.69%) while Profile 5 which was under poorly grazed land gave the lowest values of 51.8 ppm and 0.06% respectively for organic-S and %N. This meant that there is a relationship between organic-S and nitrogen which can be expressed as a ratio. Such ratios were shown by calculated values presented in table III.

4.0.4. The C:N:S ratios

Table III shows the results of the calculated C:N:S and C:S ratios. The nitrogen content was taken as a constant (10) for the C:N:S: ratios and sulphur content was taken as a constant (1) for the C:S ratios. Taking N content as a constant, it was noticed that the C:N ratios varied (ranging from 5.9 to 17.2) much more than the N:S ratios (from 7.3 to 13). This could be attributed to relationship between sulphur and nitrogen as discussed in the above section.

The forest soil samples (4a - 4c) had a low C:S ratios in the top horizons probably due to accumulation of organic matter which is well decomposed. The C:S ratios are exceptionally high in profile 1 and 5. The probable reason for the high ratio in Profile 5 could be the fact that the soil is very low in both clay and

TABLE III: C:S[1] AND C:N:S RATIOS

SAMPLE NUMBER	C	:	N	:	S	C	:	S
N.A.R.S., Kitale								
1a	112.7	:	10	:	0.73	154.4	:	1
1b	136.2	:	10	:	1.1	123.8	:	1
1c	146.3	:	10	:	0.98	149.3	:	1
N.A.R.S., Kitale								
2a	92.1	:	10	:	0.98	94.0	:	1
2b	118.3	:	10	:	0.74	159.9	:	1
2c	131.3	:	10	:	1.09	120.5	:	1
Endebbes								
3a	96.4	:	10	:	0.93	103.7	:	1
3b	107.7	:	10	:	1.01	106.6	:	1
3c	89.1	:	10	:	0.90	99.0	:	1
Cherengani, Forest								
4a	59.1	:	10	:	1.1	53.7	:	1
4b	80.0	:	10	:	1.0	80.0	:	1
4c	133.1	:	10	:	1.3	102.4	:	1
Cherengani, Grass								
5a	128.8	:	10	:	0.79	163.0	:	1
5b	148.6	:	10	:	0.74	200.8	:	1
5c	171.7	:	10	:	1.1	156.1	:	1
Field Station, Kabete								
6a	84.5	:	10	:	1.1	76.8	:	1
6b	92.9	:	10	:	1.3	71.5	:	1
6c	116.3	:	10	:	0.89	130.7	:	1

1 Organic-sulphur used in these calculations.

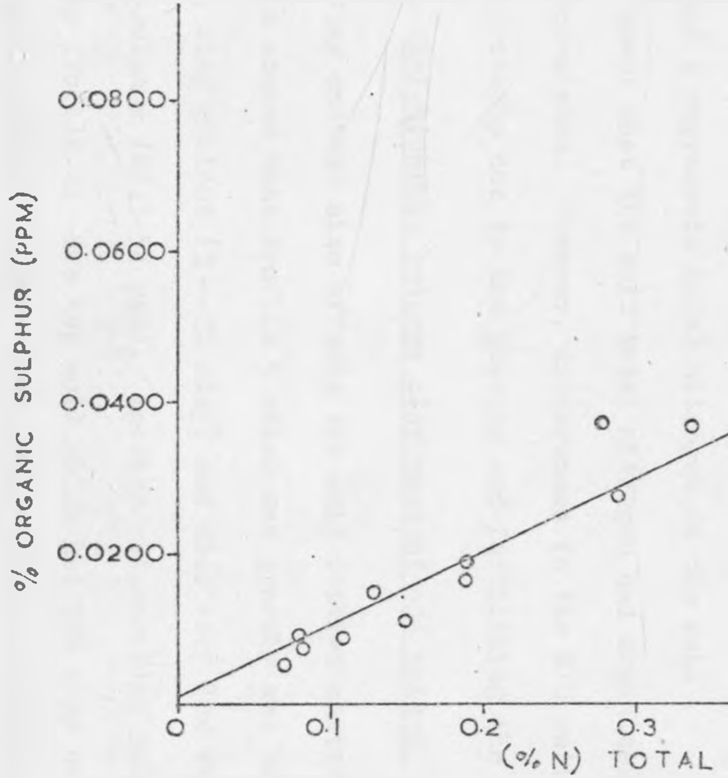
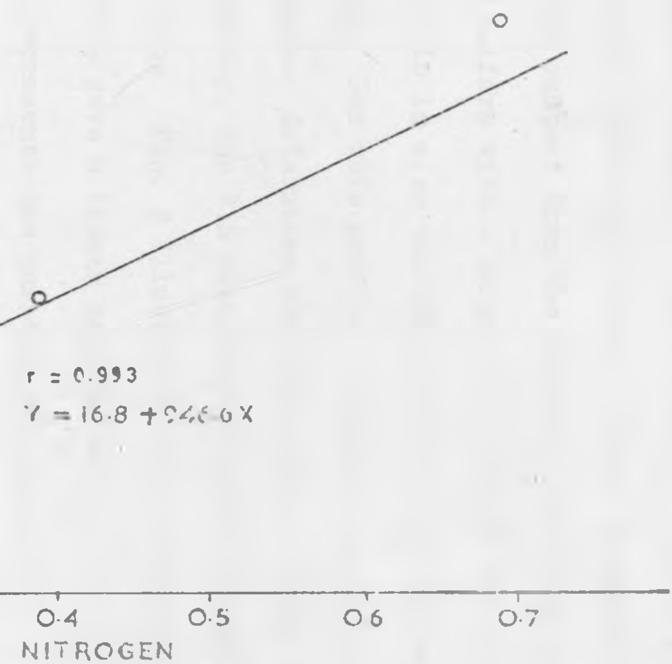


FIG.2. RELATIONSHIP BETWEEN



TOTAL NITROGEN AND ORGANIC -S

cation content and so the sulphur binding ability of the soil is reduced. The sulphur present in the soil could then be subjected to a high degree of leaching . However, it does not appear possible to attribute clay content of the soil to the odd increase of the C:S ratio in sample 2b from N.A.R.S., Kitale and sample 6c from Kabete Field Station. Profile 1 seems to agree with the pattern of clay content down the profile. The clay content in Profile 1 is uniform with a slight increase in the middle horizon and the C:S ratio is also uniform with a slight decrease in the middle horizon. For this profile, it seems the clay binding ability of sulphur determines the C:S ratios. While the C:S ratios vary widely, the N:S ratios do not seem to vary as widely as the C:S ratios. Fig. 2 illustrates this variation. Calculations from the results gave a linear relationship of $y = 16.8 + 946.6x$

where y represents the quantity of organic-s

and x represents total nitrogen in the soil

These meant that the soil total nitrogen and organic-sulphur are well correlated. However, differences in the N:S ratios often occur probably due to the plowing and fertilizing the land.

4.0.5. Relationship between clay content and soil-S

Clay content also affects the soil total-S content. The results showed that Profile 5 which was gravelly and had very little clay content (3 — 2% clay) had also very low values of total-sulphur (67.3 54 ppm). Another sulphur-clay relationship was given by Profile 4. The top soil which had 69% clay had also very high total-sulphur content (780 ppm). The clay content drastically dropped in the lower horizons to 10% and 13% and this was also followed by a drop in total-sulphur to 399 ppm and 374 ppm respectively. Profile 1 had slight increase in clay content in the second horizon and this also occured in the values for total-S There was an odd rise in horizon 2 to 158 ppm total sulphur. Profile 3 gave a fairly uniform pattern of total sulphur, (277, 280 and 237 ppm). This uniform content also appeared for the values of Profile 6 which had fairly high values of total-sulphur which decreased with depth (383.8, 416.6 and 182.4 ppm), and the clay content was also fairly high but uniform down the profile (80, 81 and 78%). The patterns of profile 6 suggested that it was not the quantity of clay that affected the total-sulphur content but possibly other mechanisms were involved in the sulphur binding in the soil.

There are several mechanisms in the sulphur binding of sulphur in the soil. Two of these mechanisms are the surfaces of aluminum and iron oxides, and the ligands of clay edges. In soils with mollic epipedons, as it appears in Profile 4 (sample 4a), the clay soils (other things being equal) often have high organic matter contents. In such soils, the organic matter aids in the binding of soil sulphur by some mechanisms that are not quite clearly known. In ultisols as represented by Profiles 3 and 6, clay edges bind sulphur as much as other mechanisms. The edges of clay particles possess ligands which are not fully co-ordinated in the "ideal lattice". The co-ordination is completed by -OH groups and water molecules. Positive charges develop at low pH values at these sites by the adsorption of H^+ ions from solution.

The positive charges attract ions as NO_3^- and $SO_4^=$. In this manner, the clays bind the $SO_4^=$ ions in the soil. In ultisols, the oxides of aluminum andiron are present. These hydrated oxides develop positive charges in a similar manner to the clay edges. The oxides then adsorb $SO_4^=$ ions present in the soil.

In general, it can be said that the sulphate adsorption depends on the anion exchange capacity of the soil and therefore clay content plays a part in the $SO_4^=$ adsorption. The extent of leaching also affects the sulphate-sulphur content in the soil. The ultisols (possibly profiles 3 and 6) show fairly high clay contents without any illuviation. The sulphate-sulphur content of these soils show an increase with depth which may suggest $SO_4^=$ ion leaching down the profile. Similar patterns are seen in Profile 1 (12.1 fo 39.1 ppm) and Profile 2 (7.1 to 50.2 ppm) as can be seen in table I. Cherengani Hills which have low rainfall relative to other sites do not show any sulphate leaching down the profile. Furthermore, an unfertilized soil under grass where total-sulphur is low cannot show a sulphate-sulphur bulge because the grass roots take in sulphur as fast as it enters the soil. It therefore appeared that the sulphate ion adsorption (among other soil properties) also depends on the extent of leaching of the soil.

4.0.6. Effect of vegetation on the sulphur content of the soil

All the six profiles had previously been under different vegetation. It is, therefore, possible to examine the possible effects of the previous vegetation on the sulphur content of the soil. Total-sulphur on the samples analysed consists more of organic-sulphur than sulphate-sulphur. Since organic-sulphur depends on the amount and type of vegetation it must have a part to play in this case. Vegetation which was previously grass shows a relatively low total-sulphur content. An example appears in Profile 2 from N.A.R.S., Kitale, which is an unbroken grass sward. This site had been under grass for at least six years without fertilizer application and it shows slightly higher total-S values than profile 5 but still lower than other profiles from other types of vegetation. Profle 5 which was used for rough grazing, with some shrubs gives the least values for total-S content (less than 70 ppm.). Profile 1 which was previously under bush and was not grazed falls between Profile 2 and Profile 5. Since the pattern of organic-S follows that of total-S, the effect of vegetation on these two types of sulphur is the same in all cases. The type of vegetation relates closely to the soil organic carbon and hence soil organic matter.

The organic matter effects appear in Profiles 3, 4 and 6. These Profiles were under cultivation. Profiles 3 and 6 had fairly high values of organic-S. This could be attributed to crop residues in the field which increase the soil organic matter. Profile 4 had very high organic-S values (756.76). While this high content could possibly be attributed to the high clay content, it was also possible that the high rate of litter turn-over provided a high organic matter content and hence high organic- sulphur content in the soil.

The sulphur content under undisturbed vegetation tends to stabilize (when other nutrients are not limiting); once the outgoing sulphur (through leaching and plant uptake) equals the incoming sulphur, under natural conditions, an equilibrium state is attained. In this case, the forest soils would reach a much higher equilibrium than the grassland soils. Because organic-sulphur forms most of the total-sulphur in the soil, total-sulphur depend on the soil organic matter and therefore the type and amount of vegetation.

4.1. PLANT AND SOIL ANALYSES

The experiment in the greenhouse had three distinct treatments. These were:

c - Treatment where sulphur was supplied to the plants.

e - Treatments where sulphur was not supplied to the plants.

r - Treatments without sulphur supply and without plants.

Analysis of both plants and soils was carried out in the laboratory for the total-sulphur and the sulphate-sulphur (adsorbed + soluble-sulphur). Results were tabulated as in Appendix IV. All long the plant growth period, the changes in every pot were recorded.

4.1.0. Observation on plant performance

Establishment of plants in all the pots was excellent because percent germination of 95% was recorded. The growth rate in all treatments in the first week was very rapid. Germination started two days after planting. The average height of the plants was 4.2 cm. However, this rate of growth subsided in many pots during the second week after planting. This could be due to exhaustion of sulphur in those soils which had very low sulphur content. An example of the antecedent is Profile 5 from Cherengani Hills (under rough grazing.)

Two pots had been specifically planted without soil and without sulphur supply. Sand was used for mechanical support of the plants. These pots, marked "symptom recognition pots", were used to observe the sulphur symptoms in millet plants. The symptoms showed in the first pot on the seventeenth day after planting. The second pot showed symptoms two days later. The symptoms, which appeared as paleness in the younger leaves, chlorosis in all leaves at later stages, were clearly seen in these pots. The plants, for at least 17 days, had been utilising seed-sulphur and sulphur impurities of the nutrient solution.

The pots containing soil but without added sulphur were closely observed. The first symptoms occured in pots of Profile 5 (from Cherengani Hills) after 28 days. The last pots to show symptoms were from Profile 4 and Profile 2. (Cherengani Hills - previously under forest and N.A.R.S. under grass sward). Unfortunately, the pots of Profile 3 and 6 (volcanic soils - high in clay content) did not grow well in the first cycle of planting. The reason for this was thought to be poor aeration of the soil. An equal amount of nutrient solution supply to all the pots flooded the pots of Profiles 3 and 6. Fresh pots containing these soils were then planted with a less water supply, (water had been previously added to the pots whenever the nutrient solution was not added to keep the pots moist), and with more sand added to the pots to improve the aeration.

4.1.1 Observations on the appearance of sulphur deficiency symptoms

This was best demonstrated in plate I to IX. Plate I shows the symptoms of sulphur deficiency in the millet plant. Paleness was seen mainly in the longest leaves which happened to be the youngest open leaves in plants.

4.1.2 Performance of treatments supplied with sulphur

Plants with sulphur supply were used as controls in the experiment. These had their labelling system ending in 'c'. These plants showed very good performance. The plants were healthy, tall, green and had broader leaves than the symptom recognition pots (Plate II). Plate IV and V also shows the plants with sulphur quite healthy. This indicates that sulphur is an important nutrient in the plant growth.

4.1.3 <u>Performance of treatments without sulphur supply</u>

Plate III show similarities of the pots without sulphur supply with those of symptom recognition pots. Soil samples 5 (Cherengani Hills gravely soil) showed very poor plant growth. The pot marked 5ae was already starting to die but some paleness could be seen starting to appear. The pots had already exhausted most of the nutrients from the soil and it seems that there was an imbalance in the nutrient uptake due to lack of sulphur in the soil. This was thought to be so because the control which had similar treatment but had sulphur in addition showed very good growth. A comparison of plate II and those marked 5be and 5ae in plate III could show a clear contrast between the pots with sulphur and those without sulphur (5be and 5ae).

The pots which had initially high sulphur content in the soil showed very good growth. Infact they grew as well as the pots with applied sulphur. Plate IV, V and VI shows the good growth of soil from N.A.R.S., Kitale and Cherengani Hills (forest area). The photographs were taken two days before harvesting and the symptoms had just started to appear. These pots also showed very clear sulphur deficiency symptoms on their third and fourth leaf (Plants had upto four leaves only).

In the first planting cycle, the volcanic clay soils (Profile 3 and 6) showed very poor growth as plate VIII shows. The problem

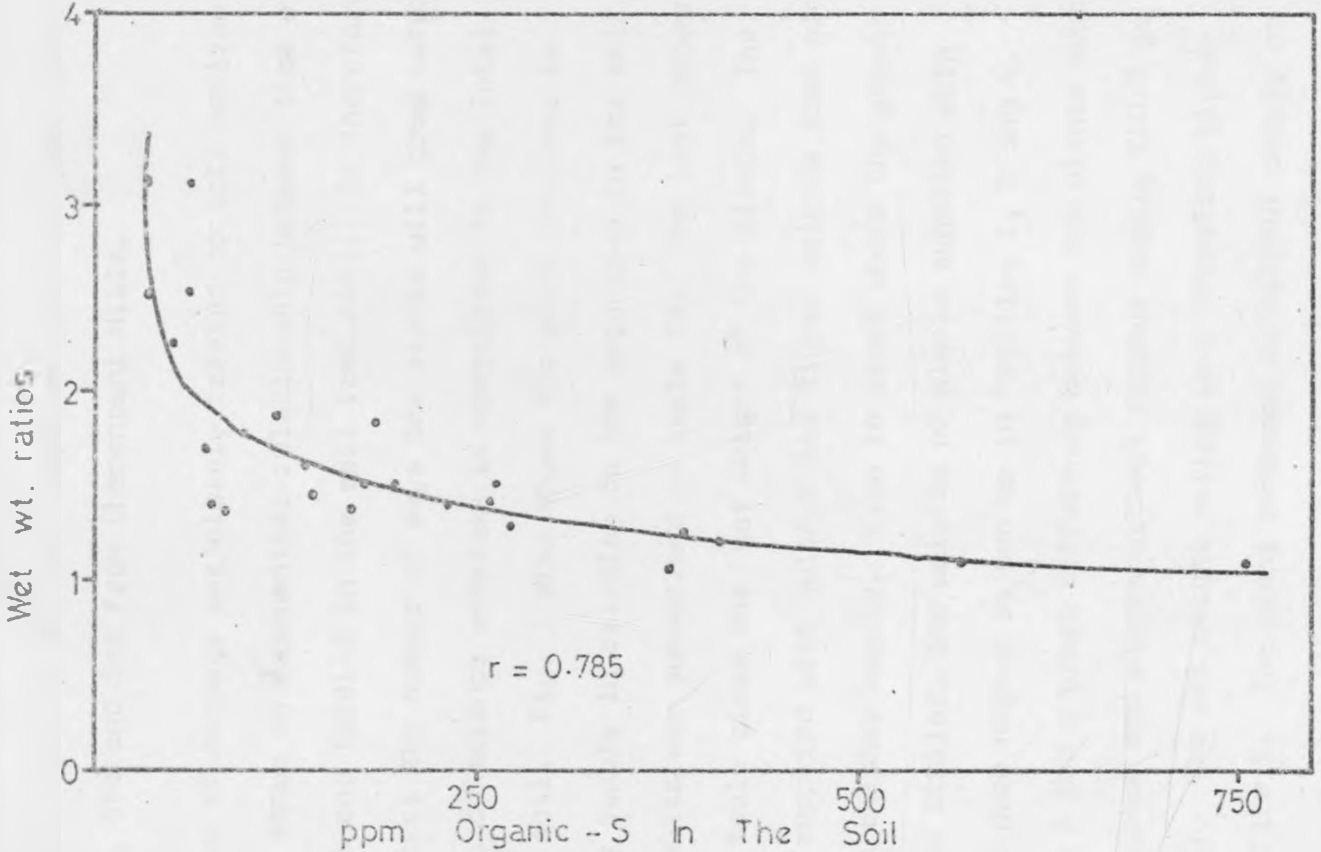


Fig. 3 Relationship between organic-S content and relative yeilds of sorghum

Wet wt ratios = (yield with added S / yield without added S) of aeration was suspected and the pots of profile 6 were left unwatered for two days. The plants showed an improvement as is seen in plate VII. Plate III also shows an improved state of 6ae in comparison with the poor growth of 5ae, 5be and 5ce from Cherengani Hills.

Time of harvest was closely related to soil horizons. Fig. 4 shows an exponential relationship between time of harvest and Total-S in the soil (r=0.869). It therefore shows that the number of days the plants will grow before showing deficiency symptoms is correlated to the Total-S in the soil. Fig. 3 also shows the plant response to sulphur supply in relation to the organic-S in the soil. The results are summarised in table IV. The last column of the table gives the wet weight of the plants. The plants supplied with sulphur had higher weights than plants without sulphur supp v. Even in cases where the growth appeared similar, the weights of plants supplied with sulphur were higher as can ue in Profiles 1, 2 and 4. Profile 5 had a great difference between the plants supplied with sulphur and plants without sulphur supply (10.7 gm on average). The wet weight ratios were therefore higher for Profile 5. The plant response to sulphur supply or the wet weight ratios we-. higher for soil horizons with low organic-S and vice-versa. The plant response to sulphur supply was found to be correlated to the soil organic-S (r=0.785). An attempt to plot plant response against total-S and sulphate-S gave a similar trend to that of organic-S.

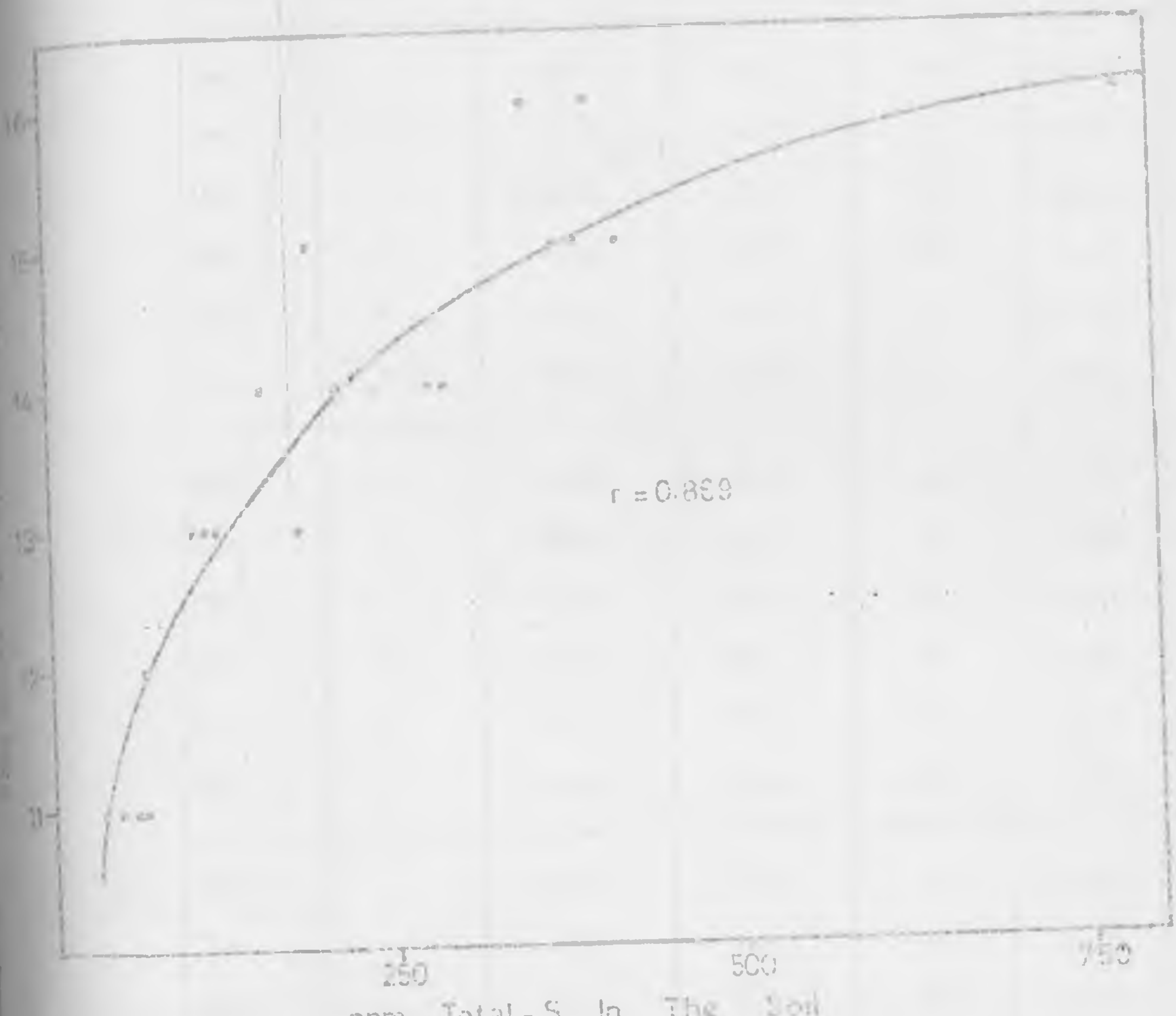


Fig 5 Relationship between time of harvest and total S in the soil. Y-axis represents the difference between the total number of days the plants grew and the number of days the symptom recognition plots grew before showing deficiency symptom.

TABLE IV: MEAN HARVEST RESULTS

SAMPLE NUMBER	NUMBER OF LEAVES	LENGTH OF THIRD LEAF (cm)	STEM LENGTH (cm)	ROOT LENGTH (cm)	WET WEIGHT (gm)
1ac	4	20	5.7	13	14.10
1ae	4	14.0	4.5	7	12.69
1bc	4	25.0	7.5	13	15.98
1be	4	15.0	5.5	10	10.88
1cc	4	22.0	6.5	13	14.69
1ce	4	18.0	4.5	7	10.51
2ac	4	21.0	6.0	9	13.59
2ae	4	18.0	6.0	6	7.38
2bc	4	18.0	5.0	15	15.97
2be	4	17.0	4.5	8	13.28
2cc	4	21.0	6.0	8	12.05
2ce	4	19.0	5.0	5	8.80
3ac	4	20.0	7.0	9	13.31
3ae	4	9.0	5.0	4	9.28
3bc	4	18.0	5.0	8	13.50
3be	4	14.0	4.0	3	8.88
3cc	4	21.0	7.0	8	13.82
3ce	4	15.0	5.0	3	9.08
4ac	4	20.0	6.5	10	12.88
4ae	3	15.0	5.0	8	11.80
4bc	4	18.0	5.5	11.0	15.07
4be	3	14.0	5.0	7	11.88

TABLE IV: MEAN HARVEST RESULTS - CONT'D

SAMPLE NUMBER	NUMBER OF LEAVES	LENGTH OF THIRD LEAF (cm)	STEM LENGTH (cm)	ROOT LENGTH (cm)	WET WEIGHT (gm)
4cc	4	19.0	5.0	11.0	14.85
4ce	3	13.0	4.5	7	11.33
5ac	4	18	6.0	15	17.12
5ae	3	7	3.0	7	6.63
5bc	4	19.0	5.0	11	17.01
5be	3	10.0	4.0	7	7.53
5cc	4	19.0	5.5	12	17.25
5ce	3	10.0	2.5	5	5.58
6ac	4	16.0	5.5	8	13.88
6ae	3	10.0	3.0	5	7.25
6bc	4	16.0	5.0	9	12.77
6be	4	14.0	4.5	10	12.19
6cc	4	14.0	4.5	6	11.07
6ce	3	7.0	4.0	4	8.05

PLATE I: Plants show the sulphur deficiency symptoms

PLATE II: A comparison between the sulphur deficient plants and plants supplied with sulphur
2bc - N.A.R.S., Kitale; 5ac, 5bc and 4cc - Cherengani Hills.

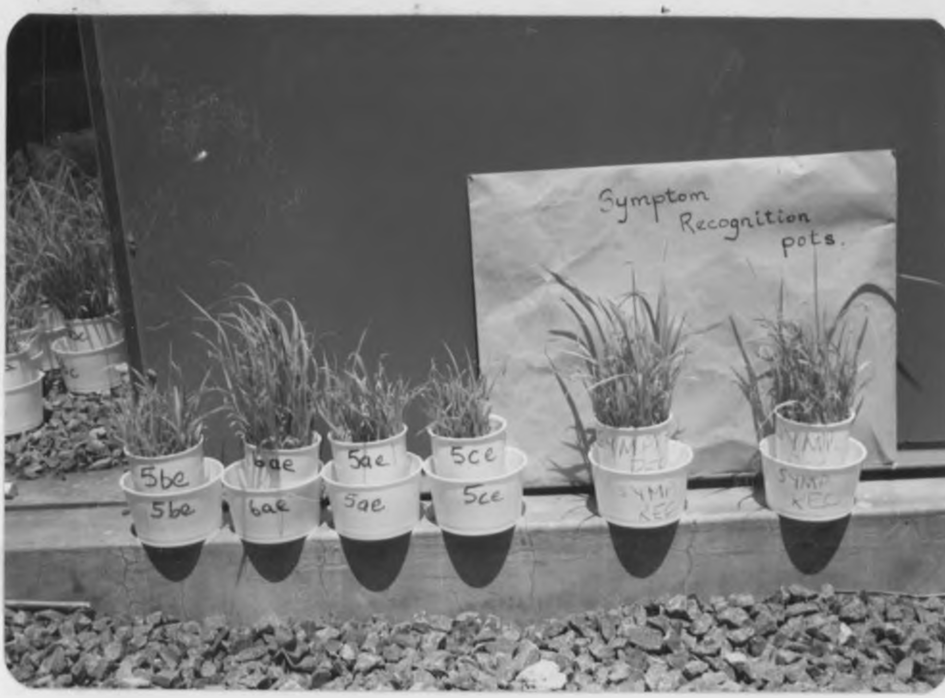


PLATE III: Plants without added sulphur (poor growth) 5ae (0 - 15 cm), 5be (15 -30 cm), 5ce (30 - 45) from Cherengani Hills and 6ae (well aerated) from Field Station, Kabete.

PLATE IV: Plants in both pots show good growth but lae is starting to become pale - N.A.R.S., Kitale

PLATE V: Just before symptoms appear, plants with added sulphur (2bc) and plants without sulphur supply (2be) show equally good growth - from N.A.R.S., Kitale.

PLATE VI: Just before symptoms appear, plants with sulphur supply (4ac) and plants without added sulphur (4ae) show equally good growth. - from Cherengani Forest.

PLATE VII: Plants with added sulphur and plants without added sulphur show equally poor growth probably due to poor aeration. 6a (0 - 15 cm), 6b (15 - 30 cm) and 6c (30 - 45 cm) from Field Station, Kabete.

PLATE VIII: Plants with added sulphur showing poor growth - 3ac (0 - 15 cm), 3bc (15 - 30 cm) and 3cc (30 - 45 cm) from Endebbes.

4.2. SULPHUR IMMOBILISATION

Table V shows rates of S mineralisation. In most pots, organic-S mineralisation occured. The last samples (6a - 6b) and samples in Profile 5 without plants show negative mineralisation. This suggested sulphur immobilisation in the pots of Profile 5 and 6. Sulphur immobilisation occured probably due to high sulphur requirements by microbes for production of their extra-cellular enzymes necessary for cellulose break-down (Stewart et al 1966). No sulphur is released under such circumstances but instead, sulphur is incorporated in the high molecule humic acid fraction of organic matter (Koter et al 1965). Those results for Profile 5 and 6 could also be due to the pattern of mineralisation (Sect. 2.9) and not an indication of immobilisation.

4.3. SULPHUR MINERALISATION

Table V shows the mineralisation of organic-sulphur in different soils. The rate of organic-sulphur mineralisation was high in profiles 3 and 4 (with plants) relative to other profiles. This could probably be attributed to the relatively low ratios of C:S in these profiles. Profiles 1 and 5 had low rates (with plants) of organic-sulphur mineralisation with slight decrease down the profile. While profile 2 had low and constant rate of organic sulpur mineralisation (0.03), profile 4 had high rates increasing with depth.

In pots with plants, the rates of organic-S mineralisation did not show any pattern while the percent mineralisation showed a definite decrease with depth especially in the lowest horizon except for Profile 4 which showed relatively high percent mineralisation increasing significantly with depth (4.2 to 9.4). The reason for these variations within profiles is difficult to suggest since the variations did not follow

TABLE V: The mean rate of organic-sulphur mineralisation

% ORGANIC-S MINERALISATION			RATE OF MINERALISATION[1]		
Sample no.	Pots with plants	Pots without plants	Pots with plants(a)	Pots without plants (b)	(b) - (a)
1a	1.32	7.90	0.04	0.25	0.21
1b	0.74	5.66	0.02	0.19	0.17
1c	0.32	1.50	0.01	0.05	0.04
2a	1.00	5.42	0.03	0.17	0.14
2b	1.00	3.41	0.03	0.11	0.08
2c	0.90	2.03	0.03	0.06	0.03
3a	3.95	5.67	0.13	0.19	0.06
3b	3.85	3.96	0.13	0.13	0.00
3c	2.93	3.39	0.10	0.11	0.01
4a	4.2	1.63	0.13	0.05	-0.08
4b	6.0	3.51	0.18	0.11	-0.07
4c	9.4	5.11	0.28	0.15	-0.13
5a	2.3	-2.03	0.08	-0.07	--
5b	0.8	-1.43	0.03	-0.05	-
5c	1.0	-1.75	0.04	-0.06	-
6a	-0.7	-1.39	-0.02	-0.05	-0.03
6b	-0.5	-2.07	-0.02	-0.07	-0.05
6c	-2.0	-5.14	-0.07	-0.17	-0.10
	S.E. = 0.0024%		S.E. = 0.0066%		

1 Rate of organic sulphur mineralisation is calculated per day.

any pattern of the previous results of organic carbon, clay content or sulphur content of the soils.

Freney (1975) reported that experimental work in the field for 30 years gave mineralisation values of less than 2% and Namilonge, Uganda had 1.8% mineralisation.* Table V gives values of Profiles 3 and 4, and sample 5a higher than the reported value of Freney. Most of the pots without plants except for samples 1c and 4a and the immobilisation pots, the percentage mineralisation was higher than 2%. The reason for this difference is mainly environmental factors. The differences in the two environments (field and greenhouse) were mainly due to:

i) – modification of soil conditions in the greenhouse. The pots had additional complete nutrient solution but without sulphur. This ensured a nutrient balance in the soil and hence produced conditions condusive to organic-sulphur mineralisation by microbes.

ii) – root density in the pots. Due to a small volume of soil provided to the plants, the root density within that volume was much more than under field conditions. Every part of the soil was reached by the plant root and hence increased in apparent mineralisation. The root density in the greenhouse was made deliberately high (in this study) to get rapid onset of deficiency symptoms and so they might also have created a different environment in some pots from the environment in the field.

iii) – Temperature changes in the greenhouse. The temperature range recorded in the greenhouse where this experiment was carried out was 15 – 32°. Most days had a range of 21 – 32°C.

---

* (Bromfield 1977).

This temperature range fell between the optimal temperature range of rapid sulphur mineralisation (20 - 40%) and so sulphur mineralisation was encouraged in some pots.

iv) – Effect of moisture. The optimal moisture range reported in the field for sulphur mineralisation is 15–40%[1] moisture. Under natural conditions, the soil may dry to a moisture level less than 15% and hence reducing the sulphur mineralisation. In this experiment, the pots were kept moist by constant watering. This could have possibly increased the sulphur mineralisation in some pots of Profiles 3, 4 and 5.

v) – Prior drying of the soil. This also has been reported by Freney and Swaby (1975). Drying of the soil prior to wetting increased the sulphur release of the soil. Since the soil samples used in the experiment had been air dried, it could be possible that there was an increase in sulphur release. Prior drying also increased sulphur release from organic matter in the soil. The high release from Profile 4 could probably be attributed to the release from organic matter mineralised in those soil samples.

vi) – Time factor. When the soils are incubated, for a short time, mineralisation for both nitrogen and sulphur may be considered higher than in the field . This is because of the modified conditions of the soil during the incubation period. The soils in this study were incubated for a maximum of 32 days and this period was short enough to show the time factor effects.

vii) The pattern of sulphur release. The section on the Literature review gives four patterns of sulphur release, during the incubation period. Some pots in this experiment seem to have followed the pattern which suggests a rapid release during the first few days followed by linear release. (Profiles 3, 4 and 5). Other pots seem to have followed the pattern of immobilisation in the initial stage followed by mineralisation in late stages. (Profiles 5 and 6). Profiles 1 and 2 might probably have given a steady release over incubation period. The differences in patterns of mineralisation could probably be the reason for the differences in the rates and percentage of mineralisation.

Due to the possible reasons given above, the rate of organic-sulphur mineralisation (especially in pots without plants) was relatively higher than would be expected in the field.

4.4 RELATIONSHIP BETWEEN MINERALISATION RATE AND C:S RATIO

Table III and table V show the ratios of C:S and the rate of organic sulphur mineralisation consecutively. It is normally expected that when the sulphur content is very low in relation to the carbon content of the soil, mineralisation rate of organic sulphur is also low. This is because the sulphur released is taken in by microbes which decompose the high quantity of organic carbon in the soil. The reverse is expected when the C:S ratio is narrow. Some results of this experiment give the expected pattern.

Profile 4 (Cherengani - previously under forest) had a narrower ratio (53.7 - 102.4) than profile 5 (Cherengani poorly grazed grass) which had a C:S ratio of 156.1 - 200.8. Profile 4 showed a higher percentage of organic-sulphur mineralised and also a higher rate of mineralisation (0.04 cf 0.28). Profile 3 which also had a narrower C:S ratio relative to Profiles 1, 2, 5 and 6 appeared to have a higher rate and percentage mineralisation of organic-sulphur (above 0.10 and 2.9% mineralisation). Profile 1 and samples 2b, and 2c had a wide C:S ratio (120:1) and consequently had a lower rate of organic-sulphur mineralisation (0.01 - 0.04) and similarly a lower percent mineralisation (0.32 - 1.32) than Profiles 3 and 4. However, the reason for samples 2a, 6a and 6b having such low rate of mineralisation or immobilisation when the C:S ratios are narrow is difficult to suggest. Probably they were affected by the pattern of mineralisation they had during the short period of incubation as had been discussed above.

However, it could be concluded from some Profiles (3, 4 and 5) and some samples (2b, and 2c) that there is apparent relationship between C:S ratio and the rate of organic-sulphur mineralisation. Hence the narrower the C:S ratio, the higher the rate of organic-sulphur mineralisation. Profile 6 and sample 2a suggested that the rate of sulphur mineralisation did not necessarily depend on the C:S ratio and hence the level of organic matter in the soil. A possible explanation for the later samples' results could be that the rate of organic-sulphur mineralisation depends on the level and nature of freshly added material to the soil other than the bulk of organic matter in the soil. A similar conclusion was also reached by Freney et al (1962) and Barrow (1961).

4.5 RHIZOSPHERE EFFECTS ON SULPHUR MINERALISATION RATES

Table V shows some apparent differences between pots without plants and pots with plants for Profiles 1, 2, 4, 5 and 6. In profiles 1 and 2 (from N.A.R.S.), the pots without plants appeared to have higher mineralisation rates than the pots with plants (difference range of 0.03-

0.21). A possible reason for this observation could be that pots without plants had no sulphur removal by plants and hence sulphur accumulated in the pots. This accumulation of sulphate-sulphur was also a source of sulphur supply to the micro-organisms involved with mineralisation and so the mineralised sulphur is released to the soil as excess. Although profile 3 appeared to have higher mineralisation rates in pots without plants than pots with plants, the differences did not appear great. Profile 4 had the reverse results to other profiles. The pots with plants had higher mineralisation rates than pots without plants. This could be due to the rhizosphere effects to the mineralisation rates. Probably the plants provided a rhizosphere conducive to microbes mineralisation. Since the C:S ratios were narrow in this profile, there was increased organic-sulphur mineralisation. Profile 5 showed a variation in the results. Pots with plants mineralised some organic-sulphur while pots without plants immobilised sulphate-sulphur. This could also be due to the rhizosphere effects. Still in Profile 6, the pots without plants immobilised more sulphate-sulphur than pots with plants. (a difference of -0.3 to -0.10). Other than the removal of the mineralised sulphur, procedural errors could also be a possible reason. Loss of plant parts (especially roots) during harvest, could reduce the accuracy of the experiment. This error did not appear in pots without plants.

It appears that the rhizosphere had an effect on organic-sulphur mineralisation but this was not true in all cases (Profile 3).

4.6 HALF-LIFE OF ORGANIC-SULPHUR.

Half-life in the greenhouse was much shorter than would be expected in the field for some soil samples (Profiles 3 and 4), other soil sample had a much longer half-life than was expected (samples 1b, 1c, 6a and 6b). Other samples (especially the ones without plants) fell within the expected range. The expected half life in the field is 42.8 years[1]. The reduced half-life in the greenhouse was probably due to lack of sulphur supply by rainwater and the almost negligible atmospheric sulphur supply, Another reason could be due to the high rate of mineralisation of sulphur in the greenhouse due to the reasons already discussed.

Sulphur decreases exponentially in the field. The exponential decrease can be used to determine the half-life of sulphur in the soil. The formula used in this experiment was:-

$$St_x = St_o \ (e^{-\alpha . x})$$

Where: St_x = % organic-S at a given time, x

St_o = Initial % organic-S at t = 0

t = time (years)

α = rate of organic-S mineralisation (% per year)

This equation was simplified to:

$$t\frac{1}{2} = \frac{0.693}{\alpha}$$

---

1. Assuming organic matter mineralisation percentage of 1.8 resulted to 48.6% sulphur mineralisation for 30 years (Freney 1975 and Bromfield 1977), then the organic-sulphur mineralisation rate is (48.6/30) = 1.62%.
   Using the above formula, the half-life of organic-sulphur in the field is 0.693/0.0162 = 42.8 years.

TABLE VI: Half-life of sulphur in the soil

SAMPLE NUMBER	Pots with plants (yrs)	Pots without Plants (yrs)
N.A.R.S., Kitale		
1a	52.5	8.7
1b	93.6	12.2
1c	216.6	46.2
N.A.R.S., Kitale(grass)		
2a	69.3	12.8
2b	69.3	20.3
2c	77.0	34.1
Endebbes		
3a	17.5	12.2
3b	18.0	17.5
3c	23.7	20.4
Cherengani Forest		
4a	16.5	42.5
4b	11.6	19.7
4c	7.4	13.6
Cherengani, Grass		
5a	30.1	34.1
5b	86.6	48.5
5c	69.3	39.6
Field Station, Kabete		
6a	99.0	49.9
6b	138.6	33.5
6c	34.7	13.5

S.E. = 0.0012%

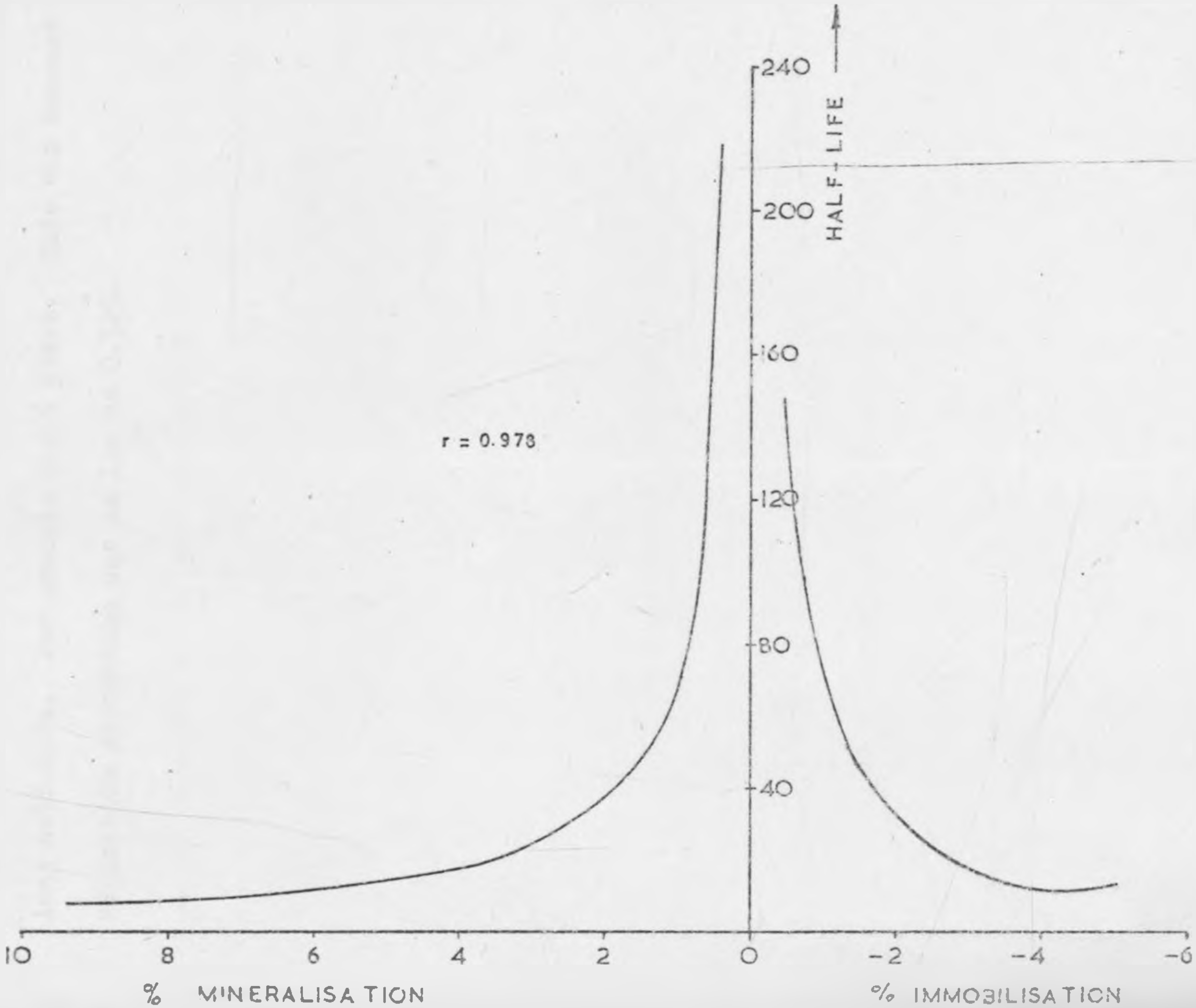


FIG 7 ORGANIC SULPHUR MINERALISATION AND IMMOBILISATION vs HALF-LIFE

Table VI shows the results of the half-life calculation. Due to some extremely high mineralisation values (9.4 or 7.9%), the half-life of sulphur, in the greenhouse, in these soils had been lowered a great deal (7.4 and 8.7 years respectively). Some results gave a very long half-life. For example 216.6 years. This was because the mineralisation percentage was as low as 0.32%.

4.7 TOTAL-SULPHUR vs. 'SULPHATE'-SULPHUR IN PLANTS

Fig. 5a and 5b are graphical relationship between plant total sulphur and plant sulphate sulphur. The perfect linear regression obtained is due to two distinct groups in which the plants fall i.e. deficient and sufficient plant groups. The whole plant was used for these analyses and so the value of 0.00847% total sulphur (84.7 ppm.) is the total sulphur of the cell structural material when devoid of any mobile sulphur compounds. In cases of deficiency, all the mobile nucleic sulphur moves from the older leaves to get distributed in the younger leaves. From analyses of the millet plant, the regression in Fig. 5b show that with no sulphur uptake, the plant will have at least 51 ppm of total sulphur in its tissue from the seed (Fig. 5b and 6).

The higher deficiency state of plants is shown in the clay soils (Fig. 5b). The plants are either deficient or sufficient. (less than 100 ppm or greater than 300 ppm). The regression for these soils (Profile 3 and 6) show that as total-sulphur decreases to 0.005%, sulphate sulphur in the tissues reduces to zero. There is no labile sulphate-sulphur, only cell structural-sulphur remains. This is probably due to the clay soils, rich in hydrated oxides and high anion exchange capacity, which have sulphur diffusing more slowly to the roots and so the roots have to grow to the point sulphur is. In so doing, the plant spends more energy getting sulphur out than it actually benefits from the process. Deficiencies occur in this case. Since both total-sulphur and sulphate-sulphur in plant give a good regression and fall into two distinct groups, they can be used as indices in determination of soil sulphur status. Total sulphur is relatively easy to determine and so it is perhaps a more useful index

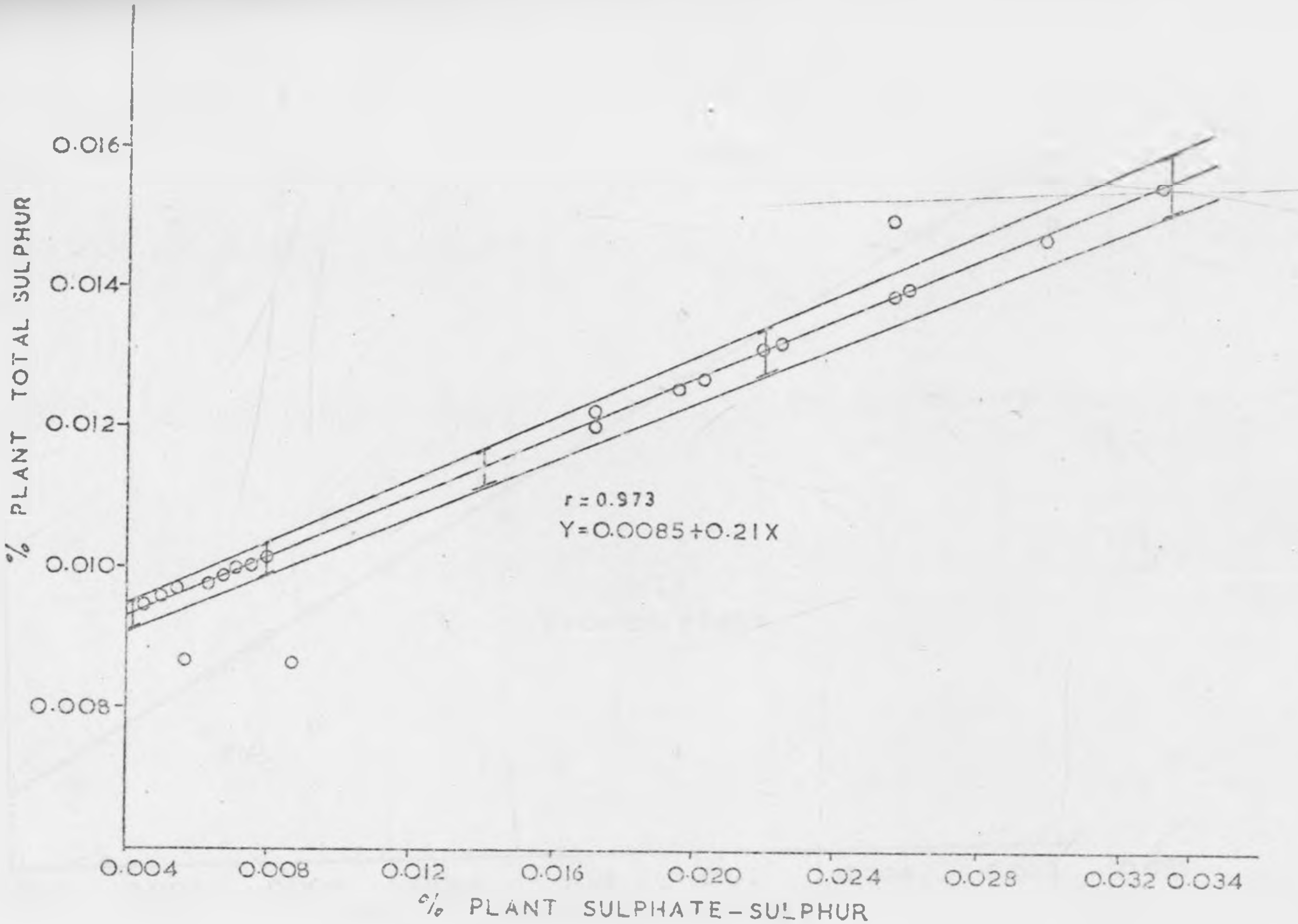


FIG. 5a. RELATIONSHIP BETWEEN SULPHATE-SULPHUR AND TOTAL-SULPHUR IN THE PLANT (Soils derived from Basement Complex)

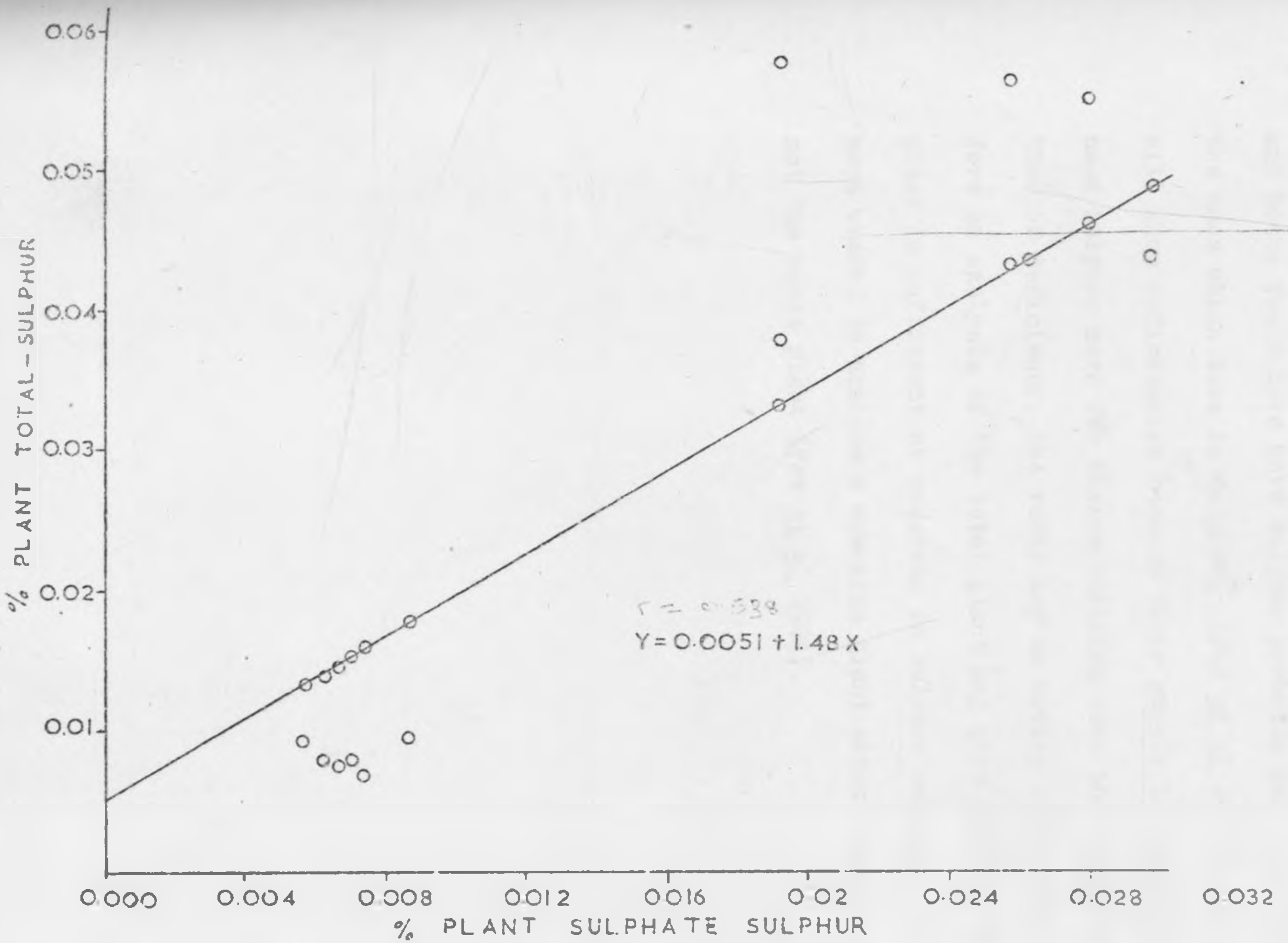


FIG.5b RELATIONSHIP BETWEEN TOTAL-S AND SULPHATE-S IN THE PLANT (Volcanic Soils)

than 'sulphate'-sulphur. However, instead of using the whole plant (as was used in this experiment), a specific tissue of the plant could be better at a particular stage of the plant growth (Cairns 1960). This is because sulphur in the plant is less mobile than other elements like nitrogen and hence roots have more sulphur probably due to priority as they are the ones which take in sulphur. (Fox et al 1964). The younger leaves will show deficiencies because their supply is limited and yet they need sulphur more for tissue building than the older leaves. At this time of deficiency, the roots may be having sufficient sulphur and therefore an analysis of the total plant may give results showing that the plant is sufficient or moderate in sulphur content. It is therefore more useful to analyse a specific plant tissue such as the leaves and not the whole plant (Fox et al 1964).

CALCULATION FOR LINEAR REGRESSION LINE FOR FIG. 5a

(All calculations are in $\mu g/g$ soil). A method similar to the one below was used for fixing the equation for Fig. 5b using results of appendix IV.

Σx	= 2779		Σy	= 2870			
$\bar{X}$	= 102.92		$\bar{Y}$	= 106.3			
Σx^2	= 651540		Σy^2	= 357944		Σxy	= 427129
$(\Sigma x)^2/n$	= 286031.1		$(\Sigma y)^2/n$	= 305070.4		$(\Sigma x)(\Sigma y)/n$	= 295397.4
Σx^2	= 622923		Σy^2	= 52873.6		Σxy	= 131731.6

$$b = \Sigma xy/\Sigma x^2$$

$$= 131731.6/622923$$

$$= 0.21$$

$$Y = \bar{Y} + b\,(X - \bar{X})$$

$$= 106.3 + 0.21\,(X - 102.93)$$

$$= 106.3 - (0.21 \times 102.93) + 0.21X$$

$$= 84.68 + 0.21X$$

∴ The regression equation is:

$$Y = 84.7 + 0.21X$$

$$\therefore\ Y = 0.0085\% + 0.21X$$

Standard deviation of the line

$$\Sigma dyx^2 = \Sigma y^2 - (\Sigma xy)^2/\Sigma x^2$$

$$= 52873.6 - (131731.6)^2/622923$$

$$= 25210$$

$Syx^2 = dy.x^2/(n-2)$

$= 25210/25$

$= 1008.4$

$\therefore Sy\,x = \sqrt{1008.4}$

$= 31.76 \qquad = 0.00318\%$

<u>Standard deviation of the regression co-efficient</u>

$S_b = Sy\,x / \sum x^2$

$= 31.76/807.18$

$= 0.039$

<u>test of significance of the regression co-efficient</u>

$t = b/sb$

$= 0.21/0.039$

$= 5.38^{*}$ with 25 df

<u>Conclusion</u>

The standard deviation of the line is small and the regression co-efficient is significant hence the equation fits the regression of the population. It can be concluded that there is a relationship between total sulphur in the plant and plant 'sulphate' sulphur. Therefore plant total sulphur 'does' depend on plant sulphate sulphur.

<u>Fixing the confidence limits about the line</u>

Standard error for Y $= SY = Sy\,x \times 1/n + (x^2/\sum x^2)$

$= 31.76 \times 1/27 + (x^2/651540)$

$= 1.175 + 0.000049x^2$

$t_{0.05}S_y = 2.06 \quad 1.175 + 0.000049(x^2)$

$\therefore$ the confidence limits are

$Y - t_{0.05}S_y < \mu < Y + t_{0.05}S_y.$

Several values calculated for X gave the following results:

Table VII

X (μg)	Confidence limits (μg)
41	$90.9 < \mu < 95.7$
80	$99.2 < \mu < 99\ 103.8$
141	$112.0 < \mu < 116.6$
220	$128.1 < \mu < 133.7$
334	$150.8 < \mu < 158.8$

The confidence limit line was drawn on the graph (Fig. 5a).

Fig. 5b has the equation

$$Y = 51 + 1.48X$$

$$\therefore Y = 0.0051\% + 1.48X$$

4.8 SULPHUR RELEASING POWERS OF THE SOILS COMPARED WITH LABORATORY DETERMINATIONS OF SULPHATE AND TOTAL-SULPHUR

The results of this experiment show that there is a good correlation between the sulphur releasing powers of the soil and the laboratory determinations. Fig. 6 shows that there is a good linear regression (Y = 51. + 0.043X) relationship between the plant total sulphur and the initial soil sulphate-sulphur. This seems to indicate that the sulphur-uptake by plants is directly related to the initial sulphate sulphur in the soil. The response of plants to initial sulphate in the soil shows a good relationship between the laboratory determined sulphate-sulphur and total-sulphur and the sulphur releasing powers of the soil (See Section 4.1.3). This suggests that both total sulphur and sulphate sulphur determined in the laboratory can be good indices in determination of sulphur deficiencies in the soil.

When the soil C:S ratios are examined, as determined in the laboratory, it appears that most profiles show that the narrower the C:S ratios, the higher the mineralisation rates and percentages. (Section 4.4). This suggests that since organic-sulphur forms most of the total-sulphur, the laboratory determined total-sulphur can be used to indicate whether the C:S ratio will be wide or narrow and hence whether the mineralisation rate will be low or high relative to other soil samples. Mineralisation or organic-sulphur to sulphate-sulphur indicates the availability of sulphate-sulphur to the plants. Results of this experiment show that the soil samples with narrow C:S ratios and hence high rates of organic-sulphur mineralisation, had also their sulphate-sulphur more readily available to plants (See Plate VI) than soils with a wide C:S ratio and low rates of organic-sulphur mineralisation

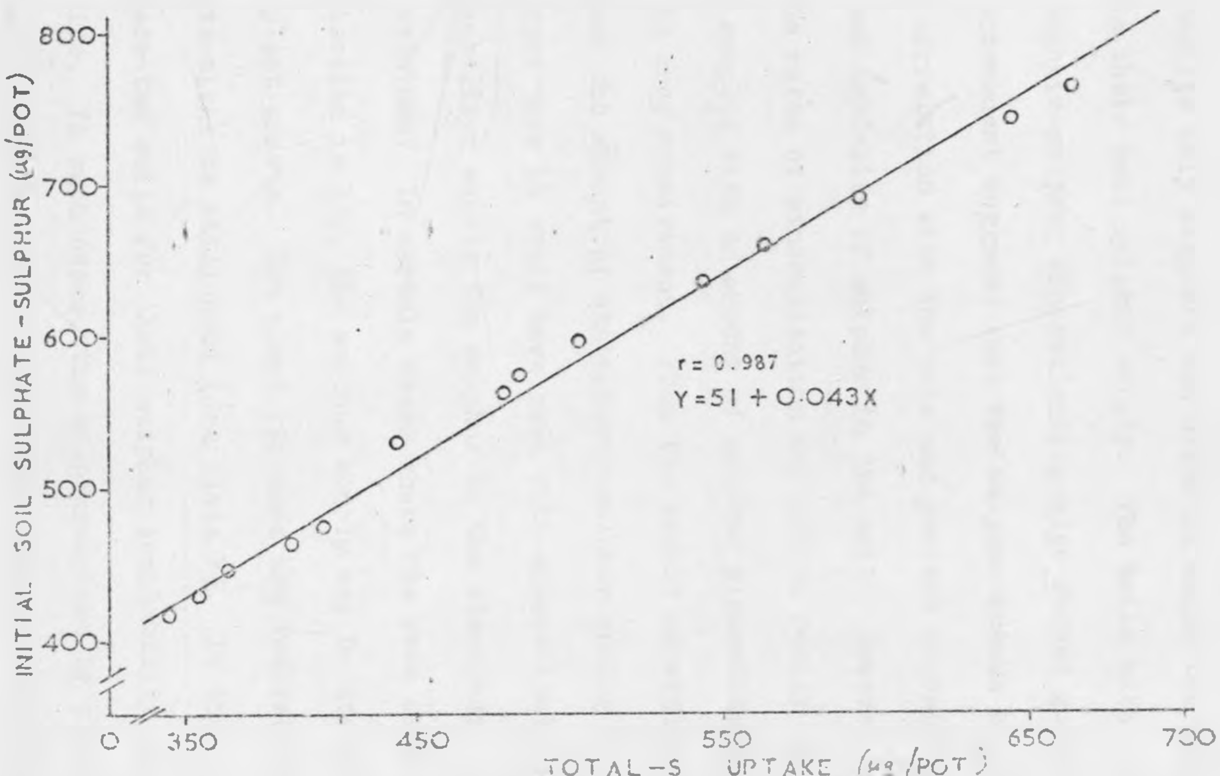


FIG 6 PLANT RESPONSE TO INITIAL SOIL SULPHATE-SULPHUR

(See Plate III). From this observation, it appears that the laboratory determination techniques have a good relationship with the sulphur releasing power of the soil.

Figure 7 shows the parabollic relationship between the half-life and percent mineralisation. It appeared that the soil with high mineralisation percentage (4.2 to 9.4%) also had a very short half-life as indicated by the greenhouse results. (7.4 to 16.5 year). Since the rate of organic-sulphur mineralisation is likely to be low in the field, the greenhouse results only suggests the order in which the soils are likely to deplete their soil sulphur supply. The soils with a high percentages of organic-sulphur mineralisation also showed good plant response. The antecedent suggests that the sulphur-uptake by plants had also a good correlation with the rate and percent organic-sulphur mineralisation and half-life of sulphur in the soil. However, it must be clear that the rates of mineralisation may not be really important unless they are coupled with an amount of sulphur mineralised and this amount related to crop requirement. When the amount mineralised is considered against the amount of atmospheric-sulphur coming in, then half-life is longer than it would have been with mineralisation alone. When sulphur mineralised equals the sulphur in the atmosphere, an equilibrium is attained. In certain cases where the rate of organic-sulphur mineralisation is low, the sulphur supply may be steady and sufficient for plant growth. The plant response and availability of sulphur to plants might be still good (See Plate V). It then becomes difficult to grade the soils for their sulphur availability according to their half-life. In such cases, the sulphur-uptake by plants as indicated in the response becomes a more useful measure than the half-life of the soil-sulphur.

Sulphur releasing powers of the soil in this experiment (among other measured) was best indicated by plant growth. Sulphur-uptake by plants of the available sulphur was best indicated by the plant growth and the number of days the plant kept growing without any sulphur deficiency symptoms. Although the differences in the number of days which the plants kept growing is not great, the differences between the first pot to show symptoms and the last pot to show symptoms is significant (5 days difference). Appendix III shows these number of days. Profile 4 appears to have had more available sulphur than Profile 5 and so plants in profile 4 grew for more days (33 days) than profile 5 (28 days). This observation appears well correlated with the total-sulphur content of the soil. Profiles 1, 2 and 6 fall between the days of Profiles 4 and 5. This, too, is the case with the laboratory determined total-sulphur. From these observation, it appears that total-sulphur determined by laboratory techniques is a good indication of the sulphur releasing powers of the soil. However, Profile 3 (30 days) seems to have shown symptoms one or two days earlier than would be expected. Probably this was due to the rate of plant growth i.e. if the rate was higher than in other profiles, available sulphur was then depleted earlier than would be expected.

Table VIII indicates that while initial soil sulphate-sulphur correlates well with the total-S uptake by plants, it does not as well have a good relationship with how long the plants will grow before they become sulphur deficient, e.g. sample 4c grew for 33 days (394 µg/pot of SO_4-S) while sample 1c grew for 31 days (444 µg/pot of SO_4-S). This is due to the fact that initial soil sulphate-sulphur does not include

TABLE VIII: Relationship between initial soil SO_4-S and total-S uptake by the plant

SAMPLE NUMBER	INITIAL SOIL SO_4-S (µg/pot)	TOTAL-S UPTAKE (µg/pot)
1a	364	442.5
1b	444	528
1c	544	635
2a*	464	177.5
2b	484	572.5
2c	644	742.5
3a	564	657.5
3b	664	765
3c	664	765
4a	474	560
4b	354	432.5
4c	394	475
5a	384	465
5b	384	465
5c*	514	40
6a	344	420
6b	594	690
6c	504	592.5

S.E. = ± 1.6 µg / pot

$y = 51 + 0.043X$

* values omitted in calculations to avoid confusion

any mineralisable organic-sulphur which becomes available to the plant with time. The number of days the plants grew appears to be well correlated with the total-sulphur content of the soil. For this reason, total-sulphur is a more useful index of the sulphur releasing powers of the soil as was demonstrated by the sulphur uptake by plants (even though this was carried out for only a short period in the greenhouse).

From the above discussion, it appears that although the results of the greenhouse are to some extent different from the field results, the results could be useful in putting different soil samples in their order of their sulphur releasing powers. Since there appears to be a good relationship between the soils sulphur releasing powers and total-sulphur content of the soil as determined by laboratory techniques, total-sulphur in the soil may be a good indication of the sulphur releasing powers of the soil in the field. However, the soil might immobilise sulphur (Profile 6) and so a wrong indication of sulphur release given.

Analysis of the plant total-S and plant sulphate-S show a good correlation with each other. The plants were either deficient or sufficient in sulphur content. The plants used for control (with added sulphur) were sufficient and did not show deficiency symptoms. The plants without added sulphur were all deficient in sulphur content and showed sulphur deficiency symptoms. The results suggest that the low total-sulphur and sulphate-sulphur in the soil indicated that the soil sulphur was depleted and there was no more release from the soil. The high sulphur content of the control plants indicated that there was still enough supply of sulphate-sulphur to the plants. Analysis of the total- and sulphate-sulphur of the plant tissue is therefore a useful indication of the sulphur status of the soil and, whether there is enough release of sulphur from the soil or not, to the plants.

However, it is not necessary to determine both the total and sulphate-sulphur in the plant tissue. Since total-sulphur is easy to determine, it is probably a more useful index of the sulphur supplying power of the soil than the plant 'sulphate'-sulphur. It must be pointed out that the soil surface samples may have the same total-sulphur and rate of mineralisation but some soils might have higher quantities of adsorbed + soluble-sulphur in the sub-soil than other soils. Hence the sulphur supplying power of the soil will depend on the plant species, the rooting depth and pattern.

4.9 CRITIQUE OF THE METHOD

During the data analyses, some weakness were discovered in the method. These were:

a) Too many seeds were planted in each pot. Since there was sulphur already in the seeds, this introduced too much sulphur in the system. Although few seeds would take a longer time to remove all the available sulphur than many seeds would take, 8 - 10 seedlings could have been sufficient instead of about 110 seeds planted.

b) The procedure of placing the ungerminated seed in pots produced some procedural errors. There was no guarantee that all the seeds germinated. The ungerminated seed could rot and release sulphur in the soil. This produced about 10% error in germination of seeds. The released sulphur was analysed as soil sulphur. The suggestion brought forward is that seeds be germinated on some blo ting paper and transplanted to pots with the growing media.

c) Addition of equal amounts of nutrient solution flooded some pots. It is therefore suggested that the quantity of water needed to bring the soil to near field capacity be calculated for each soil sample and the water or nutrient solution added according to the calculation.

CHAPTER FIVE

CONCLUSION AND SUMMARY

CHAPTER V

5.0. CONCLUSION

From the results, several conclusions could be reached. The main conclusion was that the laboratory analytical results had a good correlation with the sulphur supplying power of the soil as measured in these experiments.

Several other related conclusions were derived from the results:

a) Sulphur deficiencies can be correctly estimated using plant assay. In this estimation, total sulphur in the plant can be best used as an index since it is easy to analyse. However, both total-sulphur and sulphate-sulphur in the plant are suitable indices in the estimation of sulphur deficiencies in the soil.

b) Sulphur immobilisation and mineralisation in the green-house appears to give higher values than would be expected in the field. However, the results of the green-house may be used to rank different soil profiles in order of their sulphur status and their rates of mineralisation as the order might occur in the field.

c) With calculation of half-life in the greenhouse, soils can be placed in an order of the length of time the soil will supply sufficient sulphur to the plant before deficiencies occur.

d) The rate of organic-sulphur mineralisation depends on the soil C:S ratio. However, in certain cases, it was thought that the freshly added organic matter influenced the rate of mineralisation more than the total amount of organic matter present in the soil.

e) The pattern of sulphur content in the soil appears to relate to the soil organic carbon, clay content and the amount and type of vegetation.

f) The best estimate of the sulphur-supplying power of a soil appears to be the sulphur-uptake by plants when compared to estimates made by mineralisation rates and half-life of sulphur in the soil. The total-sulphur in a selected plant part taken at a specific time probably reflects (in the presence of no other limiting factor) as well as any other single measure, the sulphur supplying power of a soil.

5.1. SUMMARY

An experiment was conducted in a greenhouse to determine the relationship between the sulphur-supplying power of certain soils as measured by sulphur-uptake by millet. Analytical laboratory measurements of total, organic and sulphate sulphur contents of the soil, were also carried out.

Six profiles from two distinct parent materials (volcanic lava and basement system) were used for this study to allow a large number of variables in the experiment. The first two profiles were sampled at National Agricultural Research Station, Kitale (one under grass and one previously under bush but at the time of sampling, under barefallow cultivation). The third profile was from Endebbes (previously under a bean crop), the fourth & fifth profiles were taken from Cherangani Hills (one formerly under forest but under maize cultivation at the time of sampling and the other under poorly grazed land), and the last profile was taken from Kabete Field Station (under maize cultivation).

Each profile was sampled at three depths (0 - 15 cm, 15 - 30 cm and 30 - 45 cm). These samples were then tested for sulphur mineralisation with and without plants. Sulphur uptake by plants was also tested by plant assay and the results correlated to the sulphur - supplying powers of the soil as the plant growth was observed in relation to the total - and sulphate-sulphur content of the soils.

The conclusions reached from this experiment were that plant assay for recognition of sulphur status of the soil is a possible and good index. It was also clear that total - and sulphate-sulphur in the plants were good indices for determination of the sulphur status of the soil and sulphur-uptake by plants. Total-sulphur was more preferable to sulphate-sulphur due to its ease of laboratory determination.

Sulphur mineralisation and immobilization in the greenhouse was found to be only a useful measure for ranking the profiles in the field in a certain order but not to be used as a reflection of the rate of mineralisation in the field. It was also found that the rate of mineralisation of organic-sulphur depends on the C:S ratios but in certain cases, probably the freshly added organic matter may be the determinant factor other than the total organic matter in the soil. Finally, it was found that the pattern of sulphur occurence in the soil is influenced by clay content, organic-carbon and last but not least, the type and amount of vegetation.

REFERENCES

1. Ahn, P.M. (1973). Analytical methods used in Department of Soil Science, University of Nairobi. Technic. Communic., 1 and 5.

2. Alexander, M. (1961). Introduction to Soil Microbiology. Wiley and Sons. Inc., London, New York.

3. Alway, F.J., Marsh, A.W. and Methley, W.J. (1937) Sufficiency of atmospheric sulphur for maximum crop yields. Soil Sci. Soc. Amer. Proc., 2:229-238.

4. Ashford, R. and Bolton, J.R. (1960). Note on technique of S-free pot cultures for legumes. Can. J. Pl. Sci., 40:574-575.

5. Barber, R. (1977). Personal Communication.

6. Barbier, G. and Chabannes, J. (1944). Observations on retention of the SO_4 ion and on the forms of sulphur in soils. Ann. Agron., 14:145-154.

7. Bardsley, C.E. and Lancaster, J.D. (1960). Determination of reserve sulphur and soluble sulphates in soil. Soil Sci. Soc. Amer. Proc., 24:265-268.

8. Bardsley, C.E. and Jordan, H.V. (1957). Sulphur availability in seven south-eastern soils as measured by growth and composition of white clover. Agron. J., 49:310-312.

9. Bardsley, C.E. and Jordan, H.V. (1958). Response of crops to sulphur on south-eastern soils. Soil Sci. Soc. Amer. Proc., 22:254-256.

10. Barrow, N.J. (1960). A comparison of the mineralisation of nitrogen and sulphur from decomposing organic materials. Aust. J. Agric. Res. 11:317-960.

11. Barrow, N.J. (1961). Studies of mineralisation of sulphur from soil organic matter. Aust. J. Agric. Res., 12:306-319.

12. Barrow, N.J. (1967). Studies on extraction and on availability to plants of adsorbed plus soluble sulphate. Soil Sci. 104:242-249.

13. Barrow, N.J. (1969). Effects of adsorption of sulphate by soils on the amount of sulphate present and its availability to plants. Soil Sci. 108:193-201.

14. Berg, W.A. and Thomas, G.W. (1959). Anion evolution patterns from soils and soil clays.

Soil Sci. Soc. Amer. Proc. 23:348-350.

15. Brady, N.C. (1974). The nature and properties of soils. 8th Ed. MacMillan, New York.

16. Bromfield, A.R. (1972). Sulphur in N. Nigeria soils. The effect of cultivation and fertilizers on total sulphur and sulphate sulphur patterns in soil profiles.

J. Agric. Sci. Camb., 78:465-470.

17. Bromfield, A.R. (1974a) The deposition of sulphur in dust in N. Nigeria. J. Agric. Sci. Camb. 83:567-568.

18. Bromfield, A.R. (1974b). The deposition of sulphur in the rainwater in N. Nigeria. Tellus, 11:408-411.

19. Bromfield, A.R. (1977). Personal Communication.

20. Buchner, A. (1953). Schwefelversörgung der westdeutschen landwirtschaft. Landw. Forsh., 11:79-91.

21. Cairns, R.R. and Richer, A.C. (1960). A comparative study of a sulphur responsive and a non-responsive grey wooded soil.

Canad. J. Soil Sci., 40:246-254.

22. Chao, T.T.,Harward, M.E. and Fang, S.C. (1962a). Movement of S^{35} tagged sulphate through soil columns.

Soil Soc. Amer. Proc., 26:27-32.

23. Chao, T.T.,Harward, M.E. and Fang, S.C. (1962b). Adsorption and desorption phenomena of sulphate ions in soils.
Soil Sci. Soc. Amer. Proc., 26:234-237.

24. Chao, T.T.,Harward, M.WE. and Fang, S.C. (1962c) Soil constituents and properties in the adsorption of sulphate ions.

Soil Sci., 94: 276-283.

25. Cooper, P.M.J. (197_) Organic sulphur fractions in Northern Nigeria soils.

Reading University, Ph.D. Thesis.

26. Dean, L.A. (1954) Yield of phosphorus curves.
Soil Sci. Soc. Amer. Proc., 18:462-466.

27. Delong, W.A. and Lowe, L.E. (1962) Note on carbon-bonded sulphur in soils.

Canad. J. Soil Sci., 42:223.

28. Donald, C.M. and William, C.H. (1957). Fertility and productivity of a podzolic soil as influenced by subterranean clover (Trifolium subterranean L.) and superphosphate.

Aust. J. Agric. Res., 8:179.

29. Eaton, F.M. (1942). Toxicity and accumulation of chloride and sulphate salts in plants.

J. Agric. Res., 64:357-399.

30. Eriksson, E. (1959). The yearly circulation of chloride and sulphur in nature, meteorological, geochemical and pedological implications.

Tellus, 11:375-403.

31. Ensminger, L.E. (1954). Some factors affecting the adsorption of sulphate by Alabama soils.

Soil Sci. Soc. Amer. Proc., 18: 259-264.

32. Ensminger, L.E. (1958). Sulphur in relation to soil fertility.

Alabama Agric. Exp. Sta., Bull 312.

33. Ergle, D.R. (1953). Effect of nitrogen and sulphur supply on their accumulation in the cotton plant.

Bot. Gaz., 114:417-426.

34. Fomin, A.E. and Astokhova, N.K. (1959). Nutrition of plants with methionine.

Soil and Fert. (1960), 23:764.

35. Fox, R.L., Olsen, F.A. and Rhoades, H.F. (1964). Evaluating the sulphur status of soils by plant and soil tests.

Soil Sci. Soc. Amer. Proc., 28:632-635.

36. Frederick, L.R., Starkey, R.L. and Segal, W. (1957). Decomposability of some organic sulphur compounds in Soil.

Soil Sci. Soc. Amer. Proc., 21:287-292.

37. Freney, J.R. (1958). Aerobic transformation of cysteine to sulphate in soil.

Nature, 182: 1318-1319.

38. Freney, J.R. (1958). Determination of water-soluble sulphate in soils.

Soil Sci., 86:241-144.

39. Freney, J.R. (1961) Some observations on the nature of organic sulphur compounds in soils.

Aust. J. Agric. Res. 12:424-432.

40. Freney, J.R. (1975). Chapter in "Sulphur in Australasian Agriculture". p. 31.

Edited by McLanchlan, K.D.; Sydney University Press.

41. Freney, J.R., Barrow, N.J. and Spencer, K. (1962). Review of certain aspects of sulphur as a soil constituent and plant nutrient.

Pl. Soil, 17:295-308.

42. Fried, M. (1948/49): The adsorption of sulphur dioxide by plants as shown by the use of radioactive sulphur.

Soil Sci. Soc. Amer. Proc., 13:135-138.

43. Gray, R.W. (1963). Annual report of the Agricultural Research Officer, Nyanza Region.

Kenya Dept. Agric. Ann. Report. 2:134-139.

44. Hesse, P.R. (1957). Sulphur and nitrogen changes in forest soils of East Africa. Pl. Soil, 9:86-89.

45. Hewitt, E.J. (1952). Sand and water culture methods used in study of plant nutrients.

Comm. Assoc. Bureau, Kent., p. 85.

46. Hill, C.C.H. (1963). Annual Report of Officer-in-Charge, Sugar investigation.

Kenya Dept. Agric. Ann. Rept., 2:116-118.

47. Hingston, F.J., Posner, A.M. and Quirk, J.P. (1972). Anion adsorption by goethite and gibbsite 1. The role of the proton in determining adsorption envelopes.

J. Soil Sci., 23:177-192.

48. Jackson, M.L. (1962). Aluminimum bonding in soils. A unifying principle in soil Science.

Soil Sci. Soc. Amer. Proc., 27:1-10.

49. Jensen, J. (1963). Some investigations on plant uptake of sulphur.

Soil Sci., 95:63-69.

50. Johnson, O. (1959). On sulphur problems in Swedish agriculture.

K. Lantbr. Hogsk. Ann., 25:57.

51. Jones, L.H.P., Cowling, D.W. and Lockyer, D.R. (1972). Plant available and extractable sulphur in some soils of England and Wales.
Soil Sci., 114:104-114.

52. Jordan, H.V. and Ensminger, L.E. (1958). The role of sulphur in soil fertility. Advan. Agron., 10:407-434.

53. Jordan, H.V. and Bardsley, C.E. (1958). Response of crops to sulphur on south-eastern soils.
Soil Sci. Soc. Amer. Proc., 22:254-256.

54. Kamprath, E.J., Nelson, W.L. and Fitts, J.W. (1956). The effects of pH, sulphate and phosphate concentrations on the adsorption of sulphate by soils.
Soil Sci. Soc. Amer. Proc., 20: 463-466.

55. Kilmer, J.V. and Nearpass, D.C. (1960). The determination of available sulphur in soils.
Soil Sci. Soc. Amer. Proc., 24:337-340.

56. Koter, M. (1965). Studies using S^{35} on sulphate adsorption by some humic soil substances.
Roczniki Glebozn, 15:37.

57. Le Mare, P.H. (1969). A review of soil research in Tanzania. Rothamsted Expt. Sta., Harpenden Herts, England.

58. Lichtenwalner, D.C., Flenner, A.L. and Gordon, E.N. (1923). Adsorption and replacement of plant food in colloidal oxides of iron and aluminium.
Soil Science 51:157-165.

59. Lyon, T.L. and Bizzell, J.S. (1918). Lysimeter experiments. Cornell University Agric. Exp. Sta. Memoir 12.

60. MacIntire, W.H., Shaw, W.M. and Robinson, B. (1941). Influence of limestone and dolomite upon sulphate retension from annual additions of potassium sulphate.
Soil Sci., 51:73-84.

61. MacIntire, W.H., Shaw, W.M. and Robinson, B. (1945). The divergent behaviour of K_2PO_3 and K_2SO_4 in soils with and without limestone and dolomite.
Soil Sci., 59:155-162.

62. Mann, H.H. (1955). Variations of sulphur in soils under a continuous grain crop. J. Soil Sci., 6:241-247.

63. Mattson, S. (1927). Sulphur anionic and cationic adsorption by soil colloidal materials of varying $SiO_2/Al_2O_3 + Fe_2O_3$ ratios.
Intern. Congr. Soil Sci. 1st congr. Washington, . 11:199-211.

64. Mattson, S. (1930). The laws of soil colloidal behaviour III. Isoelectric precipitates. Soil Sci., 30:359-495.

65. Mattson, S. (1931). The laws of soil colloidal behaviour IV. Ion adsorption and exchange.
Soil Sci., 30:31:311-331.

66. McClung, A.C., DeFreitas, L.M.M. and Lott, W.L. (1959). Analyses of several Brazilian soils in relation to plant response to sulphur.
Soil Sci. Soc. Amer. Proc., 23:221-224.

67. Mehlich, A. (1970). Crop response to sulphur in Kenya. Sulphur Inst. J., 5:10-13.

68. Mehring, A.L. and Bennett, G.A. (1950). Sulphur in fertilizers, manures and soil ammendments.
Soil Sci., 70:73-81.

69. Nearpass, D.C. and Clark, F.E. (1960). Availability of sulphur to rice plants in submerged and upland soils.
Soil Sci. Soc. Amer. Proc., 24:385-387.

70. Nearpass, D.C., Fried, M. and Kilmer, J.V. (1961). Greenhouse measurement of available sulphur using radioactive-sulphur.
Soil Sci. Soc. Amer. Proc., 25:287-289.

71. Neller, J.R. (1959). Extractable sulphate sulphur in soils of Florida in relation to amount of clay in the profile.
Soil Sci. Soc. Amer. Proc., 23:346-348.

72. Nelson, L.B. (1956) The mineral nutrition of corn as related to its growth and culture. Advan. Agron., 8:321-375.

73. Olsen, S.R. and Watanabe, F.W. (1957) A method to determine a phosphorus adsorption maximum of soils as measured by Langmuir isotherms.

74. Overstreet, R. and Dean, L.A. (1951). In Mineral Nutrition of Plants.
Univ. Wisconsin Press, Wisconsin pg. 79-105.

75. Putman, H.D. and Schmidt, E.L. (1959). Studies on free amino acid fraction of soils.
Soil Sci., 87:22-27.

76. Russell, E.W. (1973). Soil Conditions and Plant Growth. 10th Ed. ELBS, Reading.

77. Sealbach, E. (1970). Sulphur requirements and sulphur removals of the most important crops.
Ann. Agron., 22:23-55.

78. Schell, W.R. and Jordan, J.V. (1962). Biological and anion exchange studies of pure clays.
Pl. Soil, 10:303-318.

79. Scott, N.M. and Anderson, G. (1976). Sulphur, carbon and nitrogen contents of organic fractions from acetylacetone extracts of soils.
J. Soil Sci., 27:324-330.

80. Shorey, E.W. (1930). Some methods of detecting differences in soil organic matter.
USDA Technic. Bull, 211.

81. Simon-Sylvester, G. and Boischot, P. (1962). The sulphur compounds of the soil and evolution. Relationships with microflora utilisation by plants.
Ann. Agron., 11:309-330.

82. Sowden, F.J. (1955). Estimation of amino acids in soil hydrolyzates by the Moore and Stein method.
Soil Sci. 80:181-183.

83. Stanford, J.O. and Lancaster, J.D. (1962). Biological and chemical evaluation of the readily available sulphur status of Mississippi soils.
Soil Sci. Soc. Amer. Proc., 26:63-65.

84. Starkey, R.L. (1950). Relationships of micro-organisms to transformations of sulphur in soils.
Soil Sci., 70:55-65.

85. Stauffer, R.S. and Rust, R.H. (1954). Leaching losses, rainfall and percolation from eight Illinois soils.
Agron. J., 47:207-211.

86. Stevenson, F.J. (1956). Isolation and identification of some amino acid compounds in soils.
Soil Sci. Soc. Amer. Proc., 20:201.

87. Stevenson, J. (1956). Effects of some long-time rotations on the amino acid composition of the soil.

Soil Sci. Soc. Amer. Proc., 20:204-208.

88. Stewart, B.A., Portier, L.K. and Viets, F.G. (1966). Effects of sulphur content of straw on rates of decomposition and plant growth.

Soil Sci. Soc. Amer. Proc., 30:355-358.

89. Tchan, Y.T., Balaam, L.N. and Draetta, F. (1963). Estimation of the nutrient status of sulphur in soil using an algal growth method.

Pl. Soil, 19:233-240.

90. Thomas, M.D. and Hendricks, R.H. (1943): Utilization of sulphate and sulphur dioxide for the sulphur nutrition of Alfalfa.

Plant Physiol. 18:345-371.

91. Thomas, M.D. Hendricks, R.H. and Hill, G.R. (1950) Sulphate metabolism in alfalfa. Soil Sci. 870:19-26.

92. Tisdale, S.L., Davies, R.L., Kingsley, A.F. and Mertz, E.A. (1950). Methionine and cysteine contents of two strains of alfalfa as influenced by different concentrations of sulphate ion.

J. Amer. Soc. Agron., 42:221-225.

93. Tisdale, S.L. and Nelson, W.L. (1966). Soil fertility and fertilizers. 2nd Ed. MacMillan Co., London.

94. Whitehead, D.C. (1960). Ph.D. Thesis, Reading University.

95. Whitehead, D.C. (1964). Soils and Plant-nutrition aspects of the sulphur cycle.

96. Williams C.H. and Steinbergs A. (1962). Evaluation of plant available sulphur in soils I. The chemical nature of sulphate in some Australian soils.

Pl. Soils, 17:273-194.

97. Williams C.H. (1967). Some factors affecting the mineralisation of organic sulphur in soils.

Pl. Soil., 26:205-223.

98. Williams C.H., Williams, E.G. and Scott, N.M. (1960). Carbon, nitrogen, sulphur and phosphorus in some Scottish soils.

J. Soil Sci., 11:334-346.

APPENDICES

APPENDIX 1

PROFILE NO. 1. PROFILE DESCRIPTIONS. (Rev. Std. Colour Chart) - N.A.R.S., Kitale

PROPERTIES	1a (0 - 15 cm)	1b (15 - 30 cm)	1c (30 - 45 cm)
COLOUR	air dried dark brown - (7.5 YR 3/3) Moist brown black - (7.5 YR 2/2)	air dried dark brown - (7.5 YR 3/3) Moist brownish black - (7.5YR 2/2)	air dried dark reddish brown - (5 YR 3/4) Moist very dark reddish brown (5YR 2/4)
MOTTLES	Very few fine faint dark reddish brown mottles (5 YR 3/2)	Very few fine faint	Few fine faint (5YR 5/2) dull reddish brown mottles.
TEXTURE	Sandy Clay	Sandy Clay	Sandy Clay
CONSISTENCY	Wet Slightly sticky, slightly plastic Moist very friable Dry: Slightly hard	Wet Slightly sticky, slightly plastic Moist very friable Dry: slightly hard	Wet Slightly sticky, slightly plastic Moist very friable Dry: slightly hard

PROFILE NO. 1: CONT.

PROPERTIES	1a (0 - 15 cm)	1b (15 - 30 cm)	1c (30 - 45 cm)
STRUCTURE	Weak medium sub-angular blocky	Weak medium sub-angular blocky	Weak medium sub-angular blocky
CUTANS NODULES	None None	None None	None None
POROSITY	Many fine to medium pores	Many fine to medium pores	Many fine, common medium pores.
ROOTS	Very few fine roots	Few fine roots	Few fine roots

PROFILE NO. 2: (Rev. Std. Colour Chart) - N.A.R.S., Kitale

PROPERTIES	2a (0 - 15 cm)	2b (15 - 30 cm)	2c (30 - 45 cm)
COLOUR	<u>air dried</u> dark brown (7.5 YR 3/3) <u>Moist</u> brownish black (7.5 YR 2/2)	<u>air dried</u> dark reddish brown (5YR 3/4) <u>Moist</u> dark reddish brown(5YR 3/3)	<u>air dried</u> very dark reddish (5YR 2/4) brown <u>Moist</u> very dark reddish brown (5YR 2/3)
MOTTLES	None	common fine (5YR 5/6) bright reddish brown	None
TEXTURE	Clay loam	Clay loam	Clay loam
CONSISTENCY	<u>Wet</u> Sticky, plastic <u>Moist</u> Friable when moist <u>Dry</u> Slightly hard	<u>Wet</u> Sticky plastic <u>Moist</u> Friable when moist <u>Dry</u>2 Hard	<u>Wet</u> Sticky plastic <u>Moist</u> Friable when moist <u>Dry</u> Hard

PROFILE NO. 2: CONT.

PROPERTIES	2a (0 - 15 cm)	2b (15 - 30 cm)	2c (30 - 45 cm)
STRUCTURE	Moderate medium sub-angular blocky breaking to strong fine sub-angular blocky	Moderate medium sub-angular breaking to strong fine sub-angular blocky	Strong medium sub-angular breaking to moderate fine sub-angular blocky
CUTANS NODULES	None None	None None	None None
POROSITY	Many fine, few medium pores	Many fine, common medium pores	Common fine, many medium
ROOTS	Many fine roots	Many fine roots	Few fine roots

PROFILE NO. 3: (Rev. Std. Colour Chart) - Endebbes

PROPERTIES	3a (0 - 15 cm)	3b (15 - 30 cm)	3c (30 - 45 cm)
COLOUR	<u>air dried</u> very dark reddish brown (2.5 YR 2/4) <u>Moist</u> very dark reddish brown (2.5 YR 2/4)	<u>air dried</u> dark reddish brown (5 YR 3/3) <u>Moist</u> very dark reddish brown (5 YR 2/4)	<u>air dried</u> dark reddish brown (5 YR 3/3) <u>Moist</u> very dark reddish brown (5 YR 2/4)
MOTTLES	None	Few fine (5YR 4/6) reddish brown mottles	None
TEXTURE	Clay	Clay	Clay
CONSISTENCY	<u>Wet</u> Very sticky, very plastic <u>Moist</u>: Friable <u>Dry</u>: Slightly hard	<u>Wet</u> Very sticky, very plastic <u>Moist</u>: Friable <u>Dry</u>: Slightly hard	<u>Wet</u> Very sticky, Very plastic <u>Moist</u>: Friable <u>Dry</u>: Slightly hard

PROFILE NO. 3: CONT.

PROPERTIES	3a (0 - 15 cm)	3b (15 - 30 cm)	3c (30 - 45 cm)
STRUCTURE	Weak medium sub-angular blocky	Weak medium sub-angular blocky	Weak fine sub-angular blocky
CUTANS NODULES	None None	None None	Common medium None
POROSITY	Many fine pores	Many fine, few medium pores	Many fine, common medium pores
ROOTS	Common fine roots	Common fine roots	Few fine

PROFILE NO. 4: (Revised Std. Colour Chart) - Cherengani, Forest

PROPERTIES	4a (0 - 15 cm)	4b (15 - 30 cm)	4c (30 - 45 cm)
COLOUR	air dried Gray (5 Y 4/1) Moist Black (5Y 2/1)	air dried Gray (5Y 4/1) Moist Black (5Y 2/1)	air dried Brownish black (2.5YR 3/1) Moist Black (2.5 YR 2/1)
MOTTLES	None	None	None
TEXTURE	Sandy Clay	Sandy Clay	Sandy Clay
CONSISTENCY	Wet: Sticky, plastic Moist: Friable Dry: Slightly hard	Wet: Sticky plastic Moist: Friable Dry: Slightly hard	Wet: Sticky, Planstic Moist: Friable Dry: Slightly hard
STRUCTURE	Weak medium crumb structure	Weak medium crumb breaking to weak fine crumb	Weak medium sub-angular blocky breaking to strong fine sub-angular blocky

PROFILE NO. 4: CONT.

PROPERTIES	4a (0 - 15 cm)	4b (15 - 30 cm)	4c (30 - 45cm)
CUTANS NODULES	None Few medium concretions (quartz)	None Few medium concretions (quartz)	None Common medium concretions (quartz)
POROSITY	Abundent fine, many medium pores	Abundant fine, many medium pores	Many fine to medium pores
ROOTS	Common fine roots	Few fine to medium roots	Few medium roots.

PROFILE NO. 5: (Rev. Std. Colour Chart) -- Cherengani, Grass

PROPERTIES	5a (0 - 15 cm)	5b (15 - 30 cm)	5c (30 - 45 cm)
COLOUR	air dried Dark reddish gray (2.5 YR 3/1) Moist Reddish black (2.5 YR 2/1)	air dried Brownish gray (5 YR 4/1) Moist Brownish black (5 YR 3/1)	air dried Grayish brown (5 YR 4/2) Moist Brownish black (5 YR 3/1)
MOTTLES	None	None	-
TEXTURE	Sandy Clay	Sandy Clay	Gravelly sandy clay
CONSISTENCY	Wet: Sticky, plastic Moist: Friable Dry: Slightly hard	Wet: Slightly sticky, slightly plastic Moist: Friable Dry: Slightly hard	Wet: Non-sticky, non-plastic Moist: Loose Dry: Loose

PROFILE NO. 5: (Rev. Std. Colour Chart) - <u>CONTINUED</u>

PROPERTIES	5a (0 - 15 cm)	5b (15 - 30 cm)	5c (30 - 45 cm)
STRUCTURE	Weak medium sub-angular blocky breaking to moderate moderate fine sub-angular blocky	Weak medium sub-angular blocky breaking to moderate fine sub-angular blocky	Structureles (Loose structure)
CUTANS	None	None	None
NODULES	None	None	Concretions (quartz)
POROSITY	Many medium to fine pores	Many medium to fine pores	-
ROOTS	Many fine roots	Many fine to medium roots	-

PROFILE NO. 6: (Munsell Colour Chart) -- Field Station, Kabete

PROPERTIES	6a (0 - 15 cm)	6b (15 - 30 cm)	6c (30 - 45 cm)
COLOUR	Dry: Dark reddish brown (5 YR 3/3) Moist: Dark Reddish brown (5 YR 2.5/5)	Dry: Dark reddish brown (5 YR 3/3) Moist: Dark reddish brown (5 YR 2.5/2)	Dry: Dark reddish brown (2.5 YR 3/4) Moist: Dark reddish brown (2.5 YR 3/2)
Mottles	None	None	None
TEXTURE	Humous clay	Humous clay	Clay
CONSISTENCY	Wet: Slightly sticky, slightly plastic Moist: very friable Dry: Slightly hard	Wet: Slightly sticky, slightly plastic Moist: Friable Dry: Slightly hard	Wet: Slightly sticky, slightly plastic Moist: Friable Dry: Slightly hard
STRUCTURE	Strong very fine to medium crumbs structure	Strong very fine to fine medium crumb structure	Strong very fine to fine sub-angular blocky

PROFILE NO. 6: CONT.

PROPERTIES	6a (0 - 15 cm)	6b (15 - 30 cm)	6c (30 45 cm)
CUTANS NODULES	None None	None None	Thin and very patchy None
POROSITY	Many fine, few medium pores	Many fine pores	Many fine pores
ROOTS	Abundant fine roots	Common very fine roots	Common very fine roots

APPENDIX II

SAMPLE NO.	TEXTURE % CLAY	% SILT	% SAND	CEC (Me/100g)	Na me %	K me %	Ca me %	Mg me %
1a	19	13	68	7.0	-	0.05	3.0	0.3
1c	24	14	62	5.7	-	-	3.2	0.3
1c	17	12	71	4.8	0.03	-	1.9	0.3
2a	21	14	65	5.[illegible]	0.025	0.16	2.0	0.3
2b	20	12	66	5.5	-	0.12	2.1	0.2
2c	19	10	71	5.4	-	0.06	1.8	0.3
3a	69	17	14	13.1	0.03	0.19	6.2	1.0
3b	68	10	22	12.4	TRACE	0.21	6.0	1.0
3c	65	9	26	-	-	0.17	5.1	1.1
4a	69	10	21	18.4	0.038	0.14	32.9	2.2
4b	10	9	81	14.5	0.028	0.11	8.8	1.2
4c	13	5	82	15.8	TRACE	0.08	6.4	0.5
5a	3	6	91	5.9	0.025	-	1.5	0.3
5b	2	4	94	6.5	0.025	-	1.4	0.2
5c	2	7	91	5.7	-	-	0.9	0.1
6a	80	15	5	19.0	0.05	0.19	9.0	3.5
6b	81	16	3	18.4	0.06	0.12	11.0	5.8
6c	78	15	7	18.3	0.04	0.10	7.0	4.5

Appendix II: Texture and Exchangeable Cations.

Appendix III

Sample No.	Oven dry weight.	No. of days of plant growth.	mls of solution without sulphur added.
1a	1.69	30	500
1b	1.28	31	475
1c	2.48	30	475
2a	1.25	32	475
2b	1.45	30	475
2c	2.20	32	475
3a	1.64	31	600
3b	1.45	31	650
3c	1.95	31	650
4a	2.31	33	500
4b	2.58	33	500
4c	2.59	33	500
5a	1.90	28	540
5b	1.42	28	540
5c	1.32	28	540
6a	1.15	31	650
6b	2.12	31	650
6c	1.18	30	650

APPENDIX VI: SULPHATE-SULPHUR AND ORGANIC SULPHUR (ppm)

SAMPLE NO.	ORIGINAL SOIL SULPHATE-S	FINAL SOIL SULPHATE - SULPHUR	PLANT SULPHATE-S	ORIGINAL SOIL ORGANIC-S	% PLANT SULPHATE-S
1ar	12.1	27.8	-	110.09	-
1ac	12.1	-	223	110.09	0.0223
1ae	12.1	5.2	55	110.09	0.0055
1br	13.9	28.7	-	144.09	-
1bc	13.9	-	172	144.09	0.0172
1be	13.9	6.2	70	144.09	0.007
1cr	39.1	47.9	-	77.58	-
1cc	39.1	-	260	77.58	0.026
1ce	39.1	5.0	60	77.58	0.006
2ar	7.1	23.8	-	185.65	-
2ac	7.1	-	146	185.65	0.0146
2ae	7.1	5.1	62	185.65	0.0062
2br	16.7	26.4	-	89.66	-
2bc	16.7	-	258	89.66	0.0258
2be	16.7	7.3	62	89.66	0.0062
2cr	50.2	58.6	-	86.74	-
2cc	50.2	-	334	86.74	0.0334
2ce	50.2	6.2	70	86.74	0.007

APPENDIX IV: CONT.

SAMPLE NO.	ORIGINAL SOIL SULPHATE-S	FINAL SOIL SULPHATE - SULPHUR	PLANT SULPHATE-S	ORIGINAL SOIL ORGANIC-S	% PLANT SULPHATE-S
3ar	18.5	41.6	-	259.39	-
3ac	18.5	-	280	259.39	0.028
3ae	18.5	9.8	67	259.39	0.0067
3br	17.4	36.9	-	262.59	-
3bc	17.4	-	259	262.59	0.0259
3be	17.4	-	259	262.59	0.0087
3cr	50.8	66.6	-	197.64	-
3cc	50.8	-	191	197.64	0.0191
3ce	50.8	23.0	57	197.64	0.0057
4ar	23.2	42.5	-	756.76	-
4ac	23.2	-	224	756.76	0.0224
4ae	23.2	7.4	68	756.76	0.0068
4br	2.4	23.0	-	387.58	-
4bc	2.4	-	154	387.58	0.0154
4be	2.4	6.22	60	387.58	0.006
4cr	2.6	23.5	-	272.09	-
4cc	2.6	-	196	272.09	0.0196
4ce	2.6	8.6	67	272.09	0.0067

APPENDIX IV: CONT'D

SAMPLE NO.	ORIGINAL SOIL SULPHATE	FINAL SOIL SULPHATE - SULPHUR	PLANT SULPHATE-S	ORIGINAL SOIL ORGANIC-S	% PLANT SULPHATE-S
5ar	1.87	6.9	-	62.49	-
5ac	1.87	2.93	141	62.49	0.0141
5ae	1.87	2.93	41	62.49	0.0041
5br	2.22	7.78	-	51.78	0.008
5bc	2.22	-	189	51.78	0.0189
5be	2.22	3.02	80	51.78	0.008
5cr	1.56	6.71	-	65.71	-
5cc	1.56	-	171	65.71	0.0171
5ce	1.56	3.6	74	65.71	0.0074
6ar	16.6	12.4	-	367.18	-
6ac	16.6	-	262	367.18	0.0262
6ae	16.6	9.4	62	367.18	0.0062
6br	40.5	32.7	-	376.09	-
6bc	40.5	-	298	376.09	0.0298
6be	40.5	24.5	72	376.09	0.0072
6cr	13.1	12.7	-	169.33	-
6cc	13.1	-	191	169.33	0.0191
6ce	13.1	8.0	74	169.33	0.0074

TOTAL - S

SAMPLE NUMBER	TOTAL SOIL-S (ppm)	% TOTAL PLANT-S	% CARBON
1ac	122.19	0.117	1.69
1ae	122.19	0.056	1.69
1bc	157.99	0.105	1.77
1be	157.99	0.074	1.77
1cc	116.68	0.139	1.17
1ce	116.68	0.064	1.17
2ac	192.75	0.128	1.75
2ae	192.75	0.066	1.75
2bc	106.36	0.150	1.42
2be	106.36	0.068	1.42
2cc	136.94	0.165	1.05
2ce	136.94	0.084	1.05
3ac	277.89	0.552	2.70
3ae	277.89	0.076	2.70
3bc	279.99	0.569	2.80
3be	279.99	0.086	2.80
3cc	248.44	0.579	1.60
3ce	248.44	0.086	1.60

TOTAL-S : CONT'D

SAMPLE NUMBER	TOTAL SOIL-S (ppm)	% TOTAL PLANT-S	% CARBON
4ac	779.96	0.211	4.08
4ae	779.96	0.067	4.08
4bc	398.98	183	3.42
4be	398.98	0.055	3.42
4cc	374.69	0.201	3.16
4cc	374.69	0.059	3.16
5ac	64.36	0.101	1.03
5ae	64.36	0.058	1.03
5bc	54.00	0.095	1.14
5be	54.00	0.058	1.14
5cc	67.27	0.121	1.30
5ce	67.27	0.071	1.30
6ac	383.78	0.423	2.79
6ae	383.78	0.079	2.79
6bc	416.59	0.441	2.60
6be	416.59	0.054	1.79
6cc	182.43	0.379	2.21
6ce	182.43	0.070	2.21

APPENDIX V

ILLUSTRATION OF CALCULATIONS OF ORGARNIC SULPHUR IN MINERALISATION

a) Seed total-sulphur = 0.125%

$\therefore$ µg S/g seed $= \dfrac{0.125 \times 10^6}{100}$

$= 1250$ µg/g seed

$\therefore$ 45g seed contains 1250×0.45

$= 562.5$ µg S

(10% error included in the calculation of seed total-sulphur).

b) Nutrient solution contained 0.35 µg/ml

c) Example of calculations using sample 6ae.

The formula is:

$$\frac{\text{(Total plant sulphur)} - \left\{\text{(absorbed S + soluble S + seed S} \atop \text{+ nutrient S}\right\}}{\text{Organic sulphur}} \times 100$$

$$\frac{\left((.0079 \times 10^6 \times 1,15^{(1)}) - (0.00072 \times 10^6 \times 25^{(2)}) - 562.5 - 650^{(3)} \times .35\right)}{.0169 \times 25^2 \times 10^6}$$

$= -2.0\%$

Rate of mineralisation = -2.0 / 30 = 0.07% / day

---

(1) Oven dry weight of total plant material.

(2) 25 gm of soil used in each pot

(3) ml of 'minus sulphur' nutrient solution

APPENDIX VI

Calculation of regression line for Fig. 4 (ug)

X	= 7804	Y	= 368.6		
$\bar{X}$	= 487.8	$\bar{Y}$	=23.0		
X^2	= 3681680	Y^2	= 13424	XY	= 208480
$(X)^2/n$	= 3010304	$(Y)^2/n$	= 8491.6	$(X)(Y)/n$	=179784.7

---

x^2	= 671366	y^2	= 4932.4	XY	= 28695.3

$$b = xy/x^2$$
$$= 28695.3 / 671366$$
$$= 0.043$$

$$Y^2 = \bar{Y} + b\ (X - 487.8)$$
$$= 23 + 0.043\ (X - 487.8)$$
$$= 23 - 20.96 + 0.043X$$
$$= 2.04 + 0.043X$$

$\therefore$ The regression equation is:

$$Y = 2.04 + 0.043X$$

But each pot had 25 gm of soil.

$$\therefore Y = 51 + 0.043X$$