EFFECT OF METHOD OF TERRACING ON SOME PHYSICAL AND CHEMICAL PROPERTIES OF SOILS OF MGETA, MOROGORO, TANZANIA

BY

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ABSTRACT

A field experiment was conducted on cultivated sandy clay loam Chromic Cambisols at Mgeta on the slopes of Uluguru mountains. The objectives were to study the effects of terracing methods on some soil physical and chemical properties and to relate the results to crop performance observed in the field. The main treatments consisted of bench and ladder terraces. The subtreatments were three positions on the slope, and five 10 cm interval soil depth sections. The physical properties assessed were particle size analysis, bulk and particle densities and available water capacity. The assessed chemical properties included pH, CEC, exchangeable cations, organic carbon, total nitrogen, and available phosphorus.

There were significant increases in clay, silt, available water capacity, exchangeable calcium and magnesium contents and a decreasing trend in very coarse sand particles along the slope under ladder terraces. In the bench terraces, bulk density inreased slightly while total porosity decreased significantly along the slope. Most of the soil physical and chemical properties from the bench terraces were significantly different along the slope, but lacked a defined trend. Exchangeable cations, total nitrogen, and organic carbon for the two main

treatments showed a decreasing trend from surface to the bottom of the soil profile. Other soil physical and chemical properties lacked defined trends with depth. The causes of the observed trends in the bench and ladder terraces are respectively attributed to the mechanical movement of soil and gradual but continuous transportation of fine soil materials by water down the slope.

The variations in soil physical and chemical properties within and between the two treatments were attributed to the nature of the soils and methods used in the construction of the terraces.

Variations in the studied soil properties account for the observed crop performance. In order to improve crop performance and maintain a sustainable crop production at Mgeta, several soil management and conservation measures are proposed.

DECLARATION

I, DANIELSON RAMOZ KISANGA, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation has not been submitted for a higher degree award in any other University.

Signature.....

Date.21st SEPT. 1992

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CHAPTER 1

INTRODUCTION

Agricultural development in most of the tropical countries is limited by physical, economic, social and political constraints. The physical constraints include soil fertility, precipitation and availability of plant nutrients which are the dominant factors limiting crop production. If soils are not well conserved and managed, intense precipitation can cause severe erosion on hillslope areas resulting in reduced soil fertility. In soils which are either shallow or with many stones or rock outcrops, low water-holding capacity, excessive internal drainage and low fertility result in reduction in crop yields (Buringh 1979). Some of these problems can be rectified by observing appropriate land management practices such as using appropriate soil and water conservation measures, for example terracing, addition of organic matter or plant residues to the soil, planting adapted cultivars of recommended crops and adoption of appropriate land use practices.

Some soil and water management and conservation practices have been practised in Tanzania. Terracing, for example, is extensively practised in the Uluguru and Usambara mountains and Arumeru district (Shenkalwa 1989;

Kaihura[1] 1990, Mawenya[2] 1990). Despite the use of terraces to reduce soil degradation by water, farmers are still observing spatial variation in crop perfomance and and overall reduction in yields. There is need, therefore, to investigate the causes responsible for the variations in yield and to relate these to the soil conservation methods. This would enable one to assess the effectiveness of the various conservation methods.

Mgeta is an important agricultural land on the western upper slopes of the Uluguru mountains. The conducive temperate-like climate (Delobel et al. 1988) and other physical aspects of the area have encouraged farmers to grow a large variety of both annual (vegetables) and perennial (deciduous fruits) crops. Despite the high and intense rainfall (about 2000 mm per annum) on the steep slopes, soil erosion is not as severe as would have been anticipated. The unique tillage operations practised by farmers and the rapid regeneration of vegetation after land preparation could be considered as the possible explanations of the reduced soil erosion.

