

POPULATION DYNAMICS OF SOIL MICROORGANISMS
IN TERMITE MOUNDS IN KENYA //

By

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ABSTRACT

The effect of termite activity on physical and chemical properties was examined in this study. Mainly the genus M. michelseni was investigated on six 'live' and six 'dead' mounds at a site belonging to International Centre for Insect Physiology and Ecology at Kajiado. A few other mounds were selected from Kibini, Emali, Magadi and Ruaraka.

The soil analysis indicated that cation exchange capacity, calcium, magnesium and clay contents in the mound soil resembled those of the subsoil. The findings support earlier reports that the genus Macrototermes uses the subsoil for mound construction. Carbon, clay, moisture contents and cation exchange capacity increased with depth of mound, attaining the highest levels in nursery and queen chambers of the 'open' and 'closed' mounds.

As a contrast to the adjacent soil profile, carbon content decreased with depth while clay and moisture content were almost uniform.

Microbial activity measured as CO_2 evolution were studied in termite 'modified' soils, sampled at varying distances of 0 m, 1 m, 3 m, 5 m, 10 m, 15 m and 20 m respectively from the mound. Evolution of mg. CO_2/g soil indicated that maximum microbial activity occurred between 3 - 10 m from the mound. The highest carbon content was measured in the same area.

Dilution and plate count method was used to estimate

the numbers of bacteria, fungi and actinomycete. A study of seasonal fluctuation of microbial population with respect to mound proximity showed that bacteria and fungi responded significantly ($p < 0.01$) to seasonality. The highest bacterial counts corresponded to highest soil moisture content while fungi showed an opposite response to soil moisture. The population of actinomycete showed little or no response to both seasonality and mound proximity.

In both 'open' and 'closed' mounds built by M. subhyalinus and M. michelseni respectively, microbial populations were estimated in different chambers. The three microbial groups namely, bacteria, fungi and actinomycete increased in depth of the mound towards the queen chamber. They then declined rapidly in the subsoil. In an adjacent soil profile the microbial populations depicted a significant negative correlation co-efficient (0.01) with depth.

Different groups of bacteria were enumerated using most probable number technique (MPN). Soil samples were taken at 0 m, 3 m, 20 m from the mound to a depth of 13 cm. It was found that cellulose decomposers, denitrifiers, nitrifiers mainly Nitrobacter and Nitrosomonas spp. were higher in the termite 'modified' soils than in the surrounding top soil. Using the MPN method the soil protozoa were shown to be more numerous in the 'dead' than in the 'live' mound soils.

It is suggested that cellulose decomposers and denitrifiers in the mound soils indicated presence of easily decomposable organic matter in the top soil. The high pH, Ca, Mg in the mound soil accounted for higher population of nitrifiers in the mound affected soils than in the surrounding soil.

The moisture content was shown to influence bacterial and fungal numbers. Therefore during the dry season fungi and to a lesser extent actinomycete were major organic matter decomposers, while at the period of high soil moisture content bacterial activity was most important. Although activity of micro-organism was shown to increase in termite modified soils, an indication of improved soil fertility, the foraging habits of termites might outweigh their usefulness of improving soil physical and chemical properties.

INTRODUCTION

CHAPTER 1

1. INTRODUCTION

1.1. General

The majority of the termite species are found in the tropical and subtropical regions of the world though, they do extend to a lesser extent in the temperate areas to about 45°S (Harris, 1970) and 48°N (Emerson, 1955; Araujo, 1970).

Of the 41 species 7 belong to the typically tropical genera known as Termitidae, (Harris, 1970).

About 1,900 species living or fossilised have been described (Krishna, 1969), and the greatest number was found in Ethiopia where (Bouillon, 1970) described 570 species and 89 genera. Many termite species in Africa and South America are found in rain forests whereas in Australia majority are found in woodland savannas (Calaby and Gay, 1970).

Termites have both beneficial and harmful effects on the soils and vegetation growing within their proximity. Lee and Wood (1971) summarised these effects as follows:

(1) Harmful effects

- (a) Removal of organic matter as they feed on vegetative material hence reducing that which ends up in the soil.
- (b) Nutrients held up in the termite mound until

the colony dies.

- (c) Soil erosion increase through their activity especially in dry areas (Harris, 1949).

(2) Beneficial Effects

- (a) Addition of plant nutrients from the sub-soil which is used for mound construction. With subsequent erosion and leaching those nutrients are distributed in the surrounding soils which then become enriched.
- (b) They improve the soil texture due to selectivity by workers of the soil particles they transport. Termite workers are able to carry fine particles less than 2 mm in diameter and over a period of time. Washing of the mound soil to the surrounding area could result in a stone free layer as reported by (Nye, 1955) and Williams (1968).
- (c) Aeration and drainage are improved through the presence of galleries.

The question as to whether termite activity is beneficial or harmful has not been resolved and conflicting schools of thought are prevalent today.

1.2. Reason for the Study

The study on the effect of termites on population

of microorganism would be an important indication of whether they do influence the soil physical and chemical properties. The vegetation around the mounds was observed to be more dense and persisted for a longer period during the dry season than in the surrounding areas. This alone was an indication of some differences which could have been physical or chemical. Differences in species of grasses growing on the mound and in the surrounding areas were also observed by (Arshad, 1978). For example around the mound the dominant grass was Cynodon dactylon and surrounding areas was Themeda spp. and Pennisetum spp.

It is not yet understood whether these differences in vegetation, physical and chemical properties of the soil could play a role in the behaviour pattern of soil microorganisms around the mound. Hence this study was established to investigate the dynamics of soil microorganisms around the termite mounds.

1.3. Objectives

The study was carried out with the following aims:

- (1) To determine effects of the proximity of termite mound on the population of bacteria, actinomycetes, fungi and some common groups of bacteria in the soil such as nitrifiers, denitrifiers, cellulose decomposers and nitrogen fixers on their numbers, activity through CO₂ evolution.

- (2) In relation to soil moisture content, the effect of seasonality on these three different groups on their populations was determined.
- (3) A comparison between 'open' and 'closed' mounds with adjacent soil. The species responsible for these two types of mounds are Macrotermes subhyalinus and Macrotermes michelseni respectively.

1.4. Importance of microorganisms in the soil

Vital functions for both plants and animals are carried out by soil microorganisms. They are responsible for decomposition of organic matter. They break down humus to release nutrients available to plants. Microorganisms are also of great importance in agriculture, applied and industrial microbiology because they do break down certain compounds which would otherwise be toxic in the environment. After the application of chemicals like pesticides and herbicides used in agriculture the microorganisms do control the level of accumulation by biodegrading these materials to less toxic byproducts. In certain instances the substance is broken down to water and CO_2 .

Soil microorganisms are also becoming important in other fields due to rising cost of fuels and fertilizers. In agriculture, they contribute to the nutrient cycles especially nitrogen. For example, some bacteria do fix elemental N_2 into cell-N which in turn enrich soil nitrogen. The association of legumes and

different strains of Rhizobium leading to symbiotic fixation of nitrogen is also known and widely exploited in different parts of the world. Organisms which form mycelium such as fungi and actinomycete do influence aggregation of soil particles hence soil structure. Due to the production of xanthans and polysacharides bacteria also contribute to soil granulation.

Microbiological data relevant to termite mounds is limited in the tropics. It is hoped that this study would be useful to soil microbiologists to do further research which would contribute to the understanding of the fertility-infertility syndrome of the termite mound soils hitherto unexplained by soil physico-chemical data.

LITERATURE REVIEW

CHAPTER 2

2. LITERATURE REVIEW

General

2.1. Biology of termites

Termites belong to the order Isoptera which has six genera. The genus Termitidae consists of 75% of the known termite species mainly the higher termite or fungus-growing termites. They are polyphial social insects that live in termitaria they construct. The termitaria hosts and protects the colony, used for food storage and maintains optimum conditions for the termites.

2.1.1. Nature and structure of termite nest

The structure and complexity of mound vary according to species of termite, climate and material used for construction. A mound is therefore said to represent an equilibrium between those three forces, behaviour, material and climate (Harris, 1956). Harris found that mounds constructed by a specific species could appear superficially different under different environment while two different species could produce similar mounds in the same environment.

The members of Termitidae construct two types of nests, the mound type which is constructed on the ground and the arboreal type on trees and shrubs. The mounds constructed on the soil vary in size from those

that are unnoticeable on the surface, those that are centimetres high to the giant mound constructed by the genus Macrotermes which may range from 5 - 7 m in diameter and 3 - 4 m in height or more (Pomeroy, 1976a).

Harris (1956) reported that M. goliath in Tanzania constructs mounds which are about 15 m in diameter and 4 m high. They also show a wide variation in structure and other aspects. Noirot, (1969) described epigenous nests in two categories. The homogenous structure consisting of chambers which are almost alike and no important differences between the periphery and internal portions. The second type of nest is varied, the periphery zone/or the wall and the central part called habitacle/or nursery. Epigenous nests are closed with no permanent communication with the exterior, however certain nests possess chimneys which sink deep well below the level of the ground, they form the exoecie. These giant epigenous nests by Macrotermes contain fungus combs. The source and functions of these fungus combs is very controversial. Some workers say that they are faecal material from the termites while other people think that they are built from the carton material. The fungus of the genus Termitomyces (order, Basidiomycete) grow on these fungus combs. Fungus combs could be a food source for the termites as (Hesse, 1957) found that they were continuously renewed while the old one was eaten up. Some termite species died when they were grown

in an environment free of fungus combs, hence probably they contribute in the digestion of cellulose before the termites feed on it, this was confirmed by presence of the enzyme cellulase in the conidiophores produced by *termitomyces* fungus.

Due to their spongy nature they could be important for maintaining high moisture content and temperature control (Hesse, 1957; Cheema et al., 1960).

There are two distinct types of Macrotermes mounds, a 'closed' mound with no external openings and 'open' mound with external openings. These two types of mounds are geographically separated with 'open' mounds mainly found in the lower altitude areas of Kenya such as Voi, Magadi, Tsavo and Amboseli while the 'closed' one is common in the cooler/or higher altitude areas, Kajiado, Thika, Ruaraka, etc. These two types may occur side by side in the same habitat (e.g. Konza, Bissel and Meto) and this occurrence has triggered off another reason for the construction of two different types of mounds by the same genus i.e. species or subspecies effect Darlington (1976). These two types of mounds are therefore associated with two different species of termite in the genus Macrotermes subhyalinus (Rumbar) and Macrotermes michelseni (Sjostedt) for the 'open' and 'closed' mounds respectively.

2.2. Effects of termite activity on physical and chemical characteristics of soils.

Due to selection of soil particles, their mixing with organic matter and consequent cementation during mound construction, physical and chemical effects on the mound soil could be expected to take place. Mounds constructed by Macrotermes spp. have been thought to stand for many years, Pomeroy (1976a) working in Uganda stated that the average age was 4 - 10 years but a mound could stay alive for over 50 years. During this time when the mound is inhabited most of the plant nutrients are unavailable to the nutrient cycle.

A lot of work has been done on the physical and chemical properties of the termites soil in different parts of the world but mainly in the tropics where termite activity is quite conspicuous. Problems have been encountered when trying to relate various analysis by different workers and this has been associated with differences in methods of analysis used, elements analysed, species of termites used or lack of their identification. **It is** not, therefore, easy to give any conclusive remark on the data available at present since contradictory results or uncomparable results are the only available data.

2.2.1. Physical effects on soils by termite activity

In Macrotermes spp. some degree of selectivity of

particle size is shown and the maximum size that can be transported and incorporated in the structure is a function of the size of the workers. Work on particle size analysis on the genus Macrotermes in Africa has been done by Hesse (1955); Nye (1955); Harris (1956); Maldague (1959); Stoops (1964). Leprun and Roy-Noel (1977); Pomeroy (1976); Arshad (1978) and they show that the composition was closer to that of the subsoil with slight selection for the finer particles.

Hesse (1955) working with M. subhyalinus, M. galciger and M. bellicosus showed that the shape of the mound was determined by sand:clay ratio in them and the subsoil from which they are derived. Tall thin mounds had a ratio of 1:1 and 3:1 while large dome-shaped mounds had a ratio of 2:1 and 18:1. Pomeroy (1976) working with some Macrotermes spp. in Uganda found that the mounds were constructed from the subsoil taken at a depth of 0.5 - 1.0 m. He also found that mounds of M. bellicosus and M. subhyalinus had less sand than for a sandy subsoil whereas for M. subhyalinus the mounds contained less clay where the subsoil had a high clay content. Leprun and Roy-Noel (1977) in Senegal where they worked with Macrotermes bellicosus showed that the mound soils were richer in clay but lower in organic matter than adjacent soils. Arshad (1978) working with M.

subhyalinus and M. michelseni in Kajiado area, Kenya found that the termite workers selected a certain particle size 2 mm in diameter for mound construction. He also showed that there was an increase in clay content in the mound with the highest amount recorded in the royal cell. Work with other genera of termite does also show some physical and chemical changes on termite soil Kemp (1955). Stoops (1964) working with African Cubitermes spp. found enrichment in clay relative to deep soil horizons. Watson (1960) working with Cubitermes in Rhodesia showed little difference between mound soils and deeper horizons of the surrounding soils. Pathak and Lehri (1959) working with Odontotermes obscuriceps in India reported great increase in clay and silt relative to sand in mound soils built on sandy soils. They found that in the mound soils 67.7% clay aggregates less than 2 mm compared to 48.1% in adjacent soils. Lee and Wood (1971) working with 17 different species of termites found in Australia reported that there was selection for clay and silt to coarse particles but there was no precise requirement for particle size for the structure. They also showed that soils used for mound construction were mainly from the subsoil. Subsequent erosion of these mound soils was shown to have considerable significance on the pedogenesis. Boyer (1955) noted that Macrotermes subhyalinus (Rambour) brings much finer particles to the

surface and cements them into concrete like materials on and around its mound.

Other physical properties have been looked at although by very few workers. Bulk density was investigated by Maldague (1964) who measured bulk density of termite soils in three difference genera namely, Macrotermes, Armitermes and Nasutitermes in Congo forest which had a termite population of 1000/m² and compared the measurements with those of a nearby parasol covered fallow lands. He found the forest soil had a bulk density of 1.0 g/cm³ and for fallow soil 1.27 g/cm³, he attributed the differences to termite activity.

Some work on water holding capacity has been done by some workers. Pendleton (1941) working with unidentified termites in Thailand found an increase of 0.50% in water holding capacity in termite soils in relation to adjacent soils. Pathak and Lehri (1959) in India, with Odontotermes obscuriceps found that the water holding capacity in termite soils was five times greater than ordinary soils and they associated this to high organic matter content of 6.26% in these termite soils.

2.2.2. Effects on chemical characteristics of the soil

Termites of the genus Macrotermes use soils from subsoil for construction of their nests. Hesse (1955) and Pomeroy (1976b) and so for comparison in the chemical properties subsoil samples must be compared with termite soils for any useful information to be obtained.

2.2.2.1. pH

Several workers observed pH increase in termitaries compared with adjacent soils for Macrotermes, Cubitermes and Odontotermes. Workers on Macrotermes species in Africa like Boyer (1955, 1959); Nye (1955); Robinson (1958); Watson (1962) and Wild (1952) all observed pH increase in termite soils relative to surrounding soils. Work on Cubitermes spp. by Stoops (1964); Kemp (1955) also showed an increase in pH. Stoops (1964) associated this increase in pH to increase in CaCO_3 in the termite mounds. A similar conclusion was reached by Watson (1962) who found that termite activity in Rhodesia resulted in sodium and calcium rich horizons hence higher pH values than in adjacent soils.

Lehri and Pathak (1959) in India reported a decrease in pH in relation to adjacent soil in case of Odontotermes obscuriceps while Lee and Wood (1971) reported slight increases or decreases in pH in their work with 17 species of termite in Australia. They also found that these differences were small and insignificant. They also associated pH increase to calcium carbonate accumulation.

2.2.2.2. Organic matter, carbon, total nitrogen

Effect of termite on organic matter is both positive and negative as they destroy the organic residues

to feed themselves and add some to the soil through their excrement and saliva Roy-Noel (1978).

The species that feed on humus like Cubitermes remove a lot of soil organic matter as food. Maldague (1959) and Boyer (1966b) reported that the thin layer of organic matter in Belgian Congo (Zaire) must have been due to termite influence. The foraging termites that feed on wood or grass do remove a lot of vegetation which otherwise would have become humus. This in fact pose a major problem in the use of plant material as mulch, Pomeroy (1976b). This problem is common in coffee plantations where elephant grass mulch is regularly applied due to termites foraging on it.

Termites increase organic matter in their galleries through saliva, excrement or incorporation of plant material in the nest. There are also organic matter reserves in form of fungi combs and carton material.

Several workers reported increased organic matter in the mound soils in relation to the adjacent soils. Hesse (1955) found an increase in organic matter in the inner cavities of the mound compared to surrounding soils of Macrotermes spp. Watson (1976) observed higher levels of organic matter in termites soil than adjacent soils from his studies on M. falciger on soils derived from granite in three rainfall zones of Rhodesia. Pomeroy (1976b) working with Macrotermes, Miedema and Van

Vuure (1977), with M. bellicosus (Smeathan), Stoops (1964) with M. bellicosus found very slight or no difference in organic matter content between termite soil and surrounding soils. Maldague (1959) in Zaire working with Cubitermes found higher organic matter content in termite than adjacent soils, similar observation by Stoops (1964) with Cubitermes spp. in Kinshasa has been reported. Leprun and Roy-Noel (1977) compared the walls of the nest built by M. subhyalinus (Rambur) in Senegal and upper horizons of the surrounding soils and they found that the mound soils were poorer in organic matter. Lee and Wood (1971) in their work in Australia found a general increase but occasional decreases were also observed. Organic carbon paralleled organic matter content, similarly nitrogen paralleled organic matter content but not necessarily in the same proportions as the carbon content.

The C:N. ratio on Macrotermitidae have been reported and in some cases slight differences have been observed. Hesse (1955), Maldague (1959); Boyer (1955), found that the outer layer of M. bellicosus had C:N ratio of 10 - 12 while for inner portions 6.5. Boyer (1956a) found C:N of 2.7 in the royal cell of M. bellicosus and M. subhyalinus (Rambur) as compared to 6.7 in outer layers and 10 - 12 in adjacent soils. Pathak and Lehri (1959) reported higher C:N ratio of 7.1 compared to soils with 5.0 in India in

their work with O. obscuriceps.

On their work with 46 spp. in Australian soils, Lee and Wood (1971) reported that out of 13 species only 2 samples had C:N ratio lower than the soils from which they were derived, while from 26 samples (10 spp.) composed of carton material all had C:N ratio were much higher than the surrounding soils. They associated these differences to C:N ratio between different species of termites to the different feeding habits.

2.2.3. Exchangeable cations

Several increases in cation exchange capacity of termite soils have been reported. This increase in C.E.C. has been associated mainly with the total bases i.e. Ca, Mg, K, and Na which have been shown to vary considerably due to termite activity. According to Hesse (1955) and Boyer (1966) the origin of bases in the termitaria is due to several factors. First, dissolved bases in the water flowing into the earths. Evaporation of the water in the soil leaving salts behind. The dead termites, the saliva used in the construction of the mound and the faecal material. When these materials are broken down through microbial activity cations would be released in the soil.

In different countries various authors have pointed out an increase in organic bases in termitaria.

Stoops (1964) working with Cubitermes spp. and M. bellicosus found higher C.E.C. in the inner core of the mound 2 - 10 me./100 g soil. Lee and Wood (1971) also reported higher values of C.E.C. than for surrounding soils in Australia and they associated this to high K, Mg and Ca due to plant material used as a forage by termites. Similar increases in Ca, Mg, K, Na have been reported by Nye (1955); Stoops (1964); Griffith (1938) in Uganda, Boyer (1966), Lepage (1974) with M. bellicosus, Watson (1962) in Rhodesia recorded increases in Na, Ca in the inner core of the mound. An increase in K, Mg, Ca in Macrotermes spp. mound in three different zones in Rhodesia by Watson (1975).

Other workers like Hesse (1955); Robinson (1958); Pomeroy (1976b); Malaka (1977) found no chemical differences in termitaria of Macrotermes and surrounding soils hence Hesse (1957) described termite mounds as 'heaps' of soil from the subsoil due to termite activity. The chemical and physical differences between termite mound soils and adjacent soils are later reflected in the vegetation differences, which, takes place after the mound dies (uninhabited) and the nutrients become available to plants. Such vegetation differences would be observed in Kenya where termite mounds are undisturbed. Nderitu (1972) noted that the vegetation on abandoned mounds in Tsavo East National Park was distinct from surrounding area both in composition and physiognomy.

He noted that, members of Capparidaceae were represented on the mounds and almost excluded on the adjacent soils. Wild (1952) noted the relationship between members of Capparidaceae and termite mounds and suggested that their preference for termitaria might be due to their preference for alkaline soils. Arshad (1978) showed that there were higher vegetation densities around the mound than surrounding area in Kajiado. It was noted that Cynodon dactylon was common on the mound and absent in the surrounding areas where most of the vegetation was Hyperrhenia spp. and Acacia spp. of trees.

Small scale farmers have been reported to prefer mound soils to adjacent soils and they plant maize, pumpkins, beans, pigeon peas on the mound soil than on adjacent areas. Meikeljohn (1965) also reported that maize did better on termite mounds without fertilizer application in Rhodesia. Pendleton (1941) observed that sisal grown on the mounds in Thailand performed better and was greener than those growing on the surrounding soils. Harris (1941) also reported that tobacco growers in Kenya planted this crop on the Macrotermes mounds. Utilisation of termite mounds by small scale farmers are therefore numerous. Observations have also been reported on commercially used farms. Pereira who was quoted by Robinson (1958) found that sisal at Thika was better on mound

soils than in surrounding soils. The sisal also matured earlier. This effect of mounds on crops under commercial farming was undesirable because it affected harvesting period. This vigorous growth of plants on the mound could be due to already mentioned factors like water, aggregation of soil structure and higher nutrient levels than in surrounding soils.

2.3. Microorganisms in Termite 'modified' soils

Meikeljohn (1965) found that in the mound soils there was higher biological activity and organic matter breakdown than adjacent soils. High pH, Ca, and Na influenced higher numbers of nitrifiers.

Boyer (1955) examined mounds of Macrotermitinae and reported that mound soils contained high population of cellulose decomposers and aerobic as well as anaerobic nitrogen fixers. The fungus gardens that Boyer examined contained species of nitrogen fixers for example two species of Beijerinckia.

Pathak and Lenri (1959) from their work on Odontotermes obscuriceps in India found that the rates of nitrification and denitrification were higher in mound soils than the adjacent ones. They concluded that microbial decomposition was higher in mounds than in adjacent soils.

Jakubczyk et al. (1972) observed the genus Myrmica. They worked with Lasius niger (L) and Lasius flavus (F) species which differed in their mode of feeding and life. The study site was in Strzeleckie Meadow a part of Kamprines National Park near Warsaw. In their analysis of mound soils they found that they were higher in organic matter, total nitrogen, K_2O , P_2O_5 and cation exchange capacity. They made the following observations based on microorganisms studied:

- (1) Higher bacteria and fungi development and a decrease of actinomycetes in termite hills of all species.
- (2) The number of microflora went down with decomposition of the mound material after it was abandoned.
- (3) In case of L. niger the number of microorganisms tended to be higher than surrounding soils by 14 fold for bacteria, fungi 10 fold and actinomycetes 6 fold. For Myrmica, microorganisms increase by 8 fold, 3 fold for bacteria, fungi, and actinomycetes respectively. This work was in temperate areas and would therefore be less useful under tropical conditions where termite mounds are large as compared to those small hills a few centimeters in diameter and height.

These mounds were inhabited for short periods of the year while the tropical mounds were inhabited for a long time with an average of 4 - 10 years Pomeroy (1976a). In this case termite activity would be more effective under tropical conditions where even the volumes of soil affected is quite large.

2.4. Seasonal fluctuation of soil microorganisms

There is limited information on seasonal influences on the population dynamics of soil microorganisms. The available data is from temperate climate hence it would be of little relevance in the tropical areas. The other problem of using these data are differences in soils and methods of culturing soil microorganism. In case of tropical soils, temperature fluctuation could be assumed negligible except in the top horizon. Soil moisture content and organic matter in the soil would be the major factors affecting the distribution of microorganisms.

Rahno et al. (1978) carried some work on soil types in Estonian USSR and made the following comparisons, that the development and reproduction of microorganisms was not completely determined by seasonality but that their maximum numbers could be in any season, if the

necessary factors were available. For example maximum fungal numbers were found in winter at 25 - 30% moisture content thus the number of fungi was highly correlated to soil moisture content. At this level of soil moisture content bacteria were at their minimum but maximum numbers were in autumn when organic matter was at maximum level and toxicity in the soil low due to low temperatures Rahno (1964). Feker as quoted by Rahno (1964) in Hungary found high numbers of bacteria during summer and low numbers during winter. He associated these fluctuations to temperature. His findings were the opposite of Conn (1914), working on Canadian soils.

Jensen (1934) working in South West Wales on a soil in Sydney University, Australia found that there was a definite correlation between numbers of bacteria and moisture content. For actinomycete he found a low correlation with moisture but a high correlation to bacterial numbers. A high correlation between fungi and moisture content was also observed. In his summary he mentioned that those groups of microorganism were highly correlated with organic matter increase but there was no correlation between soil reaction. He also observed a relative increase of actinomycete in relation to bacteria with decrease in moisture content and probably temperature increase. This work by Jensen

in Australia, may be useful under the tropical climate though soil differences may be present and his findings in actinomycete are similar to what Meikeljohn (1957) found in her study at Muguga, Kenya. She found that the number of actinomycete increased from less than 15% to 90% in the total plate count with the onset of the drought during the early 1953 drought. The number of actinomycete increased with decrease in soil moisture content. Some workers in Congo (Zaire) also reported high counts of actinomycete during the dry period and so they concluded that since actinomycete are drought resistant, they make a large part of the microflora in the tropical soils.

During the culturing of these microorganisms different observations were made, the colonies of actinomycete increased with increase in moisture content. They were more distinctive and larger than in the samples cultured from the wet season when bacterial colonies were prevalent, and tended to compete with actinomycete.

2.5. Techniques for studying soil micro-organisms

2.5.1. There are many methods for quantifying the microorganisms and the choice of the method depends on:

- (a) Whether relative or absolute figures are wanted.
- (b) Whether one wants viable or total counts.

(c) Type of organism to be counted.

(d) Precision of the data obtained.

2.5.2. Direct Microscopy

Examination of undisturbed thin sections of the soil Kubiena (1938), buried slide and smear-ratio technique Rossi et al. (1936) who buried microscope slide on cover slip for several days after which the slide was removed, soil washed away and the organisms were fixed, stained and observed under the microscope. The results gave organisms that grew better on a solid continuous surface. Thin section technique by Burges and Nicholas (1961) has been used to estimate fungal growth in the soil. They impregnated an undisturbed section of the soil a resin that would harden, then thin section 10 - 50 μ m thick were cut and observed under the microscope. The limitation of the method is that the section observed is a very small area of the soil surface and due to heterogeneity of the microorganisms in the soil, a large number of samples need to be observed. Secondly, due to the small area, the population of microorganisms need to be high for an organism to be seen. Smear ratio technique by Conn (1918), Thornton and Gray (1934), the numbers were estimated from an area of slide containing a known quantity of soil suspension. Use of dyes which were aimed at staining live cells in order to differentiate dead cells and organic matter was advocated by Jones and Mollison (1948).

These workers found that the acridine orange dye when absorbed by living cells and recently dead cells fluoresces green while dead cells and organic matter fluoresces red-brown. Jones and Mollison (1948) found that living cells absorbed aniline blue and held it against a solvent which washed it from organic matter and dead cells. These cells stained an intense blue colour. Use of electron microscopy where blocks of soil are stained with dyes like aniline, dried and impregnated under vacuum with thermosetting resin, then thin sections are cut 20 - 30 mm thick and observed under the electron microscope.

Certain species of bacteria and fungi can be recognised through fluorescent antibody technique, Schmidt and Bankole (1962) and Schmidt (1977). In this technique antibody of selected bacteria or fungi is obtained usually from a rabbit serum. The antibody is conjugated with fluorescent dye like fluorescein or rhodamine isothiocyanate. Soil smear are made on a slide and are washed with the antibody dye suspension. The bacteria and fungal cells absorb the antibody which fluoresce when viewed by incident or transmitted ultraviolet light.

In direct microscopy all the cells can be counted, the morphology can be seen, dimension can be measured and relative relationship between cells and soil particles

as they exist in the natural environment can be observed. The problem in the method may however be in differentiating live from dead cells and this was mentioned by Jones and Mollison (1948) who found that the cells were taking an intermediate colour between live and dead cells. Morphologically similar organisms may be difficult to identify further, also soil particles with similar shape may be included with the cells. Filamentous organisms may be difficult to enumerate and a representative sample of soil would be difficult to obtain. In case of buried slides, fast growers especially filamentous fungi and actinomycetes encounter a favourable surface with higher moisture content and so what is counted or observed may not represent what really is dominant in that soil under natural conditions. These methods are also limited to few samples and so a worker covering many samples cannot use these methods. However direct microscopy in combination with other techniques offers some promise in isolation procedures.

2.5.3. Indirect method or cultural methods

These methods require placing soil particle or appropriately dilute soil suspension in solid or liquid substrates suitable for growth of organisms. In case of placing soil particles Warcup (1950) placed 35 mg of soil in a thin layer. Fifteen millilitres of Czapek Dox medium at pH 4 were poured into the plate. The aim

was to isolate fungi from the soil. Chesters (1940, 1948) placed 'immersion tubes' containing sterile nutrient agar in the soil, he also used screened immersion plates with an aim of culturing fungal colonies representative of the soil fungi under natural conditions. These were found to favour sporulating fungi and also those existing in form of mycelia.

Agar-plate method is the commonly used technique in the determination of microbial population in the soil. The method involves the dispersion of an inoculum in a medium solidified with 1-2% agar to such an extent that individual microorganisms, spores or mycelia fragments have an opportunity when exposed to suitable conditions to develop into distinct and microscopically visible colonies. The degree of dispersion needed is achieved by making successive serial dilutions of a given soil sample.

The technique assumes that each viable microorganism present in the soil sample suspension develops into a visible colony following its seeding in the agar, that each colony develops from one cell, that the cells are all brought into suspension and are uniformly distributed in the solution. It also assumes that all the organisms in the suspension are capable of germinating in nutrient agar medium Russell (1973). It has been found however, that it is impossible to prepare any one combination of substrate

that can support the growth of all species present in the soil. Even if conditions and substrate were right viable microorganisms may fail to grow. Whereas direct microscopy would show them. Bacteria are said to be held strongly on the soil particles (Marshall, 1969). Hand shaking was therefore found to be unsatisfactory. Different workers advocate the use of mechanical shakers (Meikeljohn, 1965). Other workers argue that by shaking some cells are killed and in the case of fungi and actinomycete mycelia are fragmented resulting in higher counts.

On preparation of soil suspension the organisms are adsorbed on the surface of soil suspension and tend to settle down before the suspension are inoculated into the plates (Marshall, 1969). It is therefore important to shake the soil suspension for a few seconds before plating.

Some organisms may fail to germinate because they could be dormant. Others may fail to grow due to competition because in the media they are seeded in proximity to an organism producing antibiotic or antagonistic factors. Many workers have therefore found that plate method gives a rough estimate of a large population in the soil. So far no single media has been found to support growth of all the organisms found in nature because the soil is a complex and heterogenous medium

difficult to simulate under laboratory conditions. In case of fungi the agar plate method favours germination of spores if the medium and incubation conditions are favourable for their germination. They usually compete against the vegetative forms which are active in the soil. The method gives 1 - 10% of the total count given by direct method (Russell, 1973).

Mollison and Jones (1948) working with Broadbalk Soils, England found that plating method was 15 times less accurate than direct microscopy. Russell (1973) reported that Gray and Mollison found that direct and plate methods had very similar results for a dense soil under forest. Direct count gave $4 - 5 \times 10^8$ cells/g soil. However plate counts gives a good estimate of the metabolically active cells at the time of sampling, it being the most widely used method available for comparative studies.

The other method used in enumeration of microorganism is Most Probable Number. The method estimates population density without an actual count of single colonies or cells. It is sometimes called the method of ultimate or extinction dilution. Theoretical aspects of the method have been described by Zeigler and Havol-son (1933) and Cochran (1950). The technique determines presence or absence of microorganisms in several individual aliquots of each of several consecutive dilution of the soil. The microorganism whose population is determined must be able to bring about a characteristic

transformation in the medium to which it is inoculated. Turbidity, pellicle on the surface, gas production or colour change are some of the indications or changes that can be observed visually.

To determine different biological processes in the soil one can determine specific groups of bacteria using either differential or selective media. A selective medium is that which has been chemically formulated to allow the growth of the species of interest and suppress growth of other competitive species. Inoculation into a selective medium of an inoculum containing many different kinds of microorganisms results in the growth of one or a few species that are selected for by the growth medium. A medium can be made selective in various ways. One method is to incorporate selective substrates or inhibitory substance such as antibiotics. The other one is pretreatment of the inoculum for example if one wants to isolate organisms that form endospores, heat treatment at 80°C for 10 minutes will kill all the vegetative cells. The growth that ensues is as a result of the spore formers.

Conditions of incubation could also be used as a selective technique and this takes into account various environmental factors and their optimal growth ranges. Aerobic incubation selects Bacillus from

Clostridium which is an anaerobic organism. Differential media method is mainly used for identification rather than enumeration and isolation. It takes advantage of the fact that depending on different bacterial enzyme systems they will metabolise organic compounds to different end products, such as, cellulolytic organisms do produce cellulase which digests cellulose in plates and leave clear areas which can easily be enumerated. A media may be both selective as well as differential.

METHODS AND MATERIALS

CHAPTER 3

3. METHODS AND MATERIALS

3.1. Study sites

The study was carried out in the semi arid areas of Kenya where there are many undisturbed termite mounds. These areas included Kajiado, Voi and Magadi. The major study site was Kajiado which is 80 km south of Nairobi and 8 km from Kajiado town on the Namanga road. The site belongs to International Centre for Insect Physiology and Ecology (I.C.I.P.E.) termite project. This is a semi-arid grassland ecosystem (Lepage, 1975). The actual location of Kajiado site was $36^{\circ} 30'E$ and $1^{\circ} 43'S$ at an altitude of 1,600' - 2,000' above sea level.

3.1.1. Vegetation

This is a wooded grassland savanna with the following major grass species Themeda triandra, Pennisetum spp., Cynodon dactylon and non specified species. The major trees were Acacia tortilis, Acacia senegal and others.

3.1.2. Climate

These areas have a temperature of $16 - 27^{\circ}C$ and low rainfall of about 300 - 600 mm per year. There are two rainy seasons, long rains cover March to May and short rains cover November to December. The highest precipitation falls in April, Arsnad (personal

communication). The unpredictability of the rainfall in this area is shown by the following data obtained from I.C.I.P.E. annual reports. In 1976 - 306 mm per year were recorded, 1977 - 650 mm per year, 1978 - 744 mm and a 7 month wet period was recorded from November 1977 to May 1978, Lepage (1978). However this was a short period to draw conclusions.

3.1.3. Soil

The soils of the study site (Kajiado) were developed on undifferentiated basement rock system mainly Precambrian. The soils have been classified as chromic-Luvisol (Arshad, 1978). The soils are shallow extending to a depth of about 100 cm or less except in areas covered by mounds.

3.1.4. Land use

The site is situated in a Maasai ranch and is constantly grazed. The termites mounds were therefore disturbed by the grazing animals. The influence of termite activity on the surrounding vegetation was observed on some control plots which were fenced and protected from animals.

3.1.5. Other study sites

The other study sites namely Magadi, Emali, Ruarak, Konza and Kibini were chosen on the basis of soil groups using the F.A.O./U.N.E.S.C.O. classification. A soil map of Amboseli National Park obtained

from National Agricultural Laboratories (N.A.L.) at a scale of 1:250,000.

The nine soil groups varied in their chemical and physical properties. Except the soils from Ruaraka all the others were considered to have similar climate and vegetation as that of Kajiado. The soil groups with their location, mound types and termite species responsible for their construction are presented on Table 1.

The genus Macrotermes constructs 'open' and 'closed' mounds. In Kajiado the mounds were closed while in Emali and Magadi which are low altitude areas had open type. In some areas the two types of mounds do occur side by side like at Bissel and Konza. This contradicts statements by some workers that climate and soil difference were responsible for the two types of mounds. It has been shown at I.C.I.P.E. that two different species of the genus Macrotermes mentioned earlier are responsible for these mounds.

The two types of mounds occurring side by side at Konza, about 42 km East of Kajiado were chosen randomly. The soils of the areas are orthic-Luvisols. These two mounds were opened vertically and samples taken from different chambers. A soil profile in between the two mounds was sampled for comparison purposes. The different chambers in a 'closed' type of mound is diagrammatically shown in Figure 1.

Table 1: Description of area and soils taken from mounds and surrounding soils from different parts of Kenya.

Sampling date	Location	Grid reference	Sample soil groups No.	Mound Types	Termite Species
5.5.79	Kajiado	BH5492	87-95 Luvisol/Cambisol-UUC	Closed	<u>M. michel- iseni</u>
"	"	BH5898	96-98 Complex soil ferralsol and arenosol-PRdp-ap.	"	"
6.5.79	Konza	BJ8305	99-101 Ferralsol, Arenosol on plain steppe high level plains - PRb	"	"
10.5.79	Magadi	BJ1023	108-110 Vertisol with Solonchak - BV ₃	"	"
"	"	BJ1326	111-113 Soils from undifferentiated alluvial deposits	"	"
"	"	BJ2826	114-116 Lava flow-Laf	"	"
"	Ruaraka	BJ6565	117-119 Alluvial soil	"	"
			120-122 Valley Bottom	"	<u>Odontotermes</u>
			123-125	"	<u>M. michel- iseni</u>
26.5.79	Emali	CH3269	126-129 Ferralsol derived from olivine basalt	"	"
"	"	"	"	"	"
"	"	"	"	Open	<u>M. subhy- alinus</u>
"	Kibini	CH1366	134-136 Soils from colluvium derived from various genesis on basement complex.		

3.2. Choice of mounds and setting up of sampling sites.

Closed mound built by Macrotermes subhyalinus (Rambur) are most common in Kajiado. Six mounds were chosen randomly taking into account effects of catena (Milne, 1947), 3 were inhabited 'active' and 3 uninhabited 'dead'. A problem was encountered in determining the age of the mound and so it was assumed that age of these mounds and the populations of termite present had similar effect on the studies carried out. It was not easy either to know how long the dead ones had been uninhabited because two out of the 3 chosen 'dead' mounds had their colonies eaten by (ant-eater) the other one had been fumigated with ethyl bromide to kill the colony by I.C.I.P.E. research workers in 1975/76. It was therefore assumed that the mounds had been uninhabited for 2-2½ years Arshad (Personal communication). Each of the 3 sets of mounds were replicates.

Sampling sites were established by measuring the following distances using a 100 m tape measure and pegs.

- MS (0) soil sample from cap of the mound
- 1 m from the base of the mound
- 3 m " " " " " "
- 5 m " " " " " "
- 10 m " " " " " "

- 15 m from the base of the mound
- 20 m " " " " " "

For every distance three random points were marked round the termite mound and these were used throughout the period of study. The aim was to try and have as similar samples as possible. This was referred to as 'longitudinal sampling' and the data obtained was used for studying seasonal effects and proximity of the mound. For the samples taken in other areas outside Kajiado the distances measured were 0, 3 m, 20 m and 40 - 80 cm for subsoil.

3.3. Sampling and treatment of the samples

Soil samples for seasonal studies were taken twice every season. The first two samplings were taken during the short rains of November - December 1978. One dry season sample was also taken in September 1978. In the latter samplings of 1979 there were problems in getting a dry period because as mentioned earlier those two years 1978/79 were exceptionally wet. It was possible to take another dry season sample on March 1979. The sampling during the wet period were carried out as described in the schedule.

Two more samples representing the long rains were taken in April and May 1979. To avoid any effects of rains on the equilibrium of soil microbial populations, two weeks were allowed after the onset of rains. It

was then assumed that the microorganisms had attained an equilibrium. The samples were taken during an interval of 3 - 4 weeks. It would have been preferable to take shorter intervals for this kind of study due to rapid fluctuations that take place in the soil.

The criteria used to determine the onset of the dry period were the browning and reduction in vegetative ground cover together with development of cracks on these soils. Those were used as indicators of low moisture content in the soils.

A cylindrical core sampler 5 x 13 cm was used for taking the samples thus the soil under study was the top 13 cm. Before taking the sample the sampler was sterilised with 70% ethanol for 2 - 3 minutes and held out to dry before inserting in the soil.

For every distance from the mound three samples were bulked to give one sample. The soil samples were transported to the laboratory in presterilized polythene bags which had been prepared from a large roll. A total of 8 samples for every mound were taken making 48 samples for analysis every time. Each sample was treated aseptically and then returned to the original container. The samples were stored at 4°C in the refrigerator for 2 weeks before culturing the microorganisms. The reason for the low temperature storage was to control biostasis during the long period of storage. The two week storage period was to allow equilibration.

of the microbial population. The aim was to study soils which were as near their natural conditions as possible thus for all the microbial studies undertaken the soil were not air dried or sieved unlike in normal soil analysis studies.

For soil analysis the samples taken from similar distances in the 3 replicates were mixed to give one sample. The three active mound comprising of (3 x 3) sub samples had a total of 7 samples. The dead mound soil samples were treated in a similar way. The soils were air dried at room temperature for 2 days and then passed through 2 mm sieve, (Ahn, 1973). The soils were stored in the laboratory in air tight polythene bags for routine soil analysis, such as mechanical analysis, carbon content etc.

3.4. Preparation of dilutions and culturing of micro-organisms.

3.4.1. Water blanks

The method used was given by (Keya, 1975; Clark, 1965). Ninety five millilitres of tap water was dispensed into 300 ml screw capped medicinal bottle together with 10 spherical glass beads of 2 mm in diameter. Eighteen mls of water was dispensed into Mcartney's bottles with automatic syringe calibrated to 0.1 ml. The bottles were sterilized at 121°C at 1 atm. for 15 minutes, on removal they were stored at room temperature 25 ± 0.5 °C. For every sample one medicinal bottle

and five McCartney's bottles were used for making serial dilutions to 10^6 .

3.4.2. Preparation of serial dilutions

Ten grams of each soil sample was weighed aseptically and transferred into 95 mls sterile water blank. The contents were shaken for 5 - 10 minutes on a mechanical shaker. Upon removal and settling the suspension were shaken by hand as serial dilutions from 10^{-2} to 10^{-6} were prepared, using 2 ml sterile pipettes.

3.4.3. Preparation of the media

Selective media were used to culture different groups of microorganisms. In case of bacteria soil extract agar (Lockhead, 1940) and modified by (Keya, 1975) was prepared with the following constituents: 1.0 g glucose, 0.5 g K_2HPO_4 , 0.1 g KNO_3 , 100 ml soil extract, 15 g agar-agar, distilled water 1000 mls and pH 6.8 - 7.0 adjusted with 10% KOH. Soil extract was prepared by weighing 100 g of soil and mixing the soil with tap water. The mixture was autoclaved for 20 minutes then allowed to cool. The supernatant was filtered using Whatman No.1 and No.42 filter paper to obtain a clear solution. The solution was stored for subsequent use. Rose bengal-acid agar used to culture fungi composed of 10 g glucose, 5 g peptone, 1 g KH_2PO_4 , 0.5 g $MgSO_4 \cdot 7H_2O$, 15 g agar-agar and 33 mg rose bengal and dissolved in 1000 ml distilled water. The pH was adjusted to 3.8 by adding 0.65 ml of 10N H_2SO_4 . The medium for

actinomycete was nutrient agar (Keya, 1975) prepared as follows: 3 g beef extract, 5 g peptone, 15 g agar-agar dissolved in 1000 mls distilled water and pH adjusted between 6.8 - 7.0 using 10% KOH.

All the media were dispensed into 300 ml screw-capped medicinal bottles and sterilized at 121°C, 1 atm. for 15 minutes. If the media was not used immediately it was stored in closed containers at room temperature 25°C ± 0.5.

3.4.4. Preparation of pour-plates, incubation and counting of the colonies.

The media were autoclaved at 10 lbs in $^{-2}$ pressure and then removed to a water bath at 42°C. Petri-dishes which had been sterilized in containers at 200°C for 60 minutes were used. Using sterile 2 ml pipettes 1 ml soil suspension was dispensed into each sterile plate in duplicates for each group of organism. The dilutions used for each group were as follows: fungi dilutions from 10^{-2} to 10^{-3} , bacteria 10^{-5} to 10^{-6} and actinomycete 10^{-4} to 10^{-6} .

In each plate containing 1 ml of the inoculum, 15 - 20 mls of the appropriate media at 42°C was poured and rotated to distribute the inoculum uniformly in the media. The plates were left to stand for 20 - 30 minutes on the bench for the media to solidify. The plates were then inverted and incubated at 28° - 30°C. Different incubation periods were allowed for different groups of organisms. The incubation periods

were 10 - 14 days, 7 days and 3-4 days for actinomycete, bacteria, fungi respectively.

A colony counter (Scientifica and Cook electron, ICS Ltd.) was used for enumeration of the colonies that developed on the plates. The numbers obtained were expressed per gram dry soil.

3.5. Enumeration of different groups of bacteria

Soil samples taken at 0 m, 3 m, 20 m from both inhabited and uninhabited mound from Kajiado were also used in this study. Different groups of bacteria were enumerated using the Most Probable Number technique (MPN) according to (Meikeljohn, 1965; Alexander, 1965).

3.5.1. Serial dilutions

Ten fold dilutions were prepared as already described in section 3.4.2. Five tubes per dilution were used and the number of positive tubes out of five were recorded.

3.5.2. Inoculation

Using 5 ml sterile pipette 1 ml of the inoculant was placed into each tube containing the sterile medium. The tubes held in a rack were then incubated at 28 - 30°C. Incubation period varied according to the group of bacteria under consideration but ranged between 7 - 21 days.

3.5.3. Preparation of media used

In order to enumerate different groups of bacteria, selective media were formulated in such way that a particular media was free of certain specified nutrients capable of limiting growth of some groups except those under study. Those groups that change the pH of the media, pH-indicators were used. All the counts except for those of aerobic nitrogen fixers were carried out by the use of nutrient broth dispensed into (125 x 15 mm) screw-capped culture tubes.

3.5.4. Media for the enumeration of bacterial groups

3.5.4.1. Aerobic nitrogen fixers

The composition of the medium for the enumeration of aerobic nitrogen fixers was as follows: Mineral salt solution: 5 g K_2HPO_4 , 2 g $MgSO_4 \cdot 7H_2O$, 0.2 g. $MnSO_4$, 0.1 g $MoO_3 \cdot H_2O$, 0.1 g KI dissolved in 1000 ml distilled water.

To 100 ml of mineral solution 20 g agar-agar, 10 g sucrose, 3 g $CaCO_3$ and 900 ml distilled water were added. The media was dispensed into 300 ml screw-capped medicinal bottles and sterilized at $121^\circ C$, 1 atm. for 30 minutes. The medium was then cooled in a water bath at $42^\circ C$ before 15 - 20 ml of the medium was poured in each of the sterile plates. The plates were allowed to stand for 30 minutes before drying in the incubator for 1 hour. For every dilution 0.2 ml of the

suspension was transferred into each plate in duplicates. After gentle swirling to spread the inoculant the plates were allowed to dry. The plates were inverted and incubated at 28 - 30°C for 7 days.

3.5.4.2. Cellulose decomposers

Cellulose decomposers were determined by the method of (Jensen, 1940). The medium described by Jensen consisted of the following: 10 g $(\text{NH}_4)_2\text{SO}_4$, 1.0 g K_2HPO_4 , 0.5 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 2.0 g CaCO_3 dissolved in 1000 ml tap water. Five millilitres of the medium were dispensed into each tube and a strip of Whatman No.1 filter paper was suspended into each tube.

3.5.4.3. Nitrifying bacteria

The two groups of bacteria involved in nitrification have different culturing media as given by Clark (1965).

Nitrosomonas

The medium for culturing nitrosomonas was prepared as follows:

Ammonium - calcium nitrate: 0.5 g $(\text{NH}_4)_2\text{SO}_4$, 1.0 g K_2HPO_4 , 0.03 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 0.3 g NaCl, 0.3 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 7.5 g CaCO_3 dissolved in 1000 ml distilled water. Five mls of the medium was dispensed into each of the tubes.

Nitrobacter

The medium for culturing nitrobacter was nitrite-calcium carbonate which was composed of the following: 0.006 g KNO_3 , 1.0 g K_2HPO_4 , 0.3 g NaCl , 0.1 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.03 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 1.0 g CaCO_3 and 0.3 g CaCl_2 dissolved in 1000 mls distilled water. Five mls. of the medium was placed in each of the culture tubes.

3.5.4.4. Denitrifiers

The medium for denitrifiers was formulated by Timonin (1947) and quoted by Alexander (1965). This medium consists of two solutions as follows:

Solution A

1.0 g KNO_3 , 1.0 g asparagine, 5.0 ml of 1% solution of bromothymolblue as the indicator and 600 ml distilled water.

Solution B

8.5 g sodium citrate, 1.0 g KH_2PO_4 , 1.0 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.2 g $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, 0.05 g $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ dissolved in 500 ml distilled water.

Solution A and B were mixed in equal volumes and the pH adjusted to 7.0. Ten millilitres of the medium was placed into each test tube. The media was sterilized in the autoclave at 121°C , 1 atm. for 20 minutes. After cooling to room temperature ($25 \pm 0.5^\circ\text{C}$) the medium was inoculated with 0.5 ml of the soil suspension from the appropriate dilution. Five replicates

per dilution were used. Then tubes were incubated at 28 - 30°C for a range of 7 - 21 days and the range of dilution covered 10^{-1} to 10^{-7} .

3.5.5. Counting

The most probable number table by Cochran (1950) and quoted by Alexander (1965) was used. Positive tubes out of 5 were recorded and those records were used to estimate the number of bacteria for each group. To calculate the 95% confidence limits the MPN factors designed by Cochran (1950) which combines the number of tubes per dilution and the dilution ratio. The factor for 95% confidence was obtained and when multiplied by the MPN value gave the upper confidence interval. When this factor was divided by the MPN value the lower confidence limits at 95% were obtained.

3.6. Determination of protozoa

Using Singh's 'ring' method (1945) which is in principle extinction dilution technique described by Clark and Beard (1965).

Singh (1946) showed that not all bacteria in the soil were edible to the protozoa. He used Aerobacter aerogenes in his studies. Danso et al. (1975) showed that Rhizobium spp. served as food source for protozoa. In this experiment a strain of Rhizobium phaseoli Num 13 (006) was used. The bacteria was cultured in Y.E.M.

following the procedure outlined by Keya (1975). To increase the density of cells available to the protozoa the broth was centrifuged at 10,000 r.p.m. for 20 minutes aseptically.

Instead of using glass rings as described in Singh's method, rubber rings 1.5 cm wide and 1 cm long were used.

3.6.1. Mineral salt agar preparation

Fifteen grams of agar-agar was weighed and dissolved in 1000 ml of water. Sodium chloride was added to provide 0.5% solution before adjusting the pH to 6.5. The NaCl-agar was placed in 300 ml medicinal bottles and sterilized at 121°C, 1 atm. for 15 minutes. The NaCl-agar was cooled in a water bath at 42°C. Then 5 - 10 mls were poured in sterile plates. Sterile plastic rings (1 cm long x 1.5 cm wide) were placed in the plates before the mineral-salt agar solidified. Ten rings were placed in each plate. Into each ring 0.5 ml of the thick bacterial suspension was placed using sterile pipette.

3.6.2. Preparation of soil dilutions

Soil dilutions were prepared as already described in Section 3.4.2. Instead of sterile water blanks, 0.5% NaCl solution was used. This was to control germination of other microorganisms especially bacteria in the soil suspension. Serial dilutions were

prepared ranging from 10^{-1} to 10^{-4} . An inoculant of 0.05 ml was placed into each ring using sterile 1 ml pipette graduated to 0.001. For every dilution 5 rings were used. The plates were incubated for 2 weeks at 22 - 25°C and then observed under low power microscope for presence or absence of protozoa. A positive or negative was assigned to each ring and most probable number (Cochran, 1950; Singh, 1946) was used to estimate the number of protozoa in the soil.

3.7. Microbial activity in the soil as measured by CO₂ production.

In order to raise the moisture content of the soil 10 - 25 mls of distilled water was added into 500 ml erlenmeyer flasks to bring the water holding capacity of the soil samples to 60%. According to Keya (1975) 100 g of soil were weighed in triplicates and placed into each of the sterile 500 ml erlenmeyer flasks. Into each flask a McCartney's bottle containing 15 ml of 1N NaOH was suspended at an angle of roughly 45°C with cotton thread, then flasks were tightly covered with rubber corks and wrapped with parafilm to avoid any loss of CO₂. A control was also set in triplicate containing 25 mls water and no soil sample. The flasks were then incubated at 28 - 30°C for 10 days after which they were removed.

3.7.1. Titration for determination of CO₂ released

Prior to titrations McCartney's bottles were removed carefully from the flasks and the contents rinsed into 150 ml erlenmeyer flasks with distilled water. One ml 50% BaCl₂ and 5 drops of phenolphthalein indicator were added before being titrated against 1N HCl. The titre gave the amount of free 1N NaOH which did not mix with CO₂. The following equation was used to calculate the amount of CO₂ released:



1 mole CO₂ (44 g CO₂) reacts with 2 moles NaOH (80 g NaOH) 1 ml of 0.1 NaOH is equivalent to 2.2 mg CO₂.

$$\text{Hence } = \frac{(15 - x) \times 2.2}{100} - y \text{ mg CO}_2 \text{ per gram of soil}$$

Where,

x = amount of 1N HCl

y = CO₂ content present in the control

2.2 = amount of CO₂ which combined with 1 molecule of NaOH

100 g = soil sample used in the experiment

3.8. Soil analysis

Certain proportions of the sample were dried at room temperature for two days and then passed through a 2mm sieve. The samples were stored in polythene bags for further analysis.

Particle size distribution was done using pipette method. Total nitrogen was determined by Kjeldahl method (Bremner, 1965). Organic carbon was determined using Walkley-Balck method as outlined by (Ahn, 1973). The moisture content was determined by gravimetric method. To determine cation exchange capacity of the soil samples ammonium acetate saturation method was used. A glass electrode was used to determine the soil pH at a ratio of 1:1 both in water and a salt such as 0.01 M CaCl_2 .

RESULTS

CHAPTER 4

4. RESULTS

4.1.1. Chemical and physical properties of the soils from 'live' and 'dead' mounds.

Due to limited data on the analysis of the soils from termite 'modified' soils in East Africa, chemical and physical properties of the soil samples in this study was carried out. The results are as shown in Tables 2a and 2b and illustrated by Figure 2 in case of particle size distribution.

It was observed that the total sand for both 'live' and 'dead' mound showed a relative increase the further away the samples were from the mound. The clay and silt content showed an opposite trend. The highest quantities were from the mound samples and decreased with increase in distance from the mound. The termites are said to carry fine soil particles which are less than 2 mm mainly from the subsoil (Hesse, 1955; Pomeroy, 1976b). The material washed from the mound during the rainy season is deposited in the surrounding areas and this influences the texture of these soils. Some workers have reported that this selectivity of the fine soil particles by the termite workers may result to a 'stone-free' layer especially where the density of these mounds is very high (Williams, 1968; Pomeroy, 1976; Nye, 1955). Results on Tables 2a and 2b show similar data to that of (Arshad, 1978) who carried out

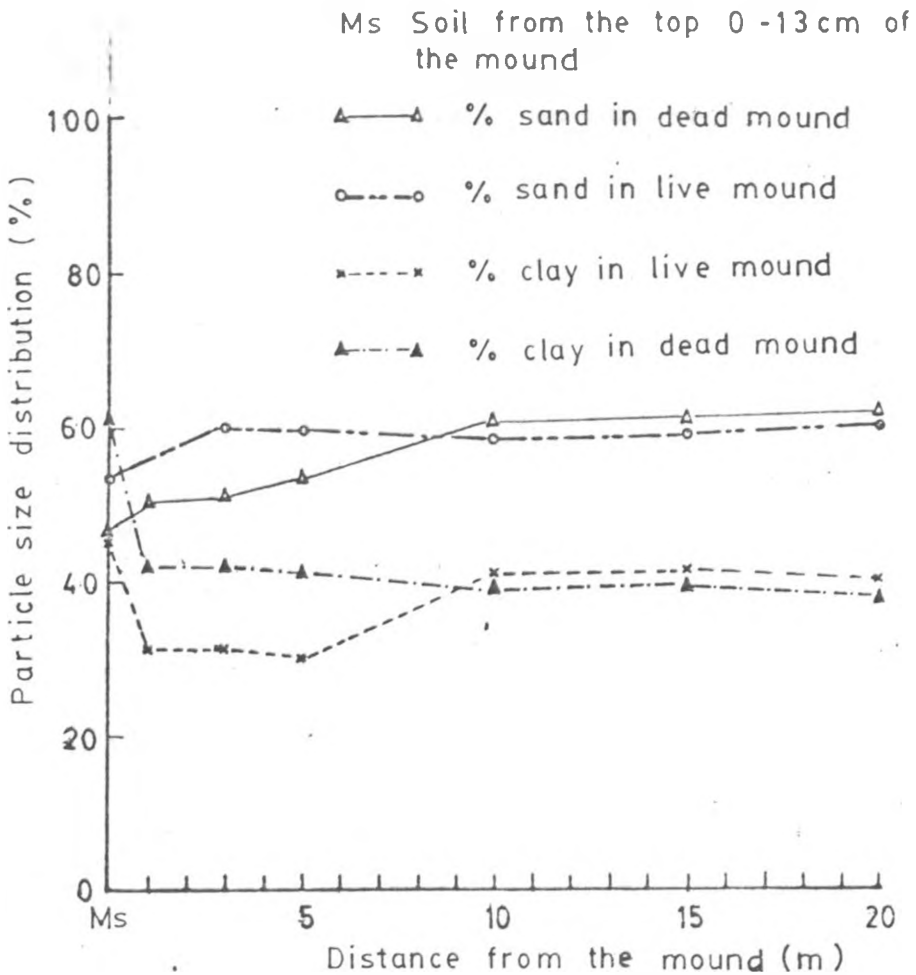
Table 2a: Soil analysis of 'live' mounds of Macrotermes

Distance from mound:	pH H ₂ O (1:1)	C.E.C. m.e./100g soil	Exchangeable Bases m.e./100g soil				Particle size distribution			C %	N %	C:N
			Ca	Mg	K	Na	Sand %	Silt %	Clay %			
Soil from mound	6.6	23.6	21.8	1.7	0.36	0.04	41.39	13.63	45.0	0.82	0.108	7.59
0	6.1	19.2	14.2	2.8	0.19	0.02	51.97	9.34	38.7	1.18	0.084	14.05
1	6.1	16.4	11.8	2.1	0.18	0.01	58.31	10.83	30.87	1.54	0.07	22.00
3	6.3	16.4	10.0	1.6	0.22	0.02	58.30	10.21	31.5	1.58	0.07	22.57
5	6.2	11.6	10.0	2.2	0.19	0.02	59.45	10.55	30.10	1.51	0.098	15.41
10	5.8	18.8	10.6	2.6	0.17	0.01	58.50	9.25	28.76	1.55	0.112	13.84
15	6.4	18.8	11.0	3.2	0.20	0.01	60.32	9.13	30.50	1.51	0.168	8.99
20	6.0	15.6	10.8	1.9	-	0.02	60.40	9.55	27.59	1.46	0.09	16.22

Table 2b: Soil analysis from 'dead' mound of Macrotermes

Soil from the mound	7.1	21.6	14.8	3.3	0.24	0.05	35.94	8.86	51.92	0.40	0.042	9.50
0	6.2	19.2	11.3	3.1	0.42	0.03	53.71	9.29	32.29	0.93	-	-
1	5.7	16.0	9.9	0.7	0.36	0.02	47.6	8.98	43.76	1.37	0.084	16.31
3	5.6	17.2	9.2	2.8	0.23	0.01	52.2	9.50	29.52	1.42	0.14	10.14
5	5.6	15.2	8.7	3.6	0.24	0.01	55.65	9.41	27.63	1.56	0.098	15.92
10	6.3	14.0	8.5	1.5	0.21	0.01	63.06	9.50	26.21	1.44	0.154	9.35
15	6.2	14.4	8.3	2.5	0.16	0.02	63.75	9.18	26.20	1.44	0.084	17.14
20	5.7	10.8	8.8	2.3	0.18	0.01	62.93	9.35	29.89	1.45	0.063	23.02
Surrounding soil												
(a) Top soil 0-20 cm	5.5						42	22	37	2.155	0.166	13.0
(b) Subsoil 70-100 cm	4.3						45	17	38	0.40	0.046	8.4

Fig 2 Particle size distribution in relation to mound proximity



soil studies at the same site at Kajiado.

The C and N contents in the soil samples from the mound were lower than in the top 13 cm of surrounding soils but close to the subsoil. Although the 'live' mound was free of vegetation cover, it had higher C and N values than the dead mound. This was contrary to expectation because the 'dead' mounds were covered by a thick grass cover which was expected to have added organic matter to the soil.

The pH in water was slightly higher in both 'live' and 'dead' mound than the top 13 cm of the surrounding soils. It can be seen that all the other soil samples from 0 - 20 m from the mound showed relatively similar results.

The cation exchange capacity (C.E.C.) together with exchangeable bases Ca, Mg, K, Na were higher in the mound soil and distance upto 10 m than the surrounding areas which were assumed to be more than 20 m from the mound. The C.E.C. and exchangeable Ca, Mg and K in the live mound were higher than in the dead mound.

An inhabited 'live' mound is resistant to weathering and erosion agents. However, when it is uninhabited, disintegration and decomposition of the organic matter and organic substances in the saliva starts to take place. The elements released were washed down the profile.

In the 'live' mound the subsoil is continuously

brought up by termite workers for increasing the size of the mound and for repair. This subsoil is unexploited by the plants hence it is higher in cations than 'dead' mound which is exploited by plants. The C.E.C. and exchangeable bases decreases with distance from the mound.

4.1.2. Moisture content

Soil moisture content for top 13 cm for both 'live' and 'dead' mound was found to decrease with distance from the mound as shown in Table 3. This pattern of moisture content could be associated with the trend of soil texture as already shown in Table 2a and 2b. As the distance from the mound increased the sand content increased which resulted in a coarse texture. The amount of soil moisture content depends on the texture and organic matter levels. Therefore the coarser the texture the lesser the amount of moisture content held by the soil hence low moisture content as the distance from the mound increased. Secondly, vegetative cover around the mound may account for the observed behaviour of soil moisture content. Apart from the cap of the mounds which was bare the distance from 1 - 10 m had a thicker cover than the surrounding areas. Losses by evapo-transpiration may have been balanced by the cover and higher organic matter. Thus in the areas beyond 15 m there was higher water loss from the bare ground. Negative correlation

Table 3: Moisture content (%) of the top soil in relation to Mound Proximity.

Distance from mound	Live mound		Dead mound	
	wet season	dry season	wet season	dry season
0	19.16	8.50	14.89	10.00
1	15.96	9.45	12.39	12.50
3	15.12	8.45	11.13	13.00
5	14.45	6.40	11.01	10.50
10	13.45	11.00	10.99	9.50
15	13.84	10.00	9.97	14.50
20	15.0	8.30	11.32	8.30
Correlation Coefficient (r)			-0.50**	
Fungi	-0.62**		0.14 ^{n.s.}	
Bacteria	0.31 ^{n.s.}		-0.24 ^{n.s.}	
Actinomycetes	-0.42 ^{n.s.}			

n.s. = not significant

* = significant at $P < 0.05$

** = significant at $P < 0.01$

coefficient of ($r = -0.62$) and ($r = -0.50$) for 'live' and 'dead' mound respectively for fungal population was obtained. Both values of correlation coefficient were highly significant. Similar negative correlation coefficient were obtained for the actinomycete ($r = -0.420$) and ($r = 0.237$) for 'live' and 'dead' mound respectively. There was no significant correlation between the population of actinomycete and moisture content. Bacteria showed insignificant correlation coefficient like actinomycete.

Figures 3 and 4 do show the trend of the moisture content during wet and dry season. During the wet season the moisture content decreased with increased distance from the mound. The soil samples at the 20 m from the mound showed an increase. This increase may have been due to the presence of a termite mound which had been worn down as a result of erosion and weathering.

The behaviour of the moisture content during the dry season was different from the wet season. The 'live' mound as stated earlier was bare, while the cap of the 'dead' mound was covered by vegetation. Therefore, it would have been expected that the soil samples taken from the cap (0 m), the moisture content in the 'dead' mound to be higher than 'live' mound.' However, soil moisture content values were similar and lower than the moisture content values in the surrounding soil.

Fig. 3 Correlation coefficient of moisture content with distance from the mound during the wet period

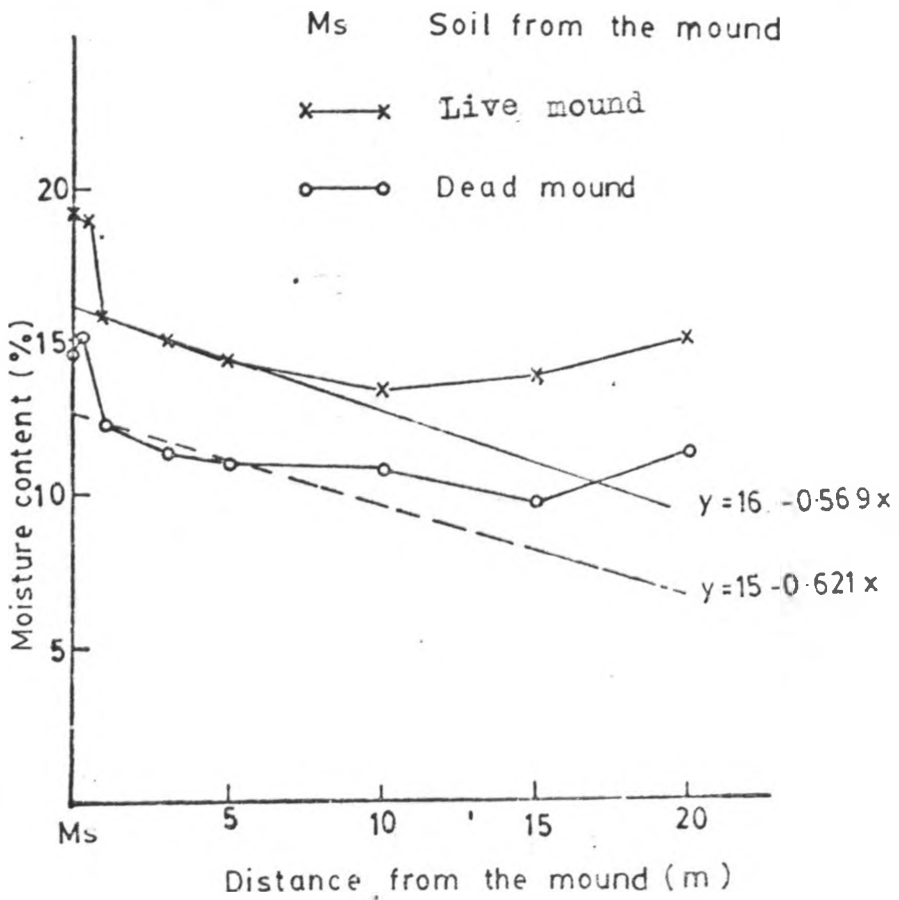


Fig.4 Correlation coefficient between moisture content and distance from the mound during dry period

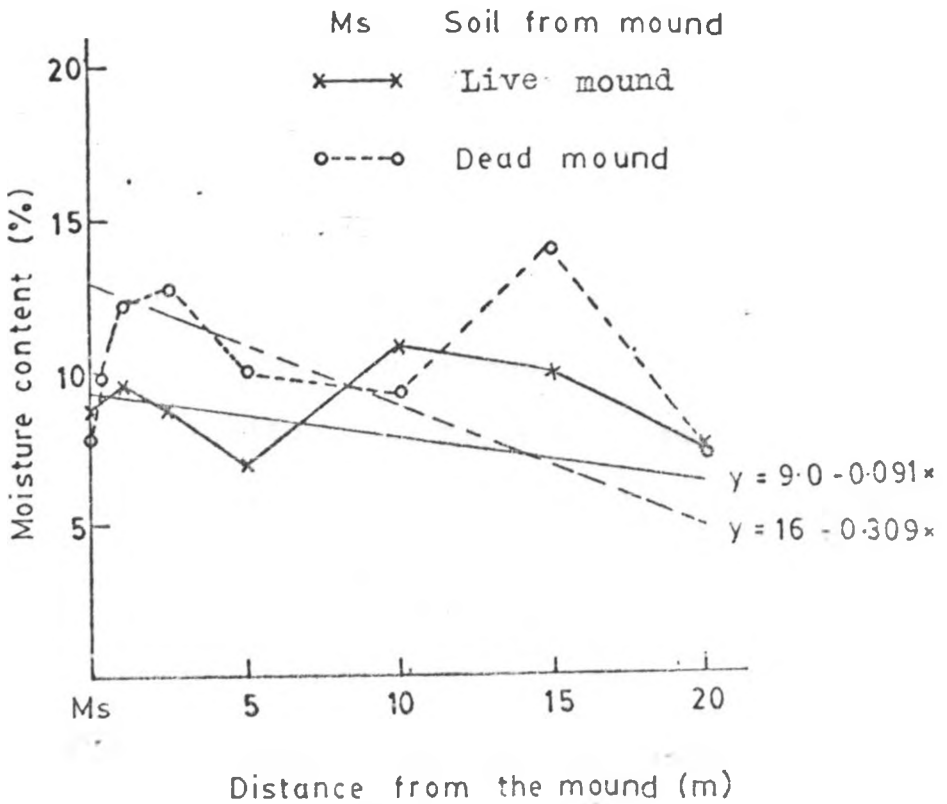
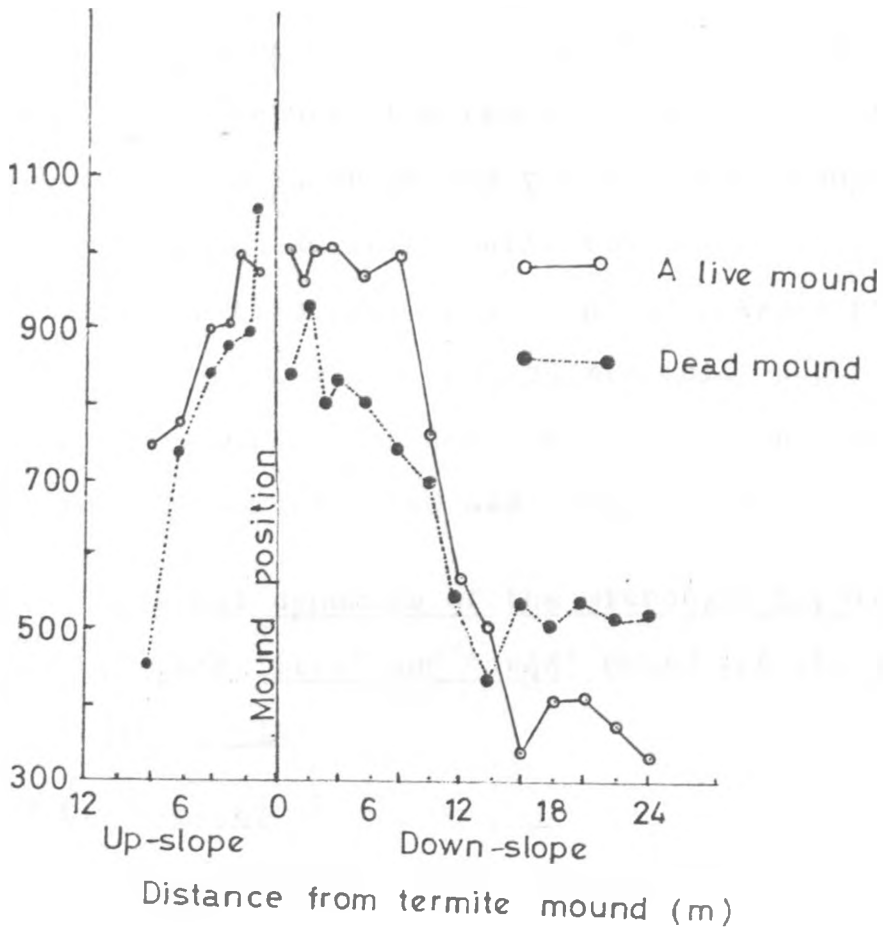


Fig. 5 Grass biomass (grams of dry matter / m²)
in relation to mound proximity (Taken from Arshad, 1978)



addition of organic matter from dead plant material. Due to the high carbon and nitrogen content the population of soil microorganisms would be expected to increase. Direct effects of vegetative cover was mainly through the roots. The release of exudate by the roots which are organic compounds. The compounds may be taken up directly by the organisms. The symbiotic associations between the roots and some microorganisms is also common in trees and grasses, for example Acacia with Rhizobium bacteria. Wild (1952) in his work in Rhodesia reported that some tropical grasses produced toxic substances which reduced microbial population. There is no work which has been done to show whether the grasses in this area had similar effects.

4.2. Seasonal dynamics of the microbial populations in both 'live' and 'dead' mound and the surrounding soils.

4.2.1. General

Seasonality is a secondary factor composed of several primary factors which influence development and activity of soil microorganisms. Such primary factors are soil moisture content, temperature and organic matter content.

In the tropics the moisture content is one of the factors which is affected by the wet and dry season. It was therefore taken as the major limiting

factor on the population of microorganisms found in this study. The study was carried out at Kajiado. Soil samples were taken during the wet and dry spells over a period of one year.

4.2.2. Actinomycete

The population of actinomycete during the wet season is shown in Tables 4, 5, 6 and during the dry season, on Tables 7, 8, 9. There were slight differences between these two periods in terms of fluctuations of the actinomycetes in the soil. During the year of study there was no long dry period which is common in these marginal areas. In Tables 4 to 9 the moisture content data during the wet and dry season did not vary significantly. The population of actinomycete did not vary very much either. High numbers of actinomycete were recorded during the wet season as shown by Tables 5 and 6 and Figures 6 and 7 when moisture content was also high. The wet and dry season were not significantly different in terms of population of actinomycete. It is not justifiable to conclude that there were no significant differences between these two seasons in terms of actinomycete population until more data on the numbers becomes available.

Table 4: Microbial population during the wet period

Date of sampling: 8/12/78

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^4$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	4.8 \pm 0.12	4.48 \pm 0.19	0.97 \pm 0.15	19.19
1	4.3 \pm 0.11	4.01 \pm 0.12	0.97 \pm 0.15	18.62
3	4.3 \pm 0.11	1.88 \pm 0.38	0.67 \pm 0.08	15.47
5	4.2 \pm 0.09	6.35 \pm 1.02	0.66 \pm 0.04	16.01
10	4.4 \pm 0.11	3.16 \pm 0	0.78 \pm 0.14	15.45
15	2.8 \pm 0.02	4.33 \pm 0.58	0.26 \pm 0.04	15.67
20	0.7 \pm 0.01	1.42 \pm 0.29	1.09 \pm 0.22	15.34

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^1$) \pm s.e.	Moisture content %
0	3.98 \pm 0.114	6.69 \pm 0.09	3.95 \pm 0.05	18.91
1	2.62 \pm 0.49	7.23 \pm 1.27	6.76 \pm 0.12	16.28
3	3.25 \pm 0.18	7.74 \pm 0.04	3.6 \pm 0.08	14.53
5	4.00 \pm 0.51	7.17 \pm 0.61	8.3 \pm 0.01	15.74
10	4.92 \pm 0.11	5.35 \pm 0.13	7.0 \pm 0.14	13.51
15	4.22 \pm 0.72	2.24 \pm 0.26	5.4 \pm 0.15	14.81
20	1.35 \pm 0.20	4.57 \pm 0.03	6.67 \pm 0.05	16.41

Table 5: Microbial population in Macrotermes mound soils
from Kajiado during the wet period.

Sampling date: 27/12/78

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	0.55 \pm 0.15	4.37 \pm 0.07	0.80 \pm 0.11	12.89
1	4.31 \pm 0.40	5.32 \pm 0.03	1.58 \pm 0.37	10.47
3	3.62 \pm 0.57	6.27 \pm 0	0.418 \pm 0.06	8.87
5	1.16 \pm 0.28	2.71 \pm 0.15	0.575 \pm 0.12	8.87
10	1.99 \pm 0.29	4.18 \pm 0.38	0.404 \pm 0.08	8.96
15	2.46 \pm 0.20	1.67 \pm 0.03	0.437 \pm 0.06	7.55
20	2.89 \pm 0	5.72 \pm 0.55	0.237 \pm 0.04	7.88

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	3.07 \pm 0.30	6.71 \pm .32	1.17 \pm 0.18	13.57
1	1.20 \pm 0.06	6.06 \pm 0	0.57 \pm 0.04	10.46
3	1.73 \pm 0.05	7.50 \pm 0	1.13 \pm 0.26	9.06
5	5.26 \pm 0.29	7.11 \pm 0.16	0.56 \pm 0.17	8.30
10	3.79 \pm 0.26	6.25 \pm 0.43	0.85 \pm 0.15	8.77
15	2.54 \pm 0.52	2.61 \pm 0.31	0.01 \pm 0.08	7.49
20	1.34 \pm 0.55	1.78 \pm 0.06	0.76 \pm 0.05	9.32

Table 6: Microbial population on Macrotermes mound soils
from Kajiado during wet period.

Date of sampling: 30/3/79

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	1.10 \pm 0	3.53 \pm 0.14	2.65 \pm 1.08	10.01
1	3.32 \pm 0.15	4.04 \pm 0.04	4.27 \pm 0.59	9.19
3	3.64 \pm 0.68	7.62 \pm 0.86	4.27 \pm 0.07	11.78
5	3.49 \pm 0	9.01 \pm 0.70	1.72 \pm 0.08	6.44
10	1.36 \pm 0.31	4.82 \pm 1.36	1.41 \pm 0.31	7.02
15	7.79 \pm 0.80	7.42 \pm 1.63	4.36 \pm 0.63	6.61
20	3.69 \pm 0.67	5.62 \pm 1.13	1.48 \pm 0.14	7.42

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	2.51 \pm 0	4.72 \pm 0.79	3.24 \pm 0.90	13.89
1	2.66 \pm 0.53	6.41 \pm 0.84	1.89 \pm 0.20	8.7
3	2.97 \pm 0	3.61 \pm 0	11.88 \pm 0	8.64
5	3.26 \pm 1.12	3.51 \pm 0	9.32 \pm 0	8.58
10	1.21 \pm 0	4.90 \pm 0.53	2.43 \pm 0.27	7.45
15	1.15 \pm 0.42	6.61 \pm 0.09	2.2 \pm 0.20	6.79
20	4.78 \pm 0.99	4.65 \pm 0.16	1.60 \pm 0.23	7.16

Table 7: Microbial population in termite mound soils from Kajiado during the dry period.

Date of sampling: 26/1/79

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^4$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	9.46 \pm 1.06	1.28 \pm 0.35	5.24 \pm 0.28	8.81
1	1.76 \pm 0	0.92 \pm 0.59	2.67 \pm 0.12	9.53
3	1.09 \pm 1.38	0.66 \pm 0.38	5.76 \pm 0.16	8.81
5	13.1 \pm 0.49	3.48 \pm 0.74	7.02 \pm 0.11	6.84
10	0.35 \pm 0.32	1.78 \pm 0.78	0.83 \pm 1.4	10.74
15	5.85 \pm 0.61	1.57 \pm 0.35	0.44 \pm 0.78	9.77
20	3.34 \pm 0.35	1.09 \pm 0.67	0.34 \pm 1.5	7.44

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^4$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	3.42 \pm 0.53	4.10 \pm 0.06	9.18 \pm 0.33	9.65
1	6.28 \pm 0.85	4.21 \pm 0.21	3.14 \pm 0.32	12.23
3	7.92 \pm 0.35	2.99 \pm 0.61	26.0 \pm 0.21	12.61
5	4.44 \pm 0.88	4.50 \pm 0.19	7.87 \pm 0.95	10.01
10	12.5 \pm 0.81	0.66 \pm 0.31	5.06 \pm 0.56	9.05
15	33.5 \pm 0.49	1.43 \pm 0.28	9.11 \pm 0.28	8.03
20	2.94 \pm 1.06	1.34 \pm 0.39	6.89 \pm 0.60	7.07

Table 8: Population of Micro-organisms in termite soils
from Kajiado during the dry period.

Date of sampling: 2/2/79

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	3.24 \pm 1.43	2.73 \pm 0.52	11.42 \pm 2.76	7.57
1	2.10 \pm 0.63	2.44 \pm 0.17	10.53 \pm 3.96	9.42
3	1.52 \pm 0.09	1.81 \pm 0.72	19.17 \pm 2.83	6.02
5	1.38 \pm 0.14	4.17 \pm 0.20	24.49 \pm 7.83	4.78
10	1.82 \pm 0.53	5.10 \pm 0.28	21.83 \pm 4.01	5.41
15	0.87 \pm n.d.	1.09 \pm 0.83	16.4 \pm 1.74	5.32
20	1.02 \pm 0.04	2.21 \pm 0.12	27.53 \pm 5.86	4.97

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^3$) \pm s.e.	Bacteria ($\times 10^3$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	2.22 \pm 0.19	2.41 \pm 0.23	11.26 \pm 2.29	7.3
1	1.95 \pm 0.07	3.03 \pm 0.80	23.52 \pm 3.45	7.12
3	2.81 \pm 0.27	3.78 \pm 0.26	31.89 \pm 6.34	6.24
5	1.26 \pm 0	1.52 \pm 0.58	29.48 \pm 7.22	5.79
10	2.14 \pm 0.36	2.70 \pm 0.36	48.9 \pm 4.48	5.67
15	n.d.	5.66 \pm 0.37	39.36 \pm 5.40	6.42
20	2.65 \pm 0.37	3.42 \pm 0.88	29.8 \pm 6.67	5.43

Table 9: Microbial population in termite mound soils
from Kajiado during the dry season

Date of sampling: 22/6/79

(a) Live mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	0.11 \pm 0	2.86 \pm 1.09	7.18 \pm 0.45	9.95
1	n.d.	4.40 \pm 0.48	11.52 \pm 0.15	11.93
3	0.56 \pm 0	3.31 \pm 0.65	12.08 \pm 0.10	10.69
5	3.22 \pm 0.27	3.28 \pm 0.22	7.38 \pm 0.99	8.6
10	4.0 \pm 0.08	4.45 \pm 0.53	10.87 \pm 1.38	9.33
15	0.49 \pm 0.03	4.03 \pm 0.12	9.18 \pm 1.07	8.60
20	n.d.	4.86 \pm 0.26	7.48 \pm 0.85	7.76

(b) Dead mound

Distance from mound (m)	Actinomycete ($\times 10^5$) \pm s.e.	Bacteria ($\times 10^5$) \pm s.e.	Fungi ($\times 10^2$) \pm s.e.	Moisture content %
0	2.15 \pm 0.43	6.58 \pm 0.45	4.46 \pm 0.94	14.82
1	1.35 \pm 0.21	6.05 \pm 0.23	12.73 \pm 0.87	13.87
3	2.08 \pm 0.30	10.90 \pm 2.51	7.44 \pm 0.82	10.30
5	1.97 \pm 0.11	5.37 \pm 1.17	5.71 \pm 0	9.73
10	1.32 \pm 0.10	4.73 \pm 1.03	4.33 \pm 1.46	9.23
15	3.46 \pm 0.20	2.49 \pm 0.18	2.85 \pm 0.38	9.30
20	-	3.93 \pm 0.72	10.64 \pm 1.51	9.18

n.d. = not determined

Table 10

A t-test on the differences between wet and dry season on microbial population.

	Live mound	Dead mound	df
Actinomycete	2.06 n.s.	3.57**	14
Bacteria	1.05 n.s.	4.68**	14
Fungi	5.90**	1.06 n.s.	14

Table 11

A t-test on the difference between 'live' and 'dead' mound.

Season	Actinomycete	Bacteria	Fungi	df
Dry	-2.38*	-5.526**	6.03**	14
Wet	0.063 ^{n.s.}	3.34**	1.21 n.s.	14

n.s. = not significant

* = significant $P < 0.05$

** = significant $P < 0.01$

Fig. 6 Population of actinomycete in a live mound

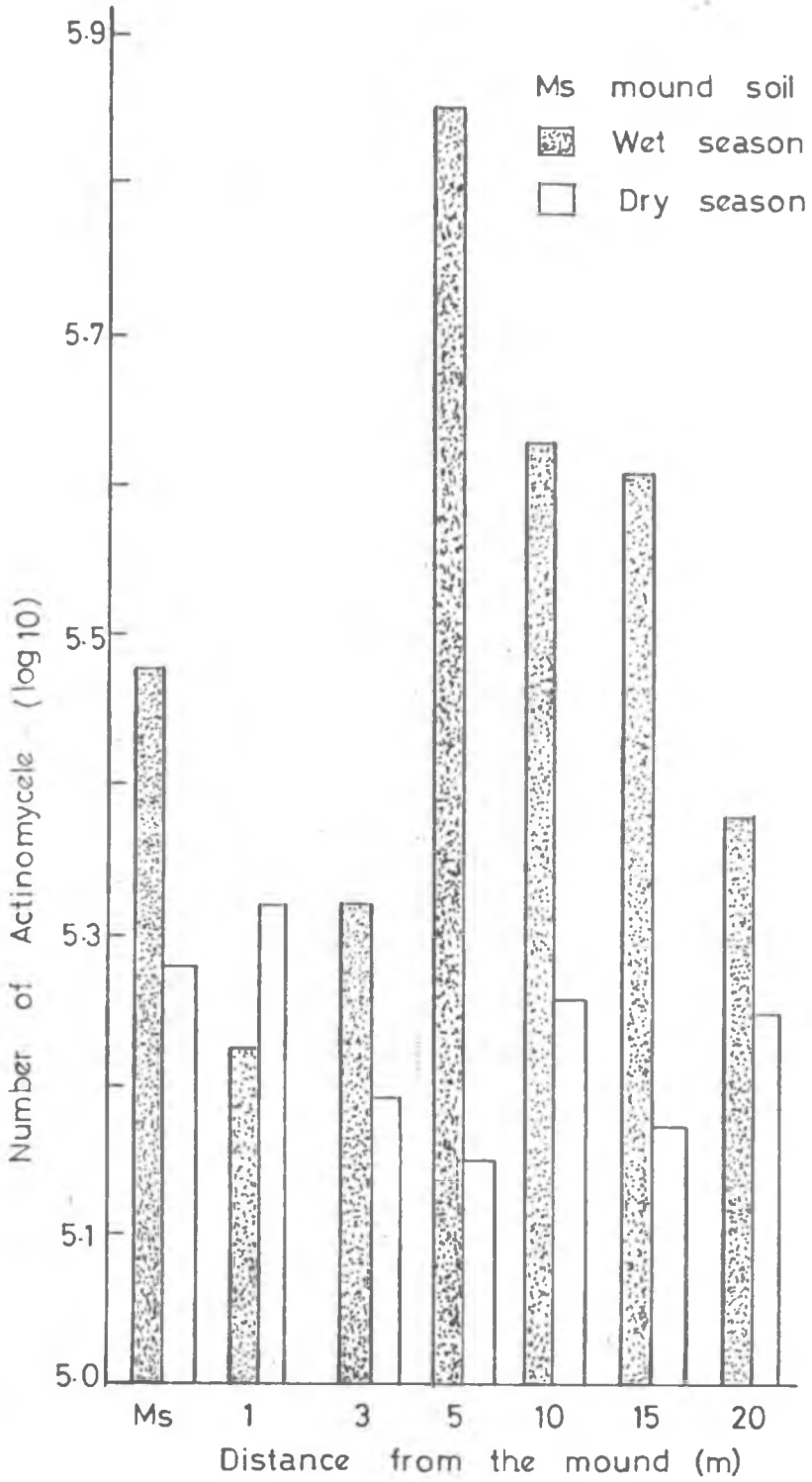
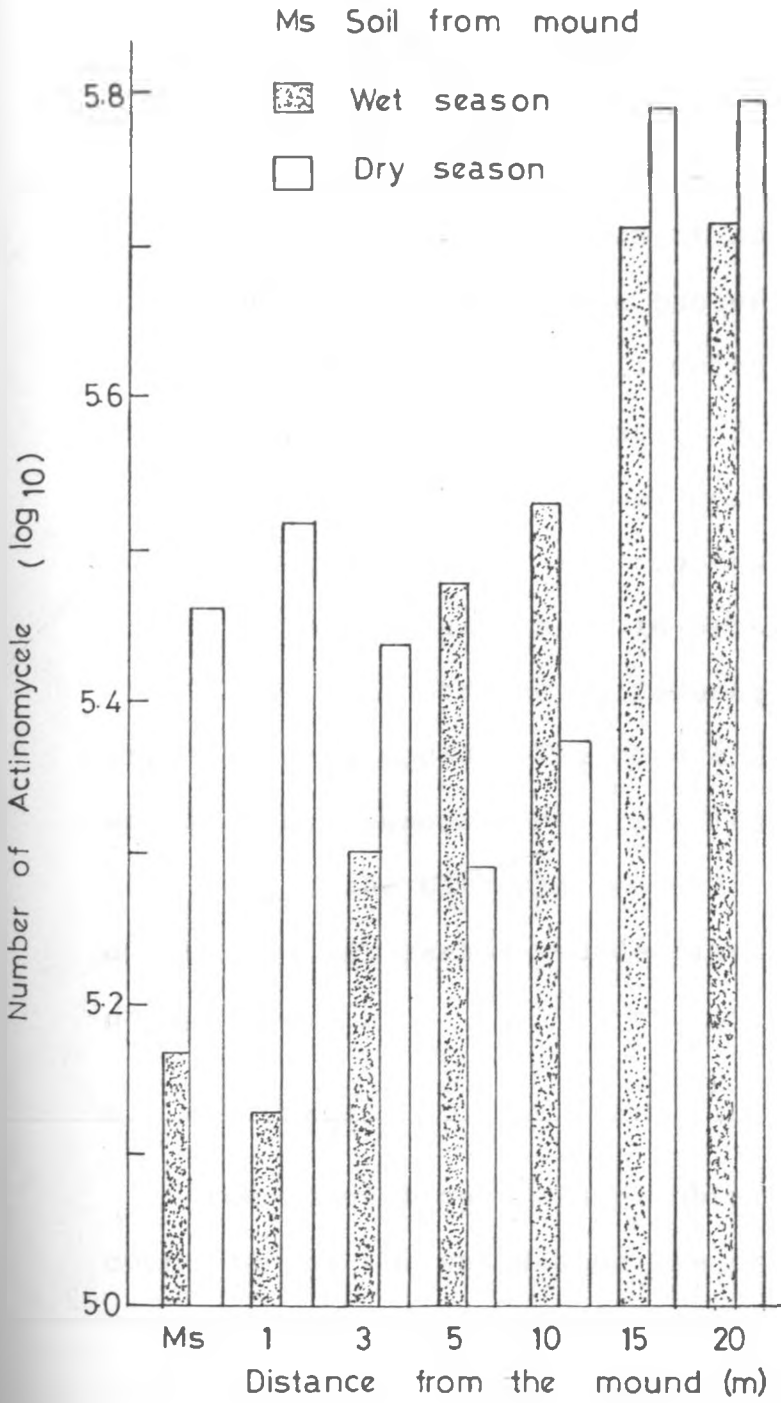


Fig. 7 Population of actinomycete in a dead mound



4.2.3. Bacteria

Bacterial population for the wet period is as presented in Tables 4, 5, 6 while those for the dry season are shown in Tables 7, 8, 9.

Unlike the actinomycetes, the bacteria showed greater response to fluctuations of soil moisture contents than the actinomycete. The bacteria are more susceptible to drought or low soil moisture. During the dry season bacterial population decreased to 10^4 /g dry soil while during the wet season they were 10^5 - 10^6 cells/g dry soil. The response was due to slight moisture changes as stated in Section 4.2.2. The data was further illustrated by Figures 8 and 9 for both live and dead mound. The counts obtained during the wet and dry seasons were significantly different ($P < 0.01$). The bacterial population were much higher during the wet season and declined markedly over the dry period.

4.2.4. Fungi

The population of fungi obtained by the plate count during the wet season are presented in Tables 4, 5, 6. Those for the dry season are shown in Tables 7, 8, and 9. High fungal population was counted during the dry season as illustrated by Figures 10 and 11. The highest values corresponded with the lowest moisture content. Decline of soil fungi during the wet

Fig. 8 Population of bacteria during in a live mound

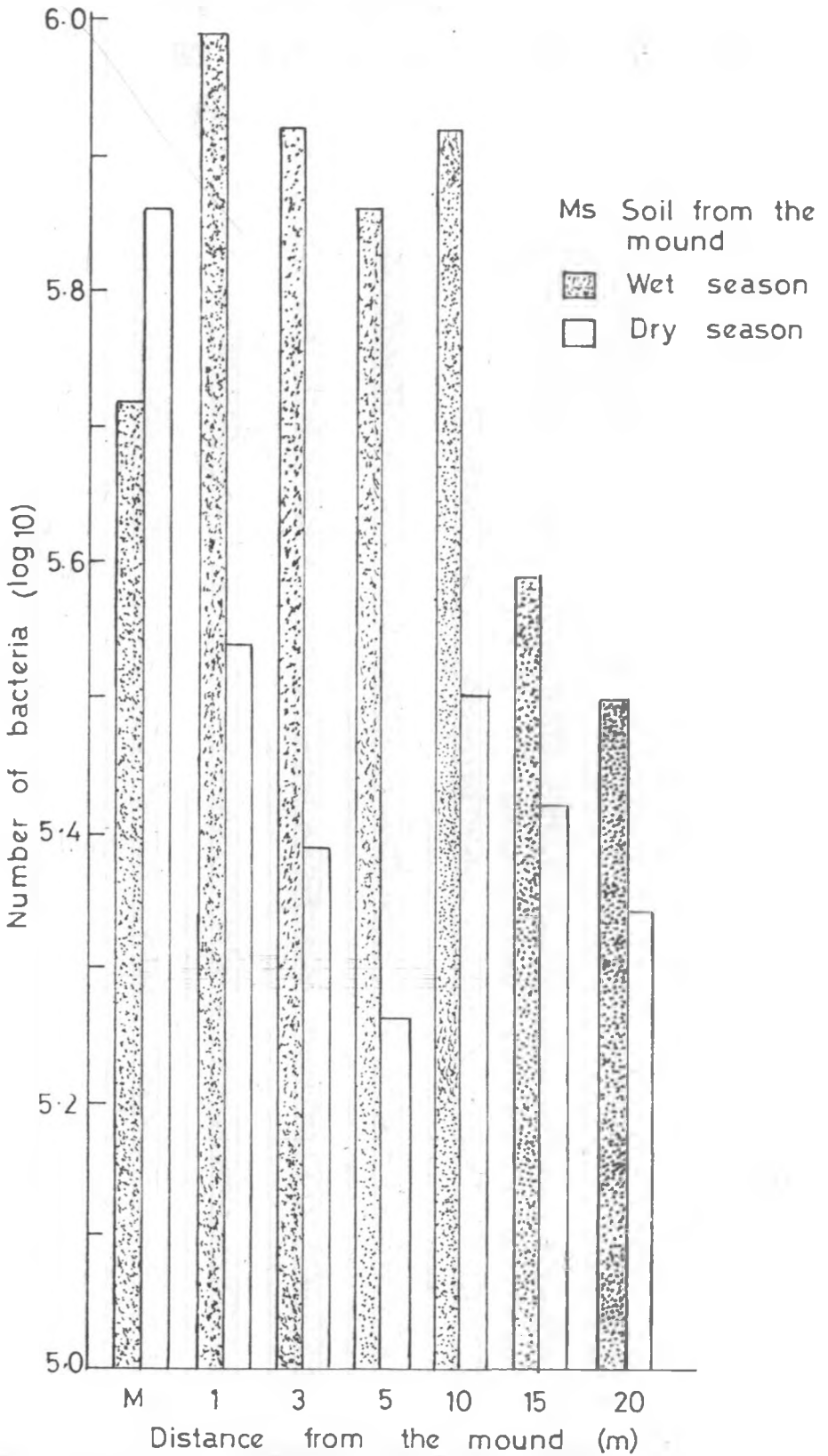


Fig. 9 Population bacteria in a dead mound

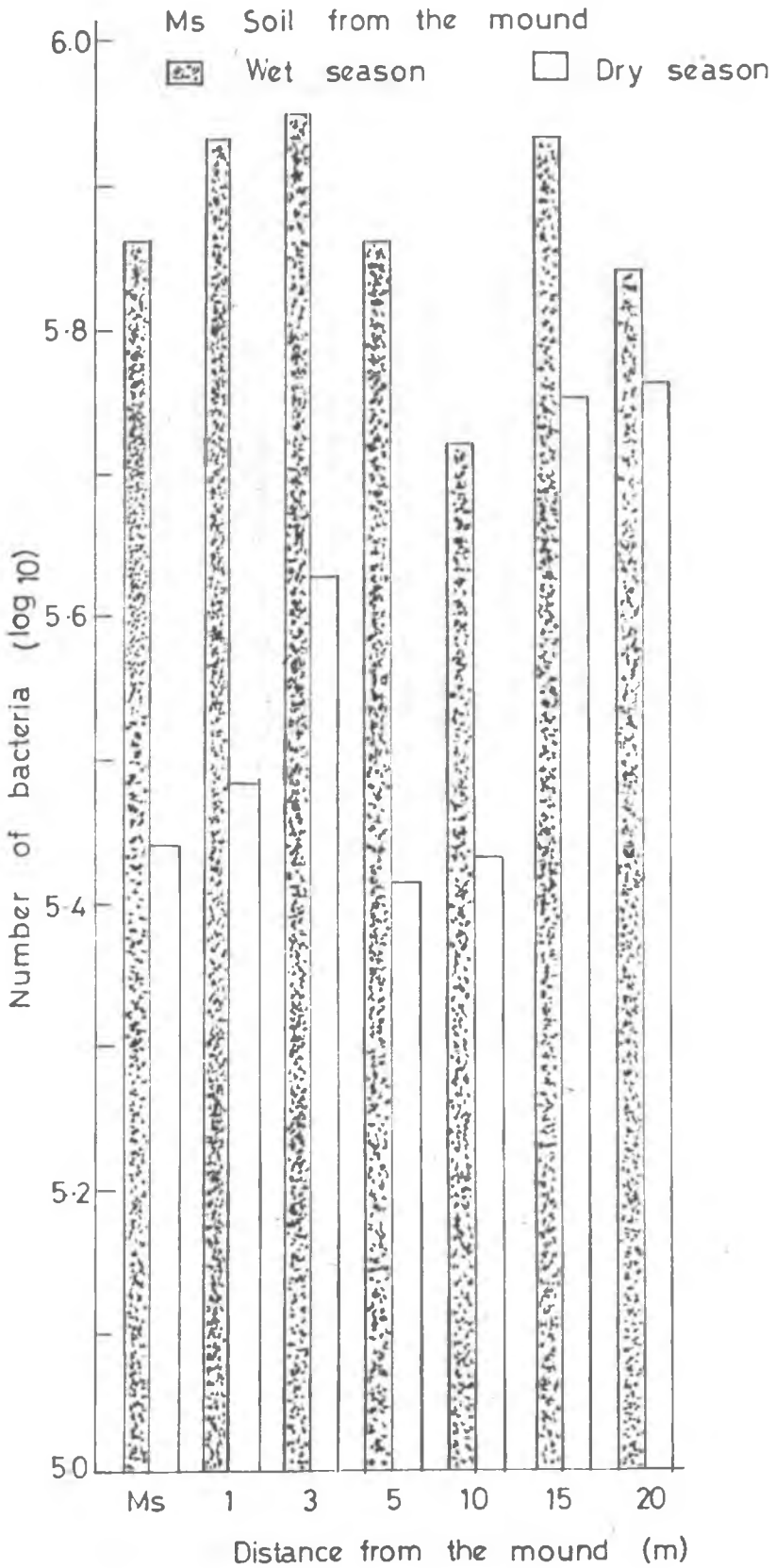


Fig.10. Population of fungi in live mound

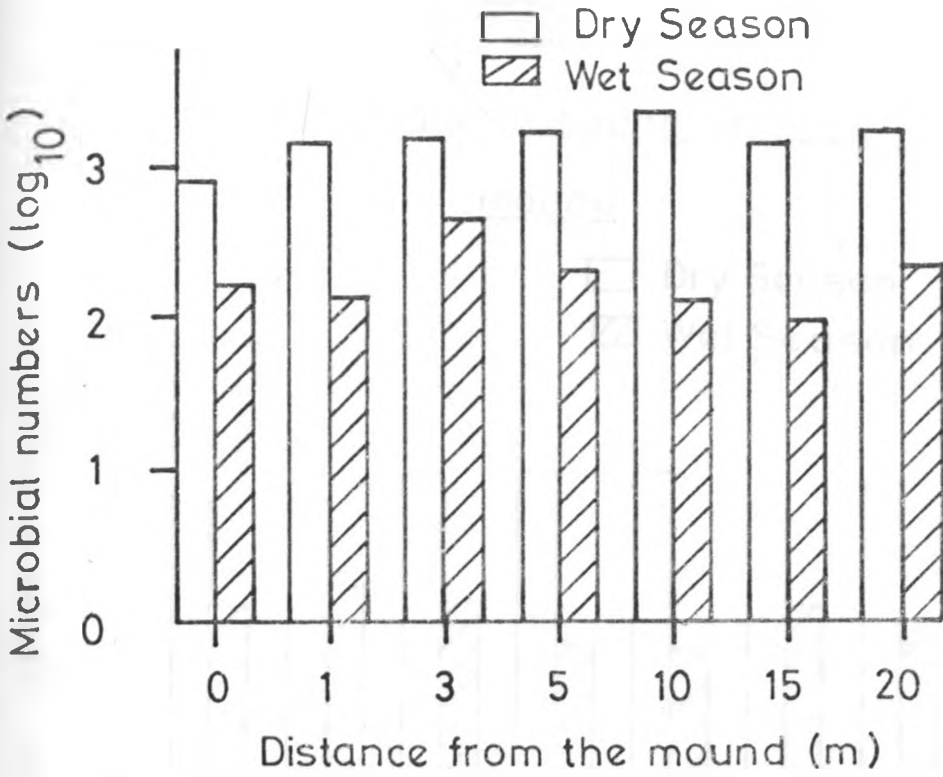
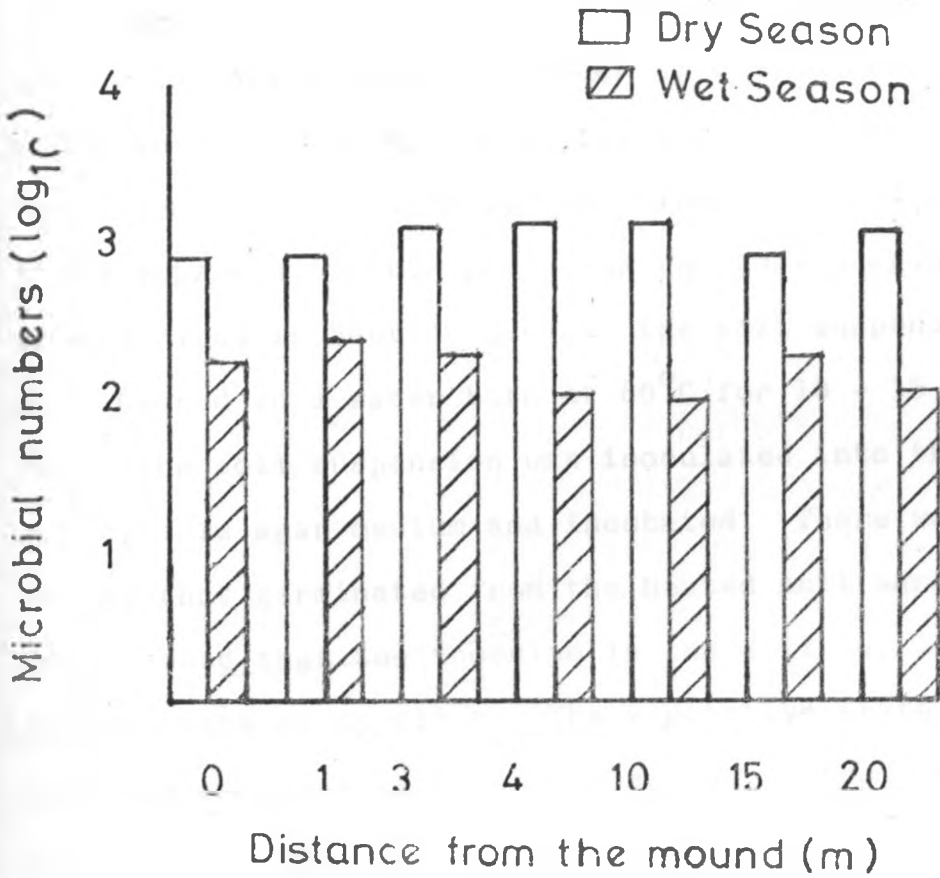


Fig.11. Population of fungi in dead mound



season could only be explained by the fact that bacterial and actinomycete increased with wetness thereby posing intense competition for energy and nutrients against fungi. The increase in numbers from the plate count may have been due to several factors. Firstly, breaking of the mycelium during mechanical shaking of the soil suspension. Secondly, increase of spores during the dry season. In order to check whether germination of spores accounted for high plate count an experiment was set up from the samples taken during the dry period. After preparing the soil suspension as described in Section 3.4.2., the soil suspension were heated in a water bath at 80°C for 10 - 15 minutes. The soil suspension was inoculated into the rose bengal-acid agar medium and incubated. There was no colony that germinated from the heated soil samples. This showed that the inoculum in the soil was in vegetative state or mycelium. The vegetative state unlike spore is not resistant to heat so the protoplasm was denatured by the heat.

There was no significant difference in fungal count between the wet and dry season in the 'dead' mound. In the 'live' mound there was significant difference between fungal numbers during wet and dry season ($P < 0.01$). Lack of differences in microbial counts in the 'dead' mound was difficult to explain since the grass cover was similar to that present in the 'live' mound.

4.2.5. Effects of 'live' and 'dead' mound on microbial population.

The microbial population in 'live' and 'dead' mound were as shown in Tables 4, 5, 6, 7, 8 and 9. The population of bacteria, fungi and actinomycete were slightly higher in the 'dead' mound than in the 'live' during wet and dry season. As shown on Table 10, the population of bacteria, actinomycete were higher in the 'dead' than in the 'live' mound during the dry period. Bacterial population was dominant in the 'dead' mound during the wet period. Fungal population was higher in 'live' mound ($P < 0.01$) than in 'dead' mound.

When a mound becomes uninhabited the agents of erosion and weathering become effective and soil nutrients are available to the microorganism hence higher population. The vegetative cover was reported to be higher in the 'dead' mound than in the 'live' mound and although in the study the organic carbon was less than in the 'live' mound, the 'available carbon' from the soil may have been higher in the 'dead' mound than in the 'live' mound from breakdown of plant material. The nonsignificant differences in fungal numbers during the wet period may have been due to low fungal counts or other factors.

There were some differences between 'live' and 'dead' mound in terms of the soil physical and chemical properties as well as in microbial activity. Pomeroy (Personal communication) found that there were

no differences between 'live' and 'dead' mounds in terms of physical and chemical properties. The significance differences in terms of microbial numbers indicates that soils from these two mounds had some differences in some soil properties.

4.2:6. The effects of mound proximity on microbial population.

In this study an investigation was carried out to find out whether the microbial population was related to some soil properties such as moisture content, vegetative biomass and organic carbon (Arshad, 1978).

The data obtained in this study was as shown in Tables 4 to 9 and illustrated by Figures 6 to 11. There was no relationship between the three major microbial groups namely bacteria, actinomycete and fungi and the mound proximity.

The data on some soil physical and chemical properties were presented in Table 2a and 2b, similarly vegetation was illustrated earlier by Figure 5. The population of the microorganism was expected to show almost a similar behaviour. The reasons for this was mainly based on the organic matter content of the soil. The vegetation was shown to be at its maximum at 3 - 10 m from the mound and then decreased with increase in distance from the mound. High amount of vegetation was an indication of favourable soil condition being

either physical, chemical or both. These favourable soil conditions would also be expected to influence a high microbial population. Since there was no observable pattern other factors may have been in effect. The effect of termites as they forage on the surface, by transferring the inoculum from one place to another may have accounted for this.

4.3. Carbon dioxide as a measure of microbial activity

In addition to assessing microbial population using dilution plate method, activity in relation to mound proximity was determined by CO₂ production.

The amount of CO₂ produced in the 'live' and 'dead' mound soils is presented in Table 12. The amount of CO₂ evolved from the soils is illustrated by Figure 12. The amount of CO₂ increased from the mound and attained a peak at 3 - 5 m from mound then it declined in case of 'live' mound. Although the amount of CO₂ evolved in the 'dead' mound was high from the cap, in the surrounding areas there were very slight increases. The CO₂ evolved exhibited a different pattern from the carbon content as shown by Figure 13.

The organic carbon and nitrogen content are an indication of soil fertility in terms of organic matter content. This fertility does influence microbial activity directly. Analysis of correlation coefficient between the CO₂ produced and microbial population at

Table 12: CO₂ evolution with proximity of the mound

Distance from mound (m)	mg. CO ₂ /g. dry soil/10 days	
	Live mound	Dead mound
0	0.026	0.036
1	0.029	0.034
3	0.041	0.024
5	0.046	0.024
10	0.025	0.024
15	0.037	0.027
20	0.018	0.022
Correlation coefficient (r)	0.63**	0.02 n.s.
Bacteria	0.15 n.s.	-0.30 n.s.
Fungi	0.04 n.s.	0.05 n.s.

* = significant $P < 0.05$

** = significant $P < 0.01$

n.s. = not significant

Fig.12 Carbon dioxide evolution in relation to the mound proximity

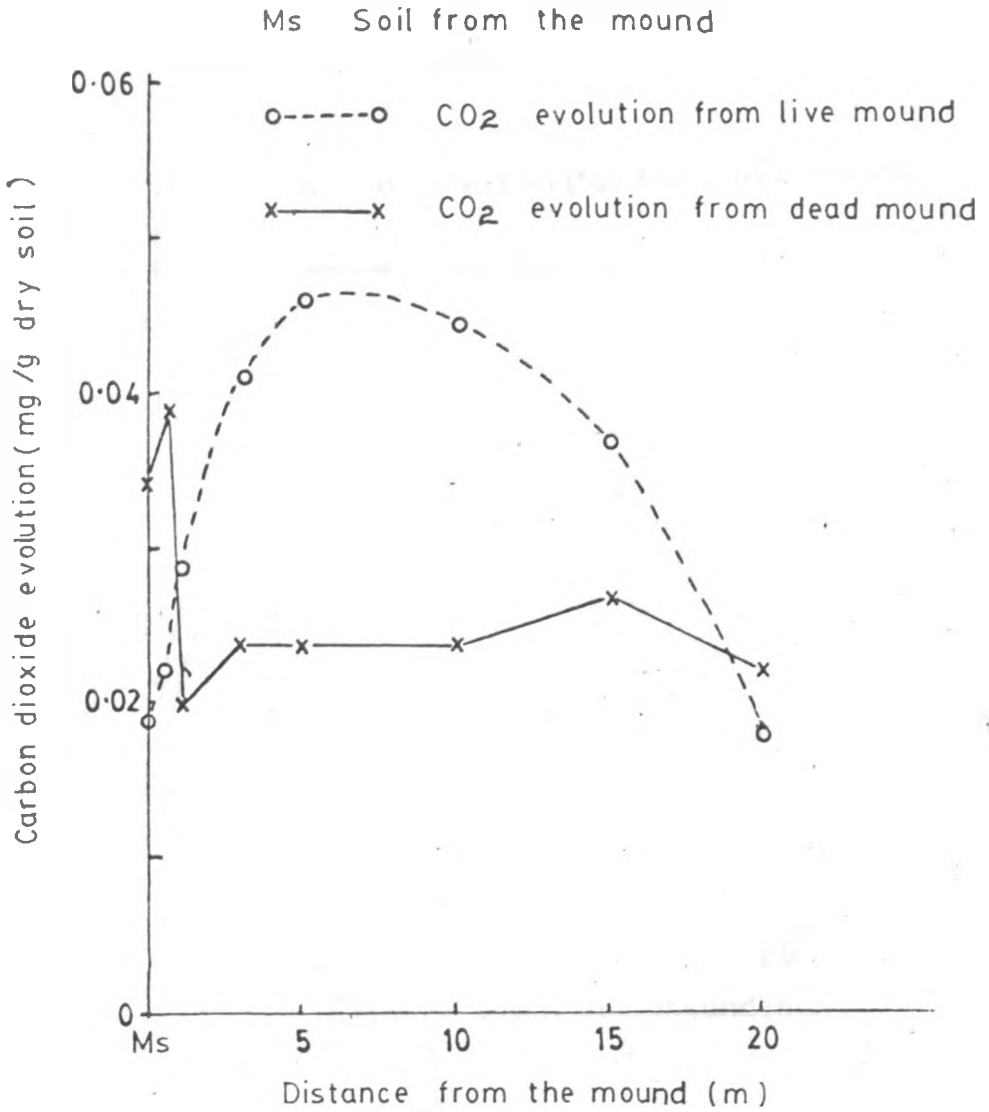
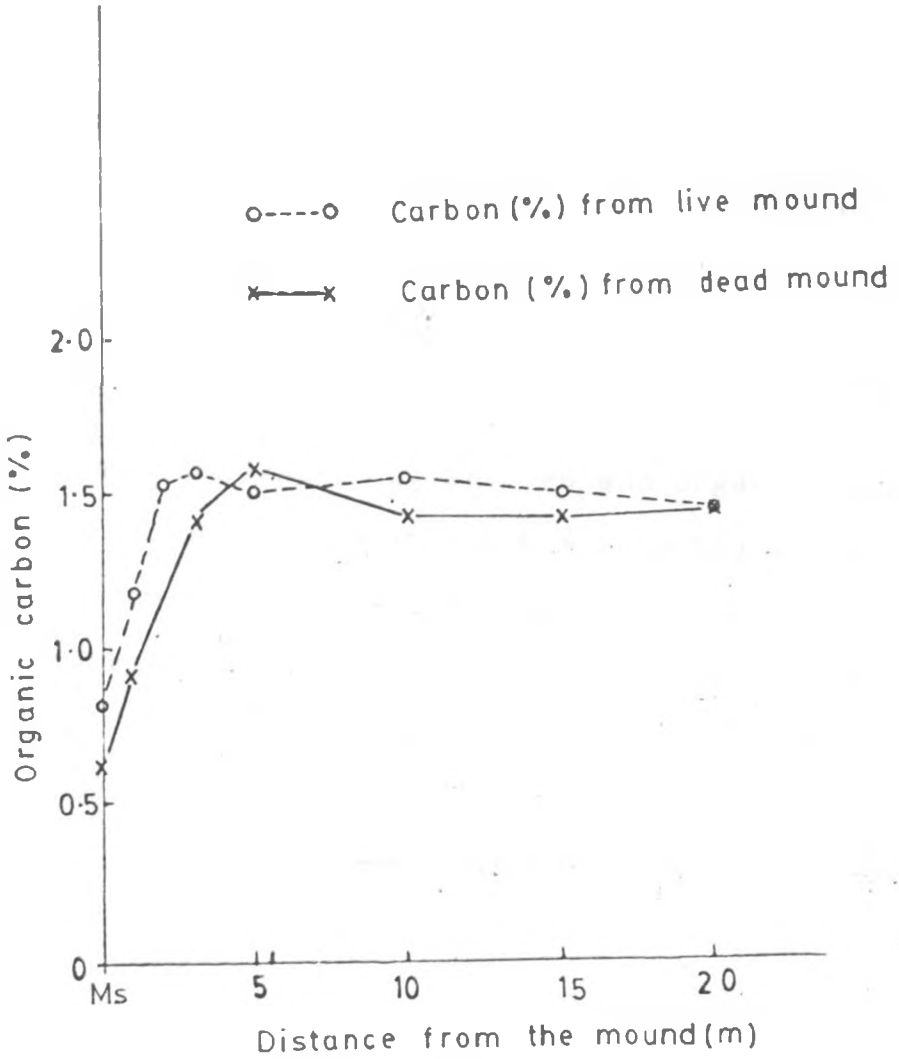


Fig 13 . Variation of organic carbon with proximity of the mound



different distances from the mound was carried out. During the wet period the population of actinomycete was significantly correlated with amount of CO_2 evolved (0.01, $r = 0.638$). The actinomycetes were the dominantly active group in the soil during the wet period and this agreed with the data presented in Tables 4, 5, 6.

During the dry season the fungal population showed a positive correlation although not significant ($r = 0.476$). The fungi accounted for microbial activity during the dry period.

Since amount of CO_2 evolved and organic carbon were at their maximum at 3 - 5 m from the mound, microbial population were also expected to be high at the same distances. The amount of microbial activity in terms of CO_2 evolved was an indication of microbial population. Bacterial population as illustrated by Figures 8, 9 were high at similar distances from the mound.

In the study the amount of CO_2 measured was as a result of total microbial activity. In the culturing of different groups of microorganism selective media were used to culture each group differently. Thus a correlation coefficient between the amount of CO_2 and different group of microorganism could not have given a good indication of the importance of any group in decomposition of organic matter in the soil. This may account for the lack of a significant correlation

coefficient between CO₂ and microbial population. Secondly, there was no single medium which could have been used to estimate all microbial population in the soil. Some workers do advocate the use of antibiotics to suppress other groups in the soil except the one under study. If similar method were used may be a better correlation coefficient would be obtained.

4.4. Population of micro-organism in other termite soils.

In order to find out the effect of mound proximity on the distribution of microorganism, soil samples were collected from different parts of Kenya as already described in Table 1 of Chapter 2.

Moisture content was high in the samples from the mound and decreased with distance from the mound as shown in Table 13. The soil samples from Ruaraka and Emali showed contrasting results, they showed an increase in moisture content away from the mound.

The carbon and nitrogen content were maximal at 3 m from the mound. Low values were obtained in the mound samples and surrounding soils at 20 m from the mound. The nitrogen and carbon contents and C:N ratio of the mound soils closely resembled those of the adjacent subsoil as shown in Table 13. However soil sample from the mound at Kajiado river valley had higher nitrogen and carbon content than surrounding soil and

Table 13: Moisture, carbon and nitrogen content in termite soil from different parts of Kenya.

Sample No.	Soil type	Moisture content	% C	% N	C:N
87 A	UUC	20.78	1.75	0.203	8.62
88 B	"	10.93	1.14	0.070	16.3
89 C	"	10.99	n.d.	n.d.	n.d.
96 A	PRdp-ap	19.84	1.18	0.063	18.73
97 B	PRdp-ap	10.93	1.74	0.175	9.94
98 C	"	8.63	1.60	0.098	16.33
99 A	PRb	10.14	0.87	0.077	11.30
100 B	"	7.65	0.83	0.098	8.47
101 C	"	7.42	0.91	0.070	13.0
108 A	BV ₃	33.61	0.93	0.063	14.76
109 B	"	29.03	1.44	0.133	10.83
110 C	"	27.76	1.37	0.084	16.31
111 A	PA ₁₇	24.53	1.29	0.203	6.35
112 B	"	22.25	0.90	0.098	9.18
113 C	"	13.64	0.80	0.112	7.14
114 A	LaF	8.10	0.40	0.077	5.19
115 B	"	11.48	1.02	0.077	13.25
116 C	"	8.58	0.72	0.084	8.57
117 A	Ruaraka	22.99	1.24	0.105	11.81
118 B		32.73	1.73	0.203	8.52
119 C		39.60	1.72	0.119	14.45
126 A	PBr ₂	24.69	0.59	0.077	7.66
127 B	"	28.21	1.35	0.077	17.53
128 C	"	26.82	1.20	0.091	13.19
134 A	FUC	11.99	0.42	0.084	5.00
135 B	"	10.08	0.79	0.070	11.28
136 C	"	10.26	0.57	0.077	7.40

n.d. = not determined

A = sample from the mound

B = top 20 cm of the surrounding soil 3 m from the mound.

C = top 20 cm of the surrounding soil 10 m from the mound.

Legend shown in table 1.

the subsoil. It was reported in Pomeroy's (1976b) work with M. bellicosus in Uganda that this species use the subsoil to build mounds in the upland soils while in the valley the same species used the top soil. The M. subhyalinus in this study may have used the top soil to construct the mound in the valley bottom. Otherwise more data is necessary to enable research workers come up with a similar conclusion for the M. subhyalinus. The high carbon and nitrogen content at 5 m from the mound was probably due to organic matter from the grass cover. The C:N ratio was influenced by carbon and nitrogen contents. The carbon and nitrogen were higher in the top soils than in the mound soil and the subsoil and this accounted for a lower ratio in the latter samples. The C:N ratio is important because it influences availability of nutrients after microbial breakdown of organic matter has taken place. If the C:N ratio is greater than 20 the nutrient N is immobilised by the microorganisms thereby made unavailable to plants. When C:N ratio is less than 20, N is released into the soil and is available to plants. In the soils under study all the C:N ratio were less than 20 meaning that on decomposition N was released into the soil, for uptake by plants.

Microbial population were as shown in Table 14 as well as the amount of CO₂ evolved. The data represents microbial population from the mound soil

Table 14: Population of micro-organism in termite soils

Sample No.	Actinomycete (x10 ⁵)	Bacteria (x10 ⁵)	Fungi (x10 ²)	mg. CO ₂ /g dry soil/10 days
87 A	14.50	7.12	1.70	0.036
88 B	2.10	8.76	2.72	0.034
89 C	1.10	8.32	2.68	0.032
96 A	2.63	7.54	18.0	0.088
97 B	1.88	6.21	6.09	0.067
98 C	4.61	9.93	16.00	0.053
99 A	0.49	0.77	14.10	0.022
100 B	2.38	6.00	26.40	0.033
101 C	2.20	5.69	13.90	0.009
108 A	7.79	6.37	6.67	0.018
109 B	5.16	6.36	10.00	0.030
110 C	6.82	10.80	2.55	0.112
111 A	7.47	9.09	6.23	0.059
112 B	3.85	1.71	0	0.026
113 C	2.39	1.25	0	0.021
114 A	1.19	2.92	15.30	0.018
115 B	2.23	3.23	0	0.053
116 C	1.74	5.14	7.87	0.053
117 A	4.30	30.1	1.97	0.018
118 B	1.06	27.5	1.92	0.123
119 C	4.65	4.32	12.60	0.053
126 A	3.68	6.61	4.87	0.006
127 B	5.13	9.61	0	0.074
128 C	3.61	6.08	1.25	0.051
134 A	0.34	0.32	0.58	0.040
135 C	2.75	9.38	2.81	0.081
136 C	0	0	0	0.015

0 = no microbial growth

A = sample from the mound

B = top 20 cm of the surrounding soil 3 m from the mound.

C = top 20 cm of the surrounding soil 20 m from the mound.

surrounding at 3 m and 20 m from the mound.

There was no increase in microbial population from the mound to the surrounding soils. This was also observed in the data obtained from Kajiado. Bacterial population in the following soil groups, FUC, PBr₂, UUC and PRb were higher in 3 - 10 m than in the mound soils. There were very few bacterial colonies which grew from the PA₁₇ soil group. Similarly there was no fungal growth in soil dilutions made from PA₁₇ soil sample. The carbon and nitrogen contents were similar to the other soil samples, thus other factors must have been responsible for these low microbial population. It is possible that the high soil pH and salt content may have been responsible for the low counts. Only strains resistant to these factors could have been present in this soil sample. The population of the fungi showed no consistent trend at all distances unlike bacteria and actinomycete. Low numbers or lack of any fungal growth were recorded in soil groups namely PA₁₇, Laf, PBr₂ and FUC.

Except for soils designated UUC and PRdp-ap in Table 13, all the other groups showed highest CO₂ evolution at 3 m from the mound. This generally agreed with the carbon, nitrogen contents and the C:N ratio determination as shown in Table 13. The high CO₂ evolution at 3 m was similar to the amount recorded at Kajiado as presented in Table 12 where highest values

were at 3 m and 5 m from the mound in case of 'live' mound.

4.5. Microbial population in 'open' and 'closed' mound soil from Konza.

4.5.1. General

These two types of mound 'open' and 'closed' are built by two different species of the genus Macrotermes namely M. subhyalinus and M. michelseni respectively. Due to this difference in species a study was conducted to find out whether these two species of termite had different effects on the soil properties hence on microbial population. At Konza the 'open' and 'closed' mounds occurred side by side. The mounds were chosen to avoid any vegetation and climate effects on the soil parameters to be analysed.

4.5.2. Soil properties

In order to understand the basic soil chemical and physical properties soil analysis was performed on the samples. The results were as presented in Tables 15a, 15b and 15c for 'open', 'closed' mound and surrounding soil.

The nursery and the queen cell are the most active parts of the mound. These chambers were found to be composed of high clay content which ranged from 58 - 62%. The sand content was 22 - 31% and a decrease with increase in depth of the soil profile was observed.

Table 15: Soil analysis for 'open' and 'closed' mounds from Konza.

(a) Open mound (M. subhyalinus)

Depth (cm)	Type of structures 20	Particle size distribution					C:N	pH _{H₂O} (1:1)	Moisture content (%)
		Sand %	Silt %	Clay %	% C	% N			
0 - 5	Outer casing of the mound	43	9	48	.76	0.077	9.9	5.6	4.49
20 - 40	Massive brown material	44	5	51	.39	0.056	6.8	4.9	9.41
70 - 80	Light brown material above nursery	42	10	48	.58	.082	10.4	4.5	20.34
80 - 90	Nursery coarse layers	35	16	49	.81	.089	9.1	5.8	21.95
90 -105	Nursery of fine and fragile layers	28	12	60	.72	.083	8.7	5.2	22.50
120 -125	Royal cell	22	16	62	.64	.076	8.3	5.4	21.07
165 -175	Subsoil	37	11	52	.30	.053	5.7	4.2	16.08

(b) Closed mound (M. michaelsoni)

Depth (cm)	Type of structures	Sand %	Silt %	Clay %	% C	% N	C:N	pH _{H₂O} (1:1)	Moisture content (%)
0 - 2	Thin outer casing of the mound	57	12	57	.67	.067	9.7	5.4	11.98
30 - 80	Pillars of massive structure	53	14	53	.69	.070	9.5	5.6	22.70
105 -125	Nursery of fine and fragile material	28	12	60	.89	.086	10.3	5.4	30.89
130 -135	Royal cell	31	11	58	.74	.092	8.1	6.0	19.19
170 -180	Subsoil	37	17	46	.39	.045	8.6	6.2	16.0

(c) Adjacent soil

Depth (m)	Type of structure	Sand %	Silt %	Clay %	% C	% N	C:N	pH _{H₂O} (1:1)	Moisture content (%)
0 - 10	Fine granular dark	52	26	37	2.16	.166	13.0	5.5	10.25
20 - 40	Massive light dark	44	20	36	1.11	.196	11.5	5.8	18.70
60 - 70	Massive light colour	39	15	36	.72	.064	11.2	5.5	16.70
80 - 90	Subsoil	45	17	38	.40	.046	8.4	4.3	10.90

Termite workers select fine particles less than 2 mm in diameter for mound construction and this may account for high clay content in the central parts of the nest. The silt content in the top 40 cm of the surrounding soils was higher than that in mound soil. This showed that the termite preferred finer particles which were less than 0.005 mm to silt and sand as their building material.

The surrounding soils in the top 40 cm had higher nitrogen and carbon contents than the soils from the mound as shown in Table 15c. The table showing analysis on mound soils the surrounding soil profile does show that C and N of the mound soil are closer to those of the subsoil. Several workers like (Hesse, 1955; Nye, 1955; Miedema and Van Vuure, 1977 and Pomeroy, 1976b) showed that the genus Macrotermes builds its mound with subsoils and soil properties of the mound reflected those of the subsoil. Nitrogen and carbon content in 'open' and 'closed' mound were lower than the top adjacent soil because they were derived from the subsoil. The result on Table 15 also showed that the values of N and C in these mounds were similar to those of the surrounding subsoil at 60 - 90 cm.

Despite low levels of carbon and nitrogen in the mound soil samples it was observed that the nursery and royal cell were richer in cations than other chambers. This could have been contributed to by fungal

combs faecal material, saliva and the dead termite bodies. There was an increase in moisture content with increase in depth attaining a maximum level in the nursery and queen cell followed by a decline with depth. This was as shown in Figures 14a, 15a and 16a.

The sampling was done during the dry season but the centre of these two mounds had a relatively high moisture content like during a wet period.

The termites are responsible for this high moisture content. They maintain this high relative humidity through different processes. Capillary water from the water table is said to rise upwards (Watson, 1960). The heavy texture of the mound soil reduce evaporation rate. The termites are said to produce metabolic water to maintain high moisture content required in nursery and royal chamber, Harris (1951).

The pH was similar in all the chambers both in 'open' and 'closed' mounds and the surrounding soils. Termite activity did not influence the pH of the soil unlike reports by (Hesse, 1955; Lee and Wood, 1971; Pomeroy, 1976).

4.5.3. Distribution of Microorganisms in 'open' and 'closed' mounds as compared to surrounding soils.

4.5.3.1. Actinomycetes

As shown in Table 16a and Figure 14b, the population

Table 16: Microbial population in 'open' and 'closed' mounds from Konza.

(a) Open mound

Depth (cm)	Moisture content %	Microbial population/g dry soil		
		Actinomycete ($\times 10^4$)	Bacteria ($\times 10^5$)	Fungi ($\times 10^2$)
0 - 5	4.49	0.85	0.56	0.42
20 - 40	9.41	1.30	1.30	2.40
70 - 80	20.34	4.33	3.49	2.33
80 - 90	21.95	3.17	3.88	1.34
96 - 105	22.50	0.40	2.38	-
120 - 125	21.07	0.38	1.05	0.80
165 - 175	16.08	0.42	1.86	1.08

(b) Closed mound

Depth (cm)	Moisture content %	Actinomycete ($\times 10^4$)	Bacteria ($\times 10^5$)	Fungi ($\times 10^2$)
0 - 2	11.98	2.25	0.15	4.0
30 - 80	22.70	1.45	3.19	3.10
105 - 125	30.89	1.19	2.75	1.2
130 - 135	19.19	0.14	0.52	2.4
170 - 180	16.04	0.12	0.47	0.4

(c) Adjacent soil

Depth (c)	Moisture content %	Actinomycete ($\times 10^4$)	Bacteria ($\times 10^5$)	Fungi ($\times 10^2$)
0 - 10	10.25	1.49	3.20	4.23
20 - 40	18.60	1.27	1.40	1.40
60 - 70	16.70	1.10	1.10	0.17
80 - 90	10.90	1.70	0.70	0.7

Fig 14a Distribution of organic carbon and moisture content in open mound

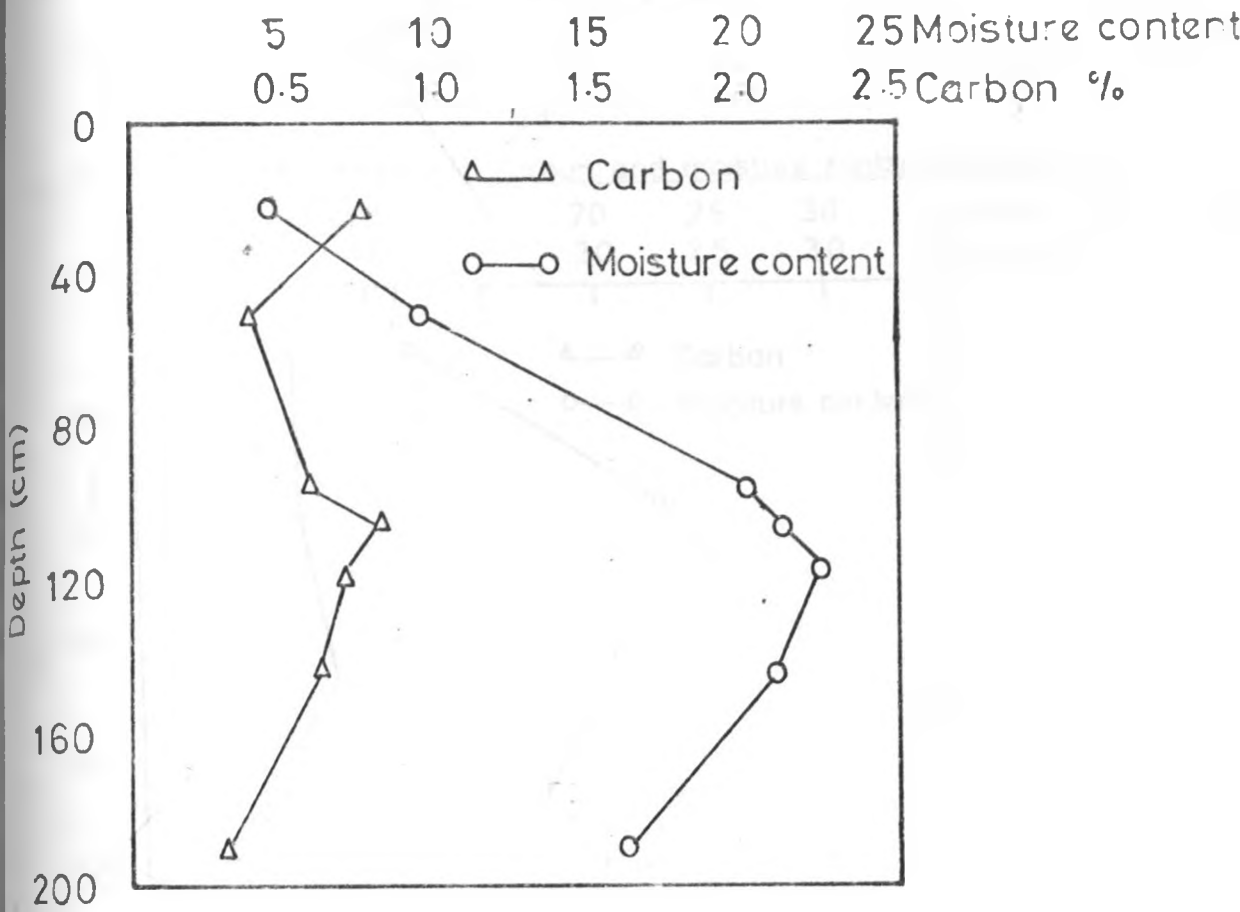


Fig 14b Distribution of microbial population with depth in open mound

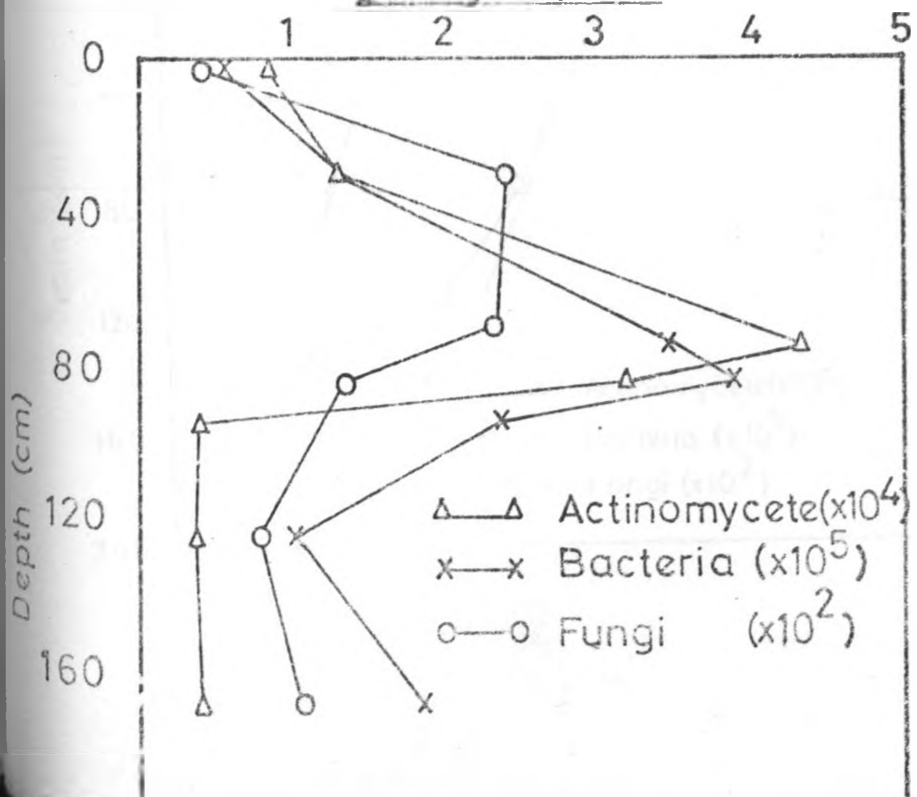


Fig 15a Distribution of organic carbon and moisture content in closed mound

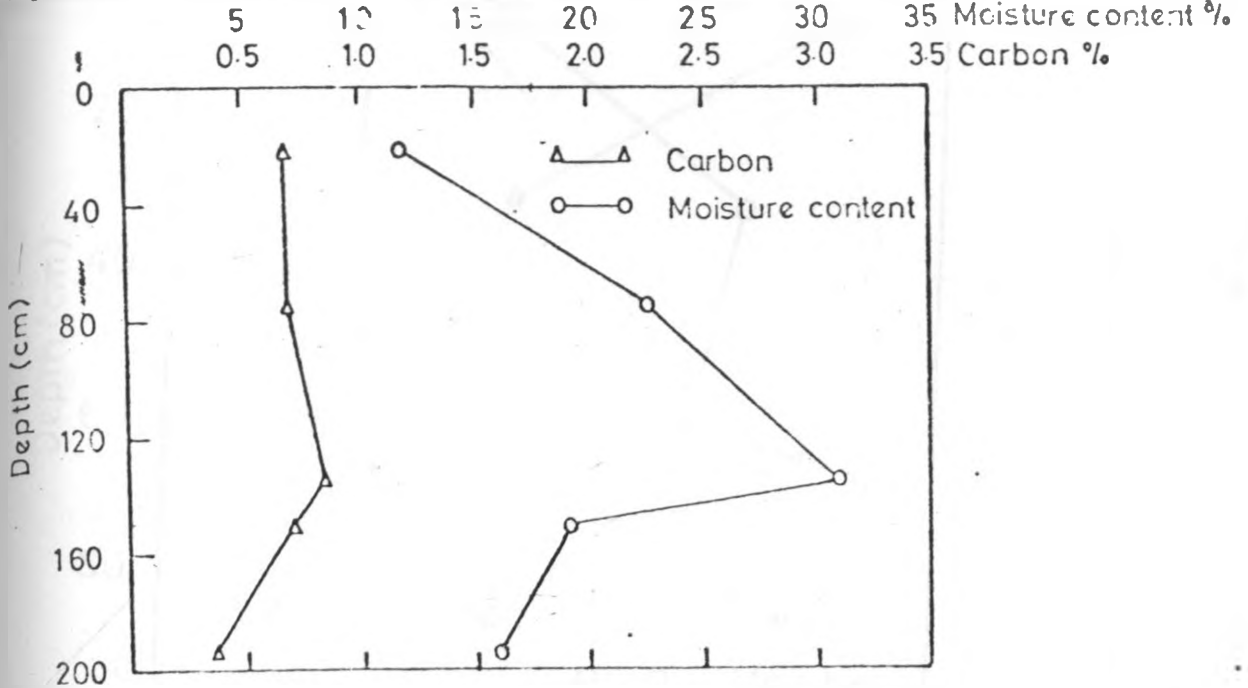


Fig 15b Distribution of microbial population with depth in closed mound

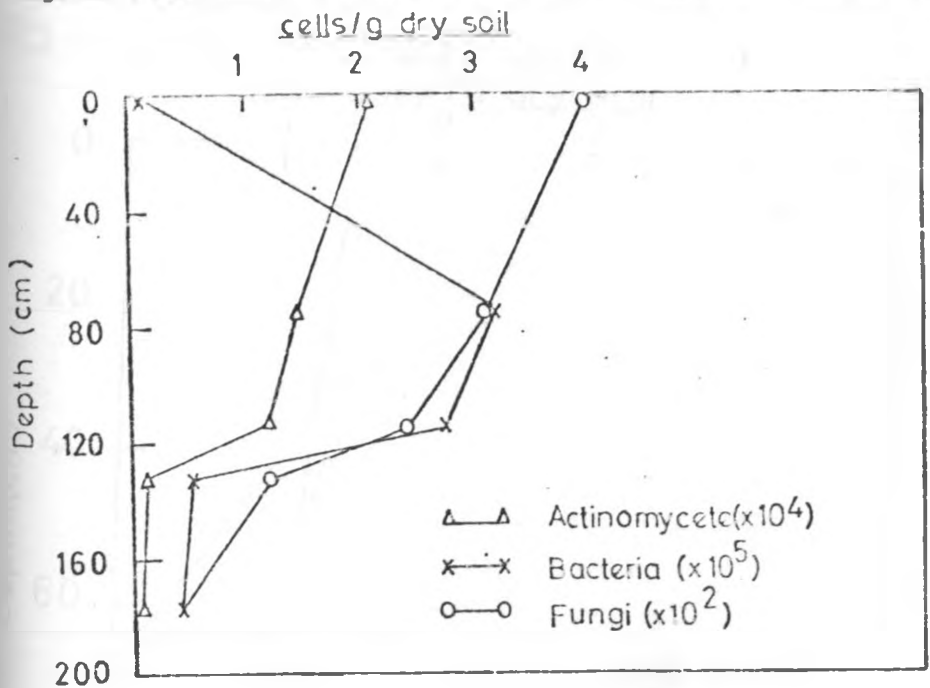


Fig 16a Distribution of moisture content and carbon in an adjacent soil profile

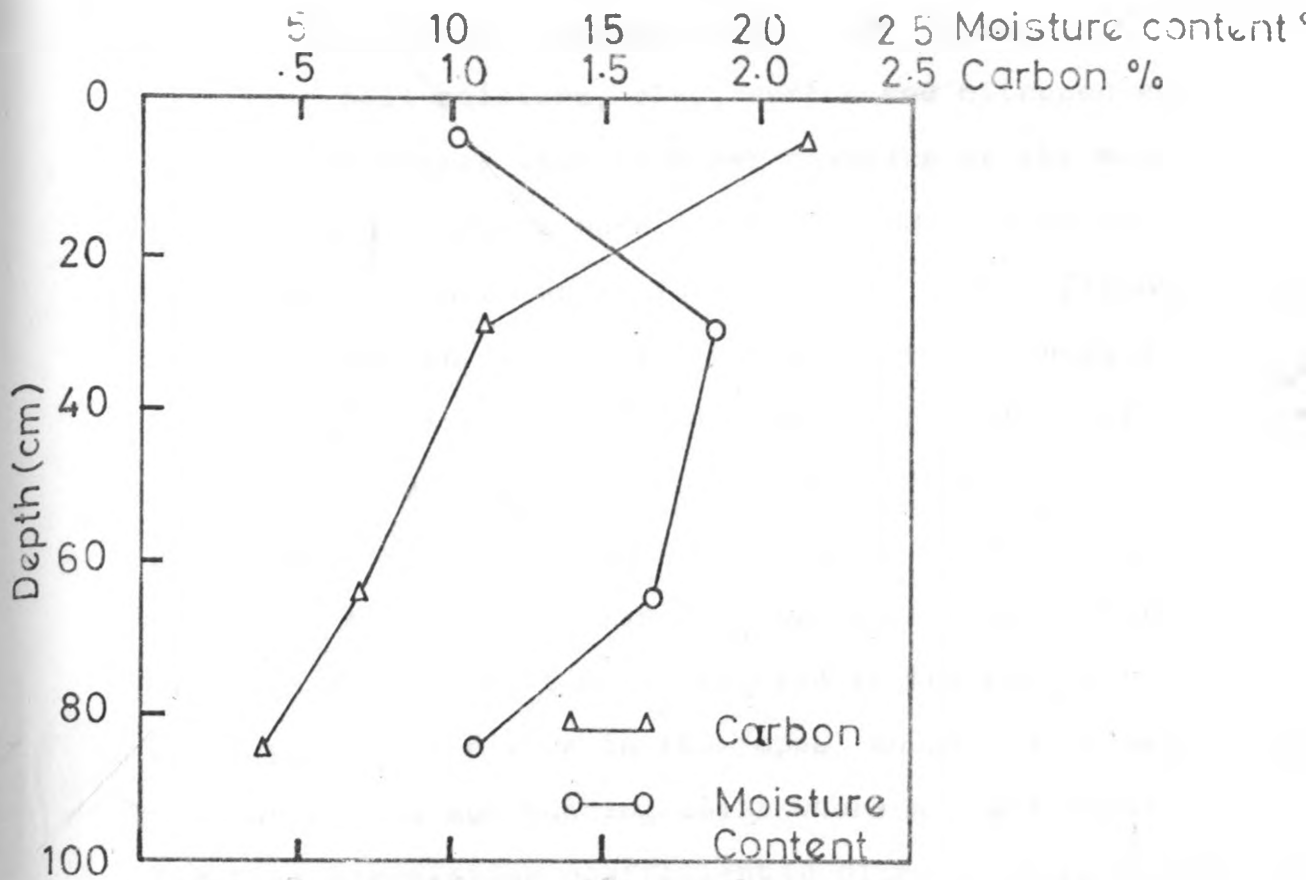
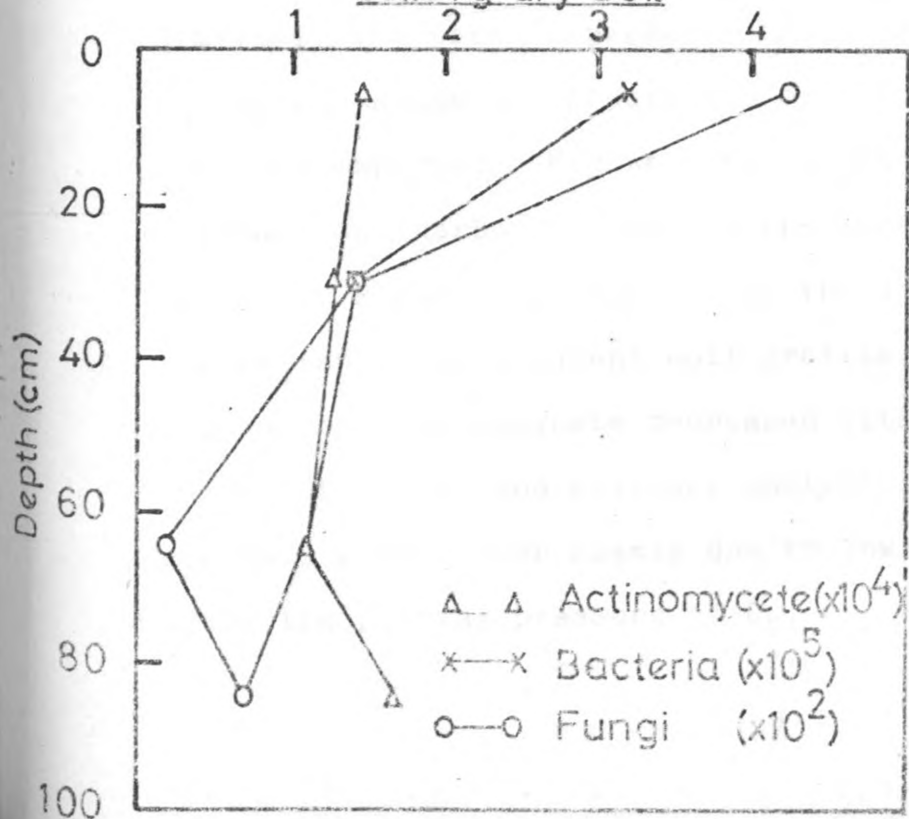


Fig 16b Microbial population in an adjacent soil profile cells/g dry soil



of actinomycete in the 'open' mound showed an increase in the nursery and the royal cell where other soil factors like soil moisture, clay, carbon and nitrogen were found to be higher than in other chambers of the mound. The microbial numbers were positively correlated to those factors as shown in Tables 15 but insignificantly with increase in depth. The behaviour of actinomycete was different from normal soils where population of aerobes decreases with increased depth of the soil profile. In the 'closed' mound the numbers gave insignificant correlation with the mentioned soil parameters although high numbers were observed in the nursery and royal chamber like in the 'open' mound. This was similar to the surrounding soils where a significant negative correlation coefficient (0.01, $r = -0.70$) was observed. However in this case, moisture content, clay, carbon and nitrogen contents decreased with depth. Similarly the partial pressure of CO_2 was shown to be increasing hence low population of aerobic actinomycete was expected. Figure 16a showed the trend of moisture and carbon content in the surrounding soil profile. Figure 16b illustrates the actinomycetes population in an adjacent soil profile. The population of the actinomycete decreased with depth as the amount of carbon and moisture content declined. The response was however mainly due to low carbon and probably low partial pressure of O_2 .

4.5.3.2. Bacteria

In 'open' mound, the bacterial population was similar to that of the actinomycete. Nevertheless bacteria also increased in the nursery and queen cell chambers in the 'closed' mound as illustrated by Figures 15b and 16b. Similarly Tables 16a and 16b also present the data obtained from the soil samples.

When moisture content and carbon content increased the numbers of bacteria were shown to increase. The bacterial population showed an insignificant but positive correlation as the depth of the mound increased.

There was a sharp decline of bacterial population after the nursery. This showed that the high bacterial population in the nursery and queen chambers was due to factors absent in the subsoil below. The presence of aerobic bacteria at these depth indicated that termites had methods of maintaining high partial pressures of O_2 which would otherwise be low in the surrounding soils at similar depths. In the 'closed' mound the highest bacterial population was at a deeper horizon than 'open' mound 105 - 125 cm as compared to 80 - 90 cm respectively. Since the 'open' mound was connected to the atmosphere through channels (Noirot, 1969), it was expected that aerobes in 'open' mound would be found in the deeper chambers than the 'closed' mound which was not the case.

In the surrounding soil profile the population of bacteria decreased significantly (0.01, $r = - 0.67$) with a decrease in clay, carbon content and other soil properties which influence microbial population. The high partial pressure of CO_2 or low partial pressure of O_2 could also have influenced a decline of microbial population in the soil.

4.5.3.3. Fungi

Distribution of numbers of fungi within the profile was similar to those of actinomycete and bacteria as shown by Figures 14b and 15b. In the 'closed' mound the highest fungal population was at nursery while in the 'open' mound the highest population was in the massive brown layer at 20 - 80 cm. In the surrounding soils fungal population dropped significantly with other soil properties like carbon and nitrogen.

A t-test was carried out to check whether the termites improved the soil properties. The 'open' mound had more bacteria as shown by Table 16a than adjacent soil and they were significantly different ($P < 0.05$). Similarly the 'closed' mound had more fungi population than surrounding soils.

The two types of mounds were similar in terms of bacteria and actinomycete population but significantly different ($P < 0.01$) in fungal population.

The surrounding soil were less than a metre deep

while the mound soil were slightly less than 2 m deep. In the 'open' and 'closed' mound, the chambers occurred at different depth. For example the nursery for 'open' mound was at 80 - 105 cm and for closed mound the same chamber was at 105 - 125 cm. It was difficult to ascertain whether this had any influence on the distribution of microorganism. In this study only aerobic microorganisms were examined. The anaerobic bacteria left in the study could have had an influence on the distribution of microbial population in the two types of mound.

In the adjacent soil profile there was a decline of fungal population in response to decline in carbon and nitrogen contents as illustrated by Figure 17b. The effect of either low O_2 or high CO_2 concentration might have reduced the population of fungi also. The behaviour of microbial population was as indicated in Table 16c and illustrated by Figure 15b.

4.6. Comparison between bacterial groups present in mound and adjacent soils.

Different groups of bacteria in the mound soils and surrounding soils are shown in Table 17. The cellulose decomposers were more numerous in both mound samples and surrounding soils than all the other groups of bacteria examined in this study. The cellulose decomposers showed a pattern being higher in the mound soil than in adjacent soil as illustrated

Table 17: Distribution of different groups of bacteria in the mound and adjacent soils

	Cellulose Decomposer ($\times 10^4$)			Dentrifiers ($\times 10^3$)			Nitrifying Bacteria						Aerobic-Nitrogen fixers ($\times 10^3$)			Protozoa $\times 10^3$)		
							Nitrosomonas ($\times 10^2$)			Nitrobacter ($\times 10^3$)								
	0 m	3 m	20 m	0 m	3 m	20 m	0 m	3 m	20 m	0 m	3 m	20 m	0 m	3 m	20 m	0 m	3 m	20 m
Live mound	6.18	3.68	3.64	11.05	-	1.1	33.1	4.28	3.5	11.0	1.1	0.7	5.9	8.60	4.8	0.21	0.27	0.39
Confidence limits	1.87- 20.39	1.12- 12.14	1.10- 12.01	3.35- 36.45	-	0.33- 3.6	1.30- 14.12	1.0- 10.92	1.06- 11.55	3.3- 3.6	.33- 3.6	.21- 2.31	-	-	-	.64- 6.83	.82- 8.91	1.19- 12.64
Dead mound	9.87	3.9	3.29	10.6	1.1	0.47	35.0	6.03	2.20	1.25	1.01	2.43	6.1	8.6	12.6	0.57	9.91	36
Confidence limits	2.98- 32.51	1.18- 12.87	1.0- 10.86	3.2- 34.98	1.42- 15.52	1.06- 11.55	1.83- 19.90	0.67- 7.26	0.38- 4.13	0.31- 3.33	0.74- 8.02	-	-	-	-	1.17- 18.65	30.03- 327.05	95.76- 1042.8

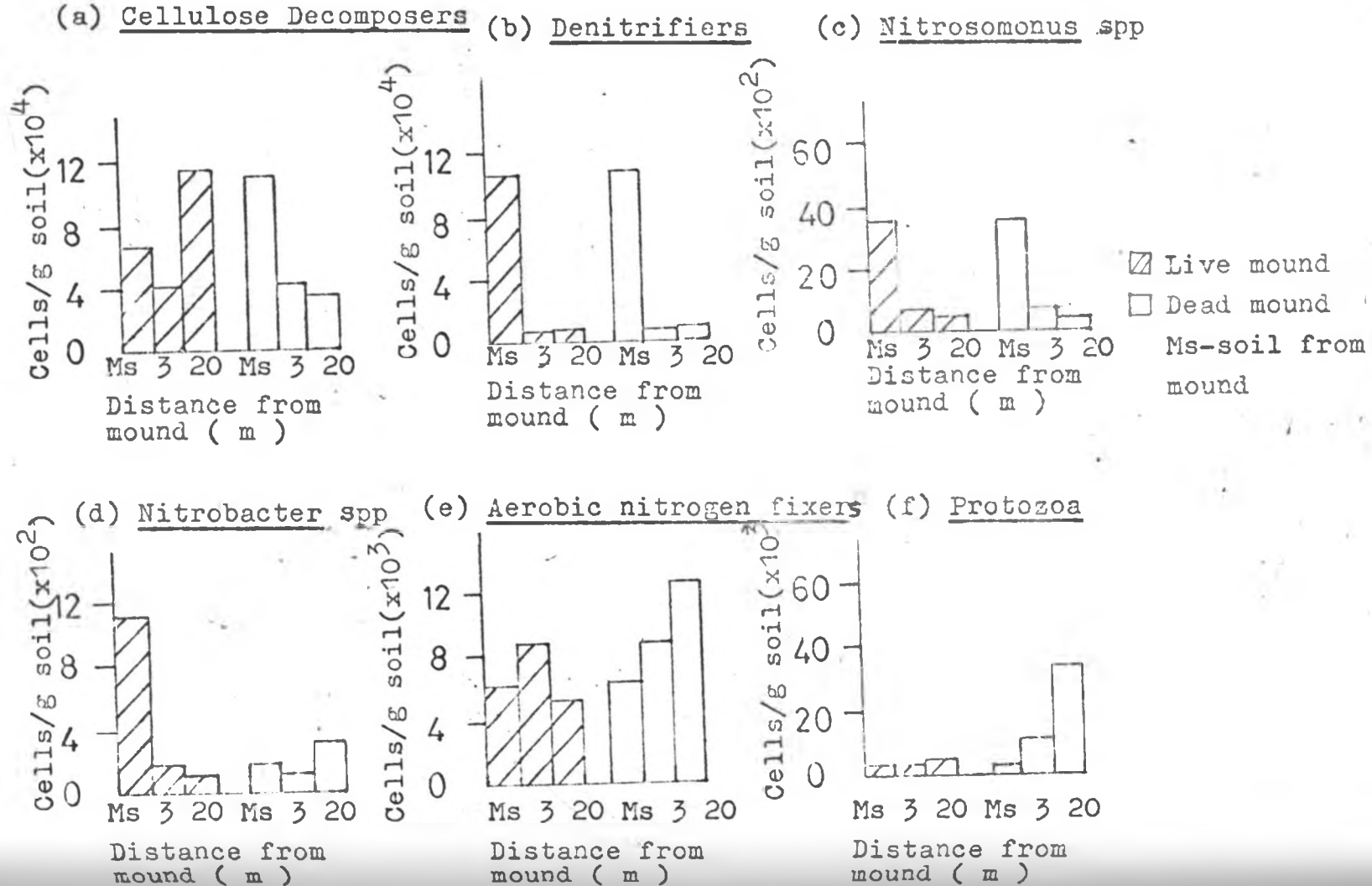
by Figure 17a. Similarly the denitrifying bacteria were the second highest in population. They were higher in mound soil than surrounding soil as illustrated by Figure 17b. The high count of cellulose decomposers and denitrifiers indicated that easily decomposable organic matter was present in higher quantities in the mound soil than surrounding soils.

The nitrifying bacteria, Nitrosomonas spp. and Nitrobacter, spp. were low as compared to other organisms, they were in the order of 10^2 /g dry soil. However the nitrifiers showed a similar trend to cellulose decomposers as presented in Figure 17c. The denitrifiers, decreased from the mound to surrounding soils as illustrated by Figure 17d. The aerobic nitrogen fixers were low as revealed by the plate count method. There was no effect of mound proximity as illustrated by Figure 17e.

Similar work in Rhodesia was reported by Meikeljohn (1965). She found the same trend, whereby all the groups except nitrogen fixers were higher in termite soils than in surrounding soils. The difference from Kajiado soils was that cellulose decomposers were more numerous while in the findings of Meikeljohn, ammonifiers and aerobic nitrogen fixers were the most numerous. Also in the study nitrogen fixers were higher in the surrounding soils than in termite soils.

Protozoa were examined in the same samples. Their

Fig 17. Numbers of different bacterial groups from mounds and surrounding soil



population was higher in the termite soils than in the adjacent ones. The population of protozoa in mound soil was similar to a soil from Kabete, their magnitude being 10^3 /g dry soil. Higher populations in the 'dead' mound as illustrated by Figure 17f and as shown in Table 17 was also evident. The succession of different soil microbial population may be influenced by the mound proximity whether 'inhabited' or 'uninhabited' by termites. In uninhabited mound breakdown of organic matter and other soil properties takes place at a faster rate and the soil properties tend to be similar to those of the surrounding soil with time. This would be followed by an increase of bacterial numbers (Rahno, 1964). The protozoa do feed on the bacteria as shown by (Singh, 1946), thus the population of protozoa in the dead mound would be expected to rise in response to availability of the prey.

The presence of different groups of bacteria in the soil samples was detected using different methods as already shown in Table 18.

Table 18: Presence of different groups of bacteria

Group of bacteria	Incubation period (days)	Positive Results	Control
Total count	14	Turbidity of the media. High dilutions wet mounted slides were prepared under microscope.	Clear broth or no organisms on wet mounted slides when observed through the microscope.
Cellulose decomposers	14	Yellowing of filter paper or development of black dots.	Clear broth except white deposits of CaCO ₃ . The filter paper remained white after incubation.
Denitrifiers	6	Gas bubbles. Blue colour at neutral pH	The medium was light green.
<u>Nitrifiers</u> <u>Nitrosomonas spp.</u>	21	Purple colour on strips of white paper dipped in griesslosvy reagent.	There was no development of purple colour.
<u>Nitrobacter spp.</u>	21	No development of purplish colour with griesslosvy reagent.	Development of purple colour.
Aerobic-Nitrogen Fixers	7	Large colonies 3 - 5 mm mucoid or viscous as Azotobacter.	Lack of this type of colonies on the medium

DISCUSSION

5. DISCUSSION

5.1. Soil physical and chemical properties

The mound soils had higher clay content than surrounding soils. Soils washed from these mounds and deposited in the surrounding area to a distance of 10 m had an influence on soil texture. It was therefore found that the clay and sand content had an inverse relationship with proximity of the mound. The clay content decreased and sand increased with distance from the mound. Macrotermes build their mounds from the subsoil, at a depth of 40 - 80 cm or more (Maldague, 1959; Lee and Wood, 1971; Hesse, 1955; Harris, 1949; Pomeroy, 1976). The texture in the mound also varied in different chambers, the nursery and queen cell were shown to have high clay content, and coarse sand was shown to be absent. This corresponded with findings by (Arshad, 1978; Midiema and Van Vuure, 1977; Stoops, 1964; Hesse, 1955; Nye, 1955). Although several workers argue that the high clay content in the mound soils agrees with that of the adjacent subsoil. (Hesse, 1955) thought that termite workers have no selectivity for finer soil particles. Different workers who compared chambers of the mound have shown that the termites workers do select certain sizes of soil particles for the most important parts of the mound. The termites preferred finer particles in the subsoil mainly clay 0.005 mm

and silt 0.002 - 0.005 mm in diameter and they tend to reject any material larger than 2 mm in diameter (Ruelle, 1964; Arshad, 1978). The sizes of material carried by workers is also a function of their size and the mode of carrying. In the case of Macrotermes the material is carried by mandibles while for other genus like Cubitermes spp. the soils are digested. Preference for fine clay particles may be due to some other requirements in the mound. For example, a need for high humidity in the mound may warrant heavy textured soils to reduce water losses by evaporation. The smoothed passages and walls by plastering would require fine soil particles. The high clay content in the centre of the mound could also be due to the material washed down to the centre of the mound, but this could not be possible. The mounds are said to have an 'umbrella' effect, according to (Nye, 1955; Lee and Wood, 1971; Pendleton, 1941) the rain water does not enter into the heavy textured mound hence there would not be enough water to drain through the mound and wash down the finer particles into the centre chambers. The 'umbrella' effect was also observed in the area of study in Kenya where 'inhabited' mound, interior soils were found to be dry while the 'uninhabited' and adjacent soils were moist after rains. Also Hesse (1955), found that the ratio of clay to sand was constant in all the chambers and corresponded to that of the adjacent surrounding

soils. Thus high clay content in mound soils and especially in the centre of the mound was mainly due to the selectivity of the workers for particles less than 2 mm in diameter (Arshad, 1978).

The moisture content was shown to be negatively correlated with the distance from the mound. This was due to textural differences. The mound soils and sample at a distance of 10 m from the mound had high clay content which increased water holding capacity of the soils. Hence high moisture content both during wet and dry season did account for higher, vegetation density around the mound. There was a 'moisture bulge' with increase in the depth of the mound as observed in both 'open' and 'closed' mounds. This corresponded with results by (Hesse, 1955; Harris, 1951; Fyfe and Gay, 1938; Watson, 1969), for both 'inhabited' and uninhabited' mounds. In comparison to the adjacent soils where the moisture content remained almost constant with depth after the top 10 cm. This bulge may have been due to the textural difference in chambers. The highest clay content was in the nursery and queen chambers where the moisture content was also at the maximum. Termites need a high relative humidity of about 90% to be active metabolically (Harris, 1951) and to maintain this high humidity then certain factors have to take place. According to (Harris, 1951) the termite produce all the water they need to maintain

a high relative humidity metabolically. The capillary effect, where water in the mound is said to move upward and downward, while in the surrounding soils the water moves downwards only. This upward movement of water in the mounds results to high water content in the centre (Watson, 1969). The nature of the mound, its dome shape, the heavy texture both protect the inner chambers from losing moisture to the atmosphere hence higher moisture content.

The cation exchange capacity (C.E.C.) for both 'dead' and 'live' mound in the top 13 cm decreased with increase in distance which was similar to the clay and carbon contents. The C.E.C. of the soil is due to the clay content and organic matter in the soil. These two were found to be high in soil samples taken near the mound to a distance of 10 m but the mound soil though high in C.E.C. was bare of vegetation. So the amount of clay and the fact that these soils were from the subsoil may have accounted for the difference from adjacent soils at 20 m and more from the mound.

Both 'open' and 'closed' mounds were also shown to have high C.E.C. and exchangeable Ca^{2+} , K^+ and Na^+ than the adjacent soils. These corresponded to findings by (Hesse, 1955; Nye, 1955; Wild, 1952; Miedema and Van Vuure, 1977; Lee and Wood, 1971; Boyer, 1959; Maldague, 1959; Stoops, 1964); Watson, 1976; Jakubczyk *et al.*, 1971). The higher C.E.C. and exchangeable bases in the

termite mound than in the surrounding soils could have been due to many factors like the mineral elements present in the vegetation material (Adamson, 1943). The forage material which was mainly grasses in the area of study could not have such a high effect on the mineral elements because the termites after carrying the material into the mound they feed on it and after digestion the mineral elements are held up in the termite bodies. The termites are said to feed on their excreta and dead bodies hence the final material released to the soil is over digested to add any significant amount of mineral elements into the soil (Hesse, 1955; Harris, 1949). The movement of water upwards and downwards by capillarity in the mound as described by (Watson, 1969) would result to an accumulation of mineral elements in the mound soils because the leaching effect taking place in the adjacent soils is absent.

The fungi combs are composed of 45 - 50% water 4 - 5% Ca, 4% Mg 0.02 - 0.2% Na and on decomposition it releases these nutrients into the mound soils. The effect of fungi combs would be difficult to estimate if Hesse's argument that the termites feed on the old fungi combs and always there is replacement with a new fungi comb is true. This means that there would be no accumulation of cations in the soil from fungi combs. There would be no increase in organic matter.

after combs breakdown and release carbon from lignin and cellulose which are its major constituents (I.C.I.P.E. Annual Report). Finally the 'umbrella effect' (Nye, 1955) reduces leaching effect in the termite soils and this would account for higher C.E.C. and exchangeable bases than surrounding soils. Each of these reasons by itself does not seem sufficient but all of them combined could result to higher C.E.C. and T.E.B. than in the adjacent soils without any influence of termite activity.

The carbon content of a soil sample from inhabited mound is similar to that of the adjacent subsoil. The 'uninhabited' mound depending on the age could be similar to the adjacent top soil in terms of carbon and organic matter contents. This agrees with (Miedema and Van Vuure, 1977). However with different chambers of the mound carbon was found to increase with depth attaining a maximum in the nursery and queen chambers. Similar observation were recorded by (Pomeroy, 1976b; Hesse, 1955; Watson, 1976 and Nye, 1955). The fungi combs which is mainly lignin and cellulose, protein substances and silica, on decomposing do release carbon into the surrounding soils. The termite excreta and their dead bodies do release carbon into the soil after they are broken down by microorganisms. (Hesse, 1955) found that 10,000 insects were equivalent to 0.8 of plant material and although the population

of termite in the mound was in millions, their effect on organic carbon content was negligible. Their effect as compared to the volume of soil under their influence could be significant considering that these termites stay in the mound for many years. The succession of colonies in the same mound, thus the dead termites on decaying would have cumulative effect on the organic matter content of the soil.

The pH in the top 13 cm was not different from the surrounding top soils in both 'inhabited' and 'uninhabited' mounds which did agree with (Hesse, 1955). Other workers have reported alkaline pH in the mound soils due to presence of higher bases (Watson, 1976; Bachelier, 1962). The high pH values could be due to CaCO_3 accumulation in mounds due to termite activity (Milne, 1947; Burtt, 1942; Pendleton, 1941). The termite activity could not have been responsible for CaCO_3 concretion in mound soils as stated by these workers. Otherwise similar species such as Macrotermes could have had CaCO_3 concretions in all regions irrespective of climate and soil. This was not true according to (Hesse, 1955). In his work in Tanzania he found CaCO_3 in termite mound soils where there was calcareous soils or where there was waterlogging. Similarly in this study the mound soils from Magadi and Konza were observed to contain CaCO_3 and this was associated to the calcareous soils otherwise the pH

was not different between termite mound soils and the adjacent soils. Joachim and Kandiah (1940) associated the presence of CaCO_3 to the fungus combs. As stated above if the termite do feed on the old fungus combs then there cannot be any accumulation of Ca to a level where concretions are formed though the Ca content is usually as high as 4% in the fungus combs. According to (Hesse, 1955) in soils with poor drainage this could account for the presence of these concretions in non-calcareous soils.

The effect of the termite activity on the soil fertility is short lived and although no work has been done in this study to find out the period these soil properties would be reflected in crop productivity, some work was done in temperate area by Jakubczyk et al. (1971). They found that on abandonment the mound became susceptible to weathering and erosion agents. Soon its properties get closer to those of the adjacent or surrounding soils. The complete reduction of the soil properties occurred after two years and over. Other workers like (Hesse, 1955; Pomeroy, 1976) argued that apart from C.E.C., Ca and Mg the mound soils are similar to the adjacent subsoil and so if it were to be spread on the top soil it would reduce the fertility of the top soil since it is low in organic matter. The effect of the high carbon content in the nursery and queen chambers may be insignificant if spread on the surface because of

the volume concerned. Secondly, some termite soils after spreading them to reduce crop production, this effect on soil fertility is not yet fully understood. What is usually found is that farmers growing their crops on old termite hills have reported better crop performance than on the surrounding soils. Maize, tobacco, cabbage, coffee and sisal as reported in different parts of the world (Meikeljohn, 1965; Pendleton, 1941; Robinson, 1958; Harris, 1951; Pomeroy, 1976) are common food crops grown on termite mound by small scale farmers. In the area of study similar influence on vegetation was observed, different grasses and herbs were found to grow on and near the mound soils to a distance of about 10 m. The biomass of vegetation was also found to be higher. Cynodon dactylon and Pennisitum spp. were common on mound soils while on the surrounding soils Hyperrrhenia spp. was the dominant grass. The grass growing near the mound upto 10 m were similar to those species in high rainfall areas. The chemical properties of the termite soils though higher than surrounding soils could not have had influences on the species of grass and so the physical properties of the soil may have been the major cause mainly through their effect on soil moisture regime.

5.2. Population of microorganisms in termite
'modified' soils.

Soil microorganisms are essential in the soil for breakdown of animal and plant material to release essential plant nutrients. The major groups of soil microorganisms involved in those complex metabolic systems are bacteria, actinomycete and fungi. Development and activity of these organisms are influenced by both primary and secondary environmental factors. According to (Alexander, 1973) these factors are difficult to isolate one single factor from the others and study its effects on microbial activity in isolation of the others.

The study carried out on the behaviour of microbial population of the soil was a generalised one though moisture content of the soil was considered as the limiting factor.

As in Section 5.1. the termite 'modified' soils had higher C.E.C., T.E.B. and a finer texture than the surrounding soils. The vegetation and species composition on the mound soils was different from that of the surrounding soils. It was therefore expected that microbial population on the mound soil would be different from those of the surrounding soil together with their activity.

However there was no recordable difference between mound soils and the surrounding soils. The

physical and chemical properties were influenced by mound proximity both in 'live' and 'dead' mounds. The C.E.C., Ca, Na decreased away from the mound as well as the clay content. The moisture content had a similar trend so was the carbon content and vegetation cover.

Thus several factors may have accounted for the lack of influence on microbial population by the above mentioned soil parameters. The plate count method is said to give 1 - 10% of the total microbial population obtained by direct methods. The numbers obtained were therefore an underestimate and in any case only aerobic microorganisms were cultured.

The soil is said to be a complex heterogenous medium which is difficult to simulate under any available laboratory conditions. The medium used may have favoured the growth of some groups of organisms leaving out others. This depended mainly on the nutrients available in the medium. Thirdly, the movement of the termite workers collecting food on the soil surface may have carried inoculum from one place to another. Similarly the runoff from the elevated mound soils to the surrounding areas may have had a spreading effect on the inoculum. These factors and others not considered in the study may account for the behaviour of the population of these organisms.

The activity of microbial population in the soil through CO_2 evolution over a period of 10 days gave a better indication of microbial population in relation to mound proximity. High microbial activity was observed at 3 - 10 m from the mound. The organic matter and carbon content were also at their highest in the same region, especially in the 'live' mound. In this region 3 - 10 m, there were more nutrients available for microbial activity than on the bare mound soil and the surrounding area.

There was no significant correlation coefficient between amount of CO_2 evolved and different groups of microorganisms except actinomycete in the 'live' mound. The $\text{mg CO}_2/\text{g soil}$ evolved indicated total microbial activity in the soil while in the cultural studies selective media were used for different groups of microorganism in the soil. Therefore the coefficient of correlation obtained was by chance and would be difficult to interpret. However, Gray and Wallace (1957) observed a significant positive correlation coefficient between bacterial numbers and the amount of CO_2 evolved in an experiment designed to study effects of straw or plant residues on soil conditions. They also found that moisture content, temperature and soil treatment did not interfere with the correlation. Similarly these factors may not have influenced the r-values in this study because the soils were kept at almost natural

a sharp decline on reduction of soil moisture content. Similar findings were reported by (Rahno et al., 1978; Jensen, 1934; Meikeljohn, 1957). Rahno et al. (1978) working in the temperate areas found high bacterial numbers at 30 - 40% moisture content.

Similar to bacterial population actinomycete were more numerous in the wet season than during the dry season. This was contrary to Meikeljohn's findings at Muguga. She found that the population of actinomycete rose from 15% during the wet season to 90% of the total microbial counts for the dry season of 1953 drought period. She also reported a decline in bacteria: actinomycete ratio as the soil moisture content decreased. Bacterial counts appearing on actinomycete plates usually account for 15 - 30% and this may have lead to an overestimation of actinomycete population in Meikeljohn's work. The period over which her work and this study were carried out were too short that no conclusion concerning effects of seasonality on the population of actinomycete and bacteria can be made. It would therefore be of some scientific interest if more intensive research was carried out in this field under tropical conditions.

The population of fungi was high during the dry period. This may have been due to low competition as the population of bacteria and actinomycete were relatively low.

The response of microbial population to seasons was not only due to moisture content but due to many soil factors which are dependent on each other. Rahno et al. (1978) reported that the population and activity of each group of organism depended on several factors such as, moisture content, organic carbon and the time when organic matter was added to the soil, the soil temperature and toxic substances.

However high soil temperatures accompanied by moisture stress would have adverse effects on the survival of these organisms. Other workers like Gray and McMaster (1934) did not observe any evidence of seasonal fluctuation on microbial population. They concluded that the amount of organic matter in the soil primarily influenced microbial activity. Although organic matter is the source of major nutrient required by microorganism, the above conclusion by Gray and McMaster was not satisfactory. As stated earlier, many environmental factors such as temperature, soil reaction, moisture content do influence microbial activity and if these factors are not at the optimum levels, even with high organic matter in the soil no microbial activity would take place in the soil.

In this study, the termite 'modified' soils showed some effect mainly on bacteria and fungi. Similarly the wet and dry period influenced the population of bacteria and fungi, and little or no effect on actinomycete.

Similar findings were reported by Jakubczyk et al. (1972) who found that the mound soils influenced the population of bacteria and fungi only. To support these findings Meikeljohn (1965) reported that the population of cellulose decomposers, amonifiers, de-nitrifiers and nitrifying bacteria were higher in the mound soils than in the surrounding soils. Similar observations were reported in this study. Mound soils were consistently higher in organic carbon, nitrogen, calcium, magnesium and phosphorus. The vegetation on the termite 'modified' soils supported many more different species than that of the surrounding soils. The higher carbon, nitrogen, moisture content and cations in the mound soils accounted for any higher microbial number and activity than in the surrounding soils which were generally low in the above mentioned soil factors.

CONCLUSION

6. CONCLUSION

The results in this study showed that the activity of the genus M. subhyalinus does influence physical and chemical properties of the soil used for mound construction. The influence is mainly mechanical through the movement of the subsoil. Cation exchange capacity, and Total Exchange bases especially Ca and Mg were the major chemical properties that were affected by termite activity. It was also observed that the density of vegetation and its species composition on the mound soils was better than in the surrounding soils. This was due to the fine textured soils which were deposited around the mound to a distance of about 10 m from the termite nest. These factors may have resulted in higher microbial activity as indicated by mg.CO₂/g soil evolved.

The 'open' and 'closed' mounds built by M. subhyalinus and M. michelseni respectively showed a clay, carbon and moisture content 'bulge' as the depth of the mound increased. The highest values of moisture, carbon and clay were however recorded in different chambers but mainly in the nursery and queen chambers. The population of actinomycete, bacteria and fungi in the mound also increased with depth of the mound unlike in the adjacent soil profile where a decline with depth of profile was observed. These results, however confirmed the findings by earlier researchers.

The study also revealed that 'live' and 'dead' mound were not significantly different in terms of microbial populations. Bacteria and fungi were shown to be influenced by seasonality significantly and slightly by termite activity. Bacteria were highest during the wet season and fungi over the dry season. Actinomycete population neither responded to seasonality nor to termite activity though their colonies were more distinct on the plate during the dry season.

This study was confined to the Macrotermes, it is therefore hoped that researchers will look into effects of other genus of termite on soil properties in different parts of Kenya. Evaluation of their economic importance need to be carried out bearing in mind their extensive distribution in the marginal areas.

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