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[1] Unpublished paper

[2] Personal communication

There are two main types of terracing methods, namely bench and small ladder terraces which are used for soil and water conservation at Mgeta. Bench terraces (Figure 1a and Plate 1) are exclusively used for growing vegetables. They are made by truncating the soil from the upper part of the slope and make level steps of about 1.5 m wide across the slope. The bench terraces, though conventionally acceptable as soil conservation measures on the steep slopes like those of Malaysia (Morgan 1986), have received a great deal of criticisms in their application in the Uluguru mountains. Due to the fact that the soils of the area are shallow, when bench terraces are constructed the infertile subsoil is often exposed. Construction of such terraces also require high labour input and maintenance. In addition, bench terraces hold back much water on the hill side making the soil saturated and consequently inducing landslides (Temple 1972b; Morgan 1986). The above stipulations, however, have not been adequately substantiated and quantified, hence the need for more investigation.

Ladder terraces (Figure 1b and Plate 2) are wide spread in Mgeta and mainly used for growing food crops such as maize, beans and others except vegetables. The ladder terraces are made such that when cultivating, vegetation and crop residues are spread and covered with soil cut

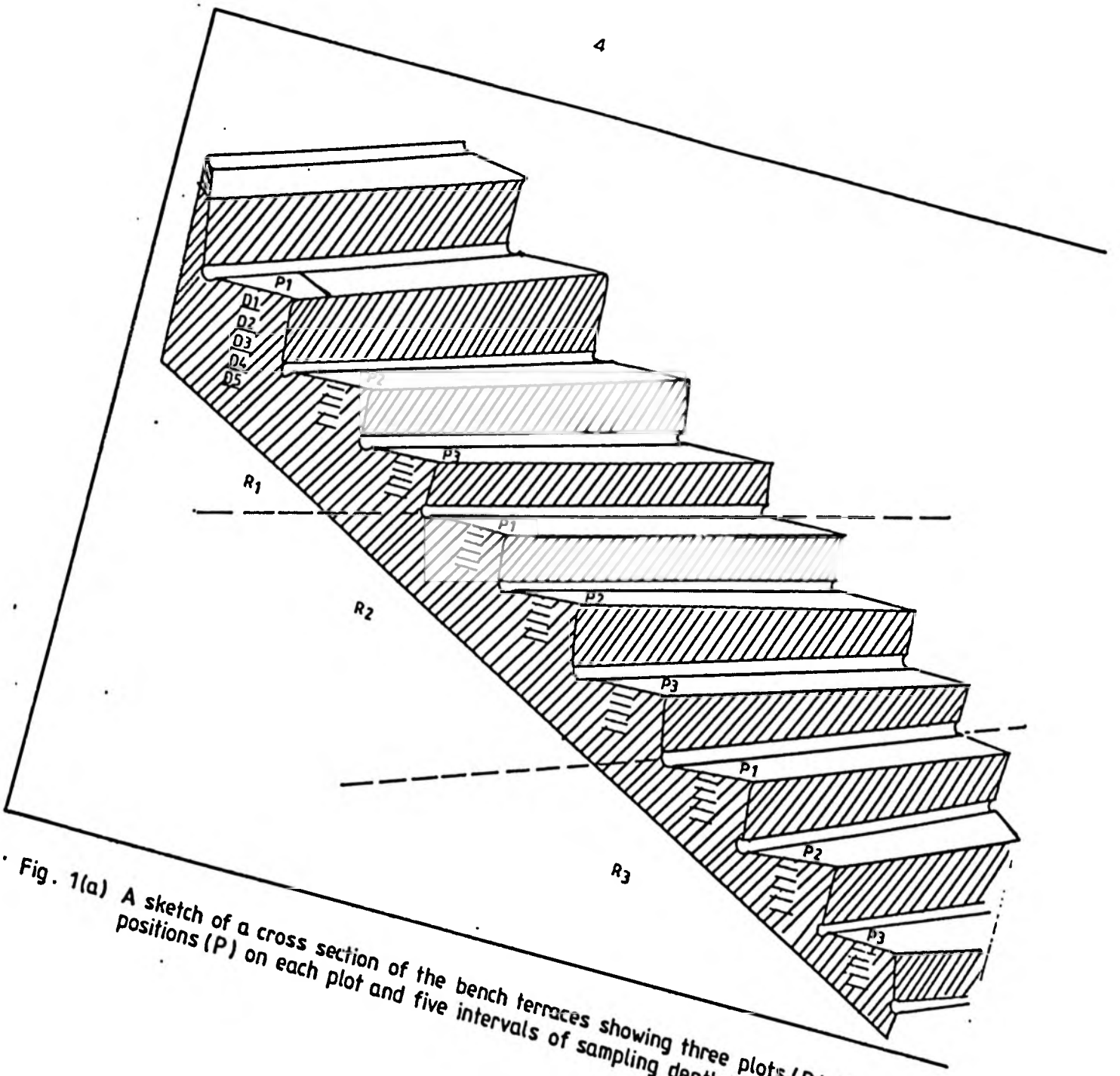

Fig. 1(a) A sketch of a cross section of the bench terraces showing three plots (R), three positions (P) on each plot and five intervals of sampling depth (D).

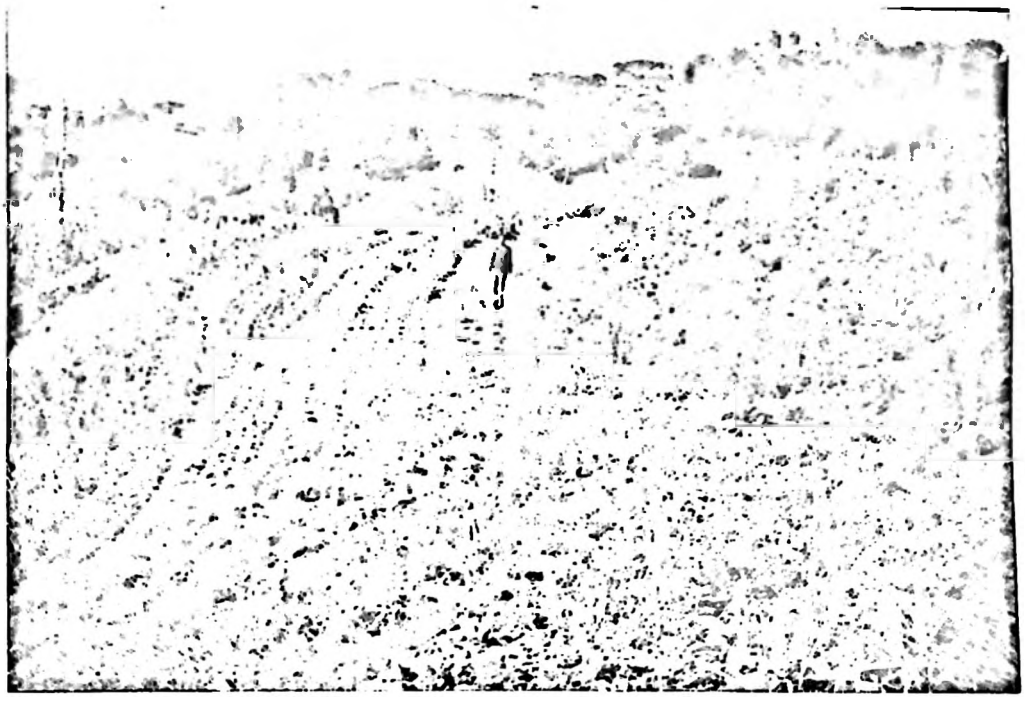

Plate 1: A photograph showing a part of bench terraces in which a current study was undertaken.

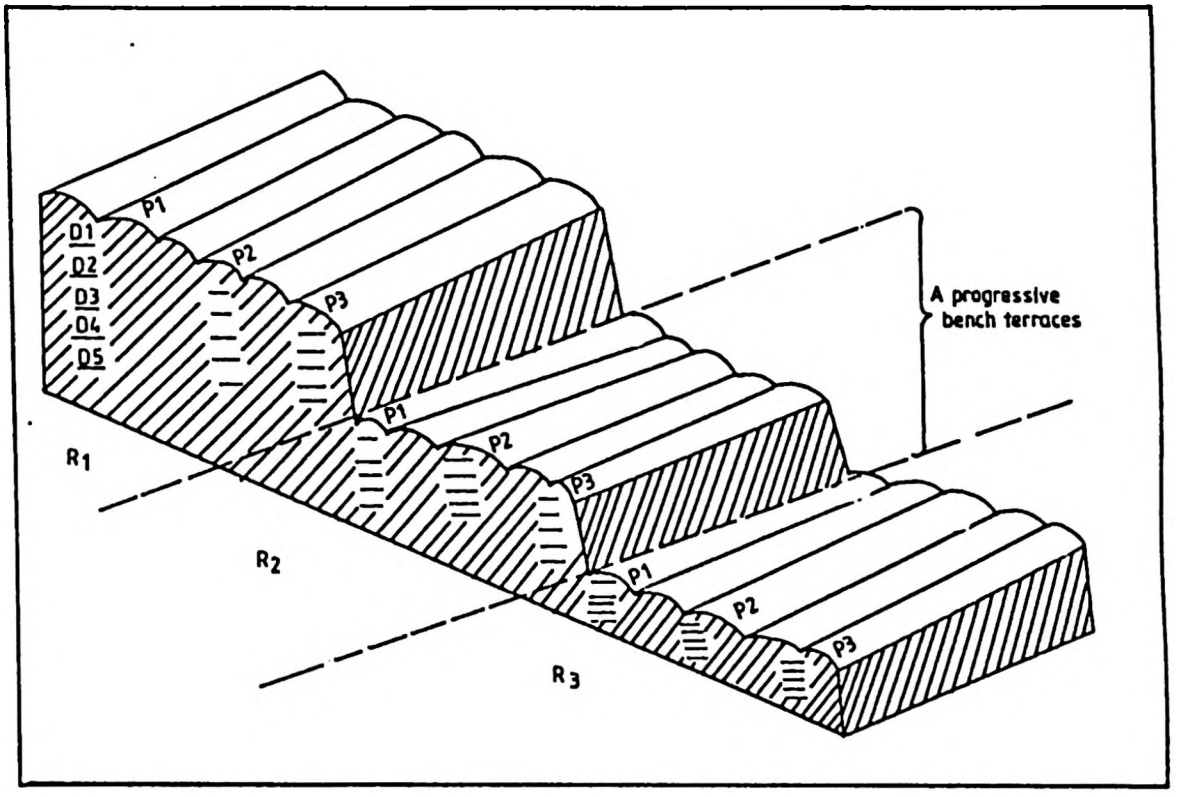

Fig .1b . A sketch of a cross section of the ladder (progresive bench) terraces showing three plots (R), three positions (P) on each plot and five intervals of sampling depth .

Plate 2: A photograph showing a part of ladder terraces in which a current study was undertaken.

from the face of the terraces above. Slow mechanical movement of soil down the slope is the main limitation associated with ladder terraces. Such movements of soil together with the land use systems operating in Mgeta have resulted in another kind of terrace known as progressive bench terrace. Progressive bench terraces have resulted from ladder terraces on plots owned by different people, but on the same slope of a given side of the mountain. The ladder terraces are not continuous, but staggered across the slope in the progressive bench terrace system. The lateral borders between plots across the slope act as barriers for soils shifted from the terraces of the above plot owned by another farmer. In the long run a single plot is transformed into a broader bench terrace.

From field observations on several farms at Mgeta and from personal communication with the Franco-Tanzania Horticultural Development Project Staff (1990) at Mgeta, crop performance in any one plot under ladder terraces varies along the slope. The performance is better at the lower end of a given plot, and worse at the upper end. On the bench terraces, one would anticipate a similar crop performance pattern, that is, higher yields on the lower end of each plot than on the upper end.

Several authors have reported occurrence of various types of erosion by water in the area, notably sheet wash and even landslides (Temple 1972a; Temple and Murray - Rust 1972; and Temple and Rapp 1972). These forms of erosion, however, were not observed in the field at the beginning of this study and were not reported by the Franco-Tanzania Horticultural Development Project Staff apart from the mechanical movement of soil during construction of the terraces. The general variation in yields and crop performance reported by the farmers in the area could be attributed to differences in soil physical and chemical fertility status resulting from the terracing systems. There is need to investigate the advantages and disadvantages of the terracing methods practised in Mgeta on soil and water conservation and maintenance of soil fertility, and their effects on crop production. The specific objectives of the study were:

(1) to study the effect of bench and ladder terraces (progressive bench) on the physical and chemical parameters of the soils along the slope (upper, middle and lower) and at different soil depths,
(2) to compare soil parameters within and between plots in the two terracing methods, and
(3) to relate the findings from this study with the crop performance observed in the field.

CHAPTER 2

LITERATURE REVIEW

2.1 Problems of conservation tillage research

The major goals of conservation tillage systems are: (1) conservation of moisture, (2) erosion control, (3) improvement of the soil productivity (Fauck 1977; Unger and McCalla 1980; Baver et al. 1983). Numerous studies have been undertaken in recent years to examine the effect of different types of conservation tillage methods on soil erosion rates, soil conditions and crop yields (Morgan 1986). The results show that the success of the systems is highly soil specific (Morgan 1986).

Earlier findings by Gill and VandernBerg (1967) indicated that, on the fertility aspect of the variables used in conservation tillage research, it was difficult to define the optimal soil physical and chemical conditions. It was suggested that tillage investigations should be long-term undertakings due to the many factors involved and the complex interactions encompassed. According to Gill and VandernBerg (1967) and Hillel (1982) the long term experiments for conservation tillage operations are important from the fact that the short-term experiments so

often undertaken are under constraints of time, and personnel, and seldom yield conclusive results. Hillel (1982) has stressed that tillage methods when compared may differ widely in terms of cost, performance and measurable effect on the soil. Additionally, final crop yields from different tillage methods may be inconsistent or insignificantly different and their results may lack universal applicability because of faulty selections of measurable criteria, inexact measurements and soil variability. Crop response to tillage also often tends to be masked by numerous unpredictable yet decisive variables acting in the field (Gill and VanderBerg 1967; Lal 1985). Examples of such variables include deficit or excess of water due to diversities of climate, fertility, pests and diseases. When carefully chosen some soil physical and chemical properties have been reported to be appropriate parameters in studying various soil management and conservation problems of different soils in different agro-ecological environments in the tropics (Lal 1985; Shenkalwa 1989). It has been reported that, although a rapid degradation in physical and chemical properties of a soil is common after clearing a land, the trend could be stopped and reversed by observing good soil and crop management and adoption of proper tillage systems (Fauck 1977; Roose 1977). It was therefore, argued that some soil physical and chemical properties could be used to

assess soil degradation by various conservation tillage methods (Fauck 1977).

2.2 Some Soil Physical Properties Influenced by Conservation Tillage Operations

Information on the physical characteristics of the tropical soils as influenced by management is far behind that of chemical and pedological characteristics. According to Lal (1979) the little information that is available still lacks uniformity in the techniques adopted to characterize the soils. For the purpose of studying and comparing various conservation tillage methods, some soil physical properties have been suggested. From various studies the soil properties considered to be important include; bulk density; particle density; soil porosity and/or aeration. Texture and particle size distribution and soil-water-plant relationship characteristics have also been included (FAO 1978; McCalla 1980; Landon 1984; Burden and Seim 1989; Shenkalwa 1989; Vareecken et al. 1989). The aforementioned soil physical properties have been termed as factors of soil degradation and are reported to influence the productivity of a given soil (Cheong 1971; FAO 1978).

2.2.1 Bulk density

Very little information is available concerning the effect of conservation tillage methods on the bulk density of sloping lands. For the few studies undertaken (Shenkalwa 1989) it was found that bulk density tended to decrease down the slope. The decrease was attributed to an increase in organic matter content down the same slope caused by the slight water erosion.

Bulk density has been used as a guide to soil compaction and soil porosity, and as an indicator of problems of root penetration and soil aeration in different soil horizons (Landon 1984). According to Landon (1984) bulk density values vary considerably with moisture content particularly those of fine-textured soils. The bulk densities of clay, clay loam and silt loam top soils have been reported to range between 1.00 to 1.60 g cm^{-3} depending on the conditions like compaction and cultivation. Sands and sandy loams usually show variations between 1.20 and 1.80 g cm^{-3} (Landon 1984). Further, there has often occurred a tendency for bulk density values to increase with depth, as effects of cultivation and organic matter content decrease (Taylor *et al.* 1966). Bulk densities above 1.75 g cm^{-3} for sands or 1.46 and 1.63 g cm^{-3} for silts and clays, have been cited as causing

hindrance to root penetration (Taylor et al. 1966; deGeus 1973). According to Taylor et al. (1966), even in horizons of similar texture lying at similar depths, there are usually great differences in bulk density values depending on organic matter levels, root penetration and soil structure. Very compact subsoils of whatever texture have been found to have bulk densities exceeding 2.0 g cm^{-3} (deGeus 1973).

Increases in soil bulk density have been reported to impose several stresses on plant root system, through the mechanical resistance to root penetration, and thus reducing the plant's ability to exploit its environment. Increases in bulk density also decrease the air filled porosity of the soil thus restricting air supply to the plant roots and facilitating build-up of toxic products such as carbon dioxide and ethylene (deGeus 1973). Compaction of the soil causes a decrease of the volume of coarse pores relative to the volume of fine ones, hence increasing the proportion of total porosity occupied by water at any given suction (Russell 1973). Soil permeability has been found to decrease with increase in bulk density thus making field crops more susceptible to the adverse effects of waterlogging (Landon 1984).

2.2.2 Soil porosity and aeration

The quantity and size distribution of pores in soils are indicators of the physical condition of the soils. Pore characteristics however, are known to change between seasons as well as within a cropping season, and are not readily quantifiable in their influence on crop productivity (Landon 1984). Apart from the quantity and distribution, the tortuosity and continuity of pores are said to be important features influencing aeration, water movement and root penetration (Landon 1984; Thomas and Troeh 1985).

The total porosity of soils has been found to lie between 30 and 70% and has been used as a very general indicator of the degree of compaction in the same way as bulk density. Total porosities of less than 40% and 50% for sands and clay respectively have been reported to restrict root growth due to excessive strength (Harrod 1975). Landon (1984) stressed that the values of total porosity should not be used as conclusive evidence for over-compaction problems in soil, but rather as indicators of likely risk.

Pores that are not filled with water at field capacity (-10 kPa matric potential) are filled with air, and an estimate of their volume is an indication of the aeration

and drainage status of a soil. In general terms, the higher the air-filled porosity (at field capacity) the better the drainage and aeration of a soil (Landon 1984; Thomson and Troeh 1985). A limiting value for air capacity of 10% has been used as a general value below which anaerobic conditions are unlikely to occur (Greenwood 1975). In practice, however, the limit depends on temperature, microbial activity, oxygen consumption by the plant and the continuity of the pores. Eavis (1972) illustrated a way of distinguishing between the effects of mechanical impedance, aerobism and soil moisture using root growth of pea seedlings in soils with various textures, compaction and water contents. According to Eavis (1972) aerobism was found to occur in soils with up to 30% air-filled porosity (AFP), but depended on local conditions around the roots and the presence or absence of intact water films. However, soils were found to be anaerobic at AFP values below 10 to 15%.

2.2.3 Soil texture and particle-size distribution

The proportions of individual soil particle ranges have often been needed in correlation studies, for instance to relate available water capacity (AWC) to silt and/or clay contents and for size grading studies to indicate, for example potential compactability (Landon 1984; Zonn

1986). Various methods have been devized to determine the relative proportion of various size groups. Due to high variability in the results obtained, it has been suggested that a standard method should be used when determining the soil texture. Various authors now advocate use of the pipette method (Dewis and Freitas 1970; Landon 1984 and Zonn 1986).

According to Thomson and Troeh (1985) each type of particle present in the soil makes its contribution to the nature of the soil as a whole. Clay, for instance has been reported to interact with organic matter and increase water and nutrient holding capacity. The finer particles bind soil together into structural aggregates whilst the largest particles act as skeleton to the soil supporting most of the weight borne by the soil and making the soil permeable as well as aerated (Hillel 1982; Baver et al. 1983 and Thomson and Troeh 1985). Sandy soils have been found to be quite permeable to air, water and roots but have relatively low water-holding and plant nutrient storage capacities. In general, sandy soils if farmed should receive frequent additions of water and plant nutrients in order to be highly productive (Thomson and Troeh 1985). The presence of a high percentage of organic matter has been reported to compensate for low clay contents in the soil. Clays hold more water than sands due to their large surface area

(Thomson and Troeh 1985). Soils with high clay content have been associated with high water-holding capacities, but inadequate aeration (Baver et al. 1983). For that reason, therefore, high content of organic matter is reported to be helpful in overcoming the problem of too much water in a clay soil and improving the water holding capacity in sandy soils (Baver et al. 1983; Thomson and Troeh 1985).

Several studies have demonstrated that tillage operations require considerably more power in clay soils than in sandy or loamy soils (Thomson and Troeh 1985). Loam and silt loam soils are considered more desirable for most uses. They have enough clay content for storing adequate amounts of water and plant nutrients for optimal plant growth (Russell 1973) but not too high to cause poor aeration or reduce workability (Thomson and Troeh 1985). Loam soils that contain between 7 and 27% clay and approximately equal amounts of silt and sand and several percent organic matter were found to be very good for most uses (Landon 1984; Thomson and Troeh 1985).

According to studies undertaken in various parts in the tropics (Landon 1984; Thomson and Troeh 1985), textural variations have been reported to be important under conservation tillage systems due to the fact that

high clay contents in the subsurface horizons were found to seriously restrict air, water and root penetration.

2.2.4 Soil-water-plant relationship

Soil as a medium for plant growth has been known to furnish water, air and plant nutrients and permit the physical development of plant root systems (Cheong 1977). The ability of soil to perform the above functions depends both on its texture and structure, which unfortunately vary over the soil profile and from area to area (Landon 1984).

Different plants require different amounts of soil moisture and show preference for different soil physical conditions. Further, several soil-water related parameters have been used to determine the real available water capacity of a particular soil for a given crop (Cheong 1971; Landon 1984). The soil-water related aspects relevant to the crop-water requirements and which have been reported to be influenced by tillage operations are field capacity (FC), permanent wilting point (PWP), available water capacity (AWC), and water retention characteristics (Oswal 1983; Landon 1984).

2.2.4.1 Field capacity (FC)

Field capacity as described by Veihmeyer and Hendrickson (1931) is the maximum water content that the soil will hold following free drainage. This has been reported not to correspond to a fixed soil water potential but represents the condition of each individual soil after the larger pores have drained freely under gravity (Landon 1984). Several attempts have been made to correlate field capacity with a particular soil-water potential, but none has been entirely satisfactory due to their failure to take into account the dynamic properties of the whole soil profile such as transmission characteristics and hydraulic gradients, hysteresis and other factors. Nevertheless, previous studies (Webster and Beckett 1972; Stakman 1974) gave some reasonable estimates concerning the field capacity, which are still used todate. In UK, for instance, Webster and Beckett (1972) reported that matric potentials 48 hours after thorough wetting do not generally exceed -5 kPa. This figure was reported to be used to determine field capacity in the laboratory by the Soil Survey of England and Wales (Avery and Bascomb 1974). Stakman (1974) in the Netherlands used -10 kPa. In the tropics or subtropics, significant losses of water in addition to drainage losses have been observed during the 24 to 48 hours period following wetting. For medium-

textured soils, field capacity moisture content corresponding to -33 kPa potential has commonly been used where field capacity in the field cannot be determined (Landon 1984). According to Russell (1973) soils at -33 kPa potential have lost water in pores larger than about 10 μm diameter, and a useful approximate relationship between tension and the size of pores was given as: diameter of pores (cm) = $\frac{0.3}{h}$, where h is suction in cm of water tension.

2.2.4.2 **Permanent wilting point (PWP)**

Permanent wilting point has arbitrarily been defined as the soil water content at which the leaves of sunflower plants wilt permanently, that is when they do not recover their turgor if subsequently placed in a saturated atmosphere (Landon 1984). Permanent wilting point has commonly been taken as the water content at -1.5 MPa potential. This has been supported by the fact that, many soil-water retention curves tend to be flatter at low potentials, and unit changes in potential produce less variation in soil-water content than at the high potentials associated with field capacity values (Oswal 1983; Landon 1984; Zonn 1986). The use of PWP, however, has been cautioned from the fact that the value of PWP depends on the climatic and soil conditions, the hydraulic conductivities at corresponding water potential levels in

the soil-plant-atmosphere continuum, and the plant species (Sykes, 1969 cited by Landon, 1984). According to Sykes (1969), an interspecies variation was found in the water potential at PWP from -7 to -39 bars. There is no literature available concerning the direct effects of various terracing methods on the field capacity and the permanent wilting point.

2.2.4.3 Available water capacity (AWC)

Available water capacity has been defined as the volume of water retained between field capacity and permanent wilting point, and is a concept that applies to freely drained soils (Landon 1984). It must be pointed out, however, that not all the water held between field capacity and permanent wilting point can be considered as equally available to plants. Milthorpe (1960) suggested that at matric potentials down to -100 kPa, water is freely available to most crops, whilst Hansen *et al*. (1980) considered that 75% of the AWC can easily be extracted. According to Landon (1984), total readily available water capacity (TRAWC) of a profile is about 66% of the total AWC. The proportion of water held at the low tensions represented by the TRAWC may sometimes be more important than the total AWC in determining crop response to soil moisture conditions (Salter and Williams 1965). According

to Salter and Williams (1965), it is TRAWC held at low tension within the larger soil pores which is particularly affected by soil structural conditions. Further, as soils become finer in texture, the TRAWC is said to increase to a maximum within the loams and silt loams.

2.2.4.4 Water retention characteristics

By determining water content at a number of matric potentials between -10 kPa and -1.5 MPa a complete water retention characteristic or release curve can be plotted. Various properties of water retention curves for various textures have been exhaustively discussed by several researchers (Taylor and Ashcroft 1972; Oswal 1983; Landon 1984).

Knowledge of water retention characteristics has been reported to be indispensable in describing soil water processes. Vareecken et al. (1989) found that, soil water processes can be modelled for better understanding of the water movement in porous media using easily measurable soil properties, often monitored during soil survey. The properties were named as particle-size distribution, dry bulk density and carbon-dioxide content. Further, the relationship between easily measurable soil properties and water retention characteristics has been suggested as very

important when studying the effect of management practices on the soil physical properties (Oswal 1983; Burden and Seim 1989; Vareecken et al. 1989). For instance, in order to improve soil structure, medium textured soils should be tilled under optimum matric potential range of -1000 to -1500 kPa (Oswal 1983). This water potential range was reported as being wider for sand and narrow for heavy soils, while soils containing good amount of organic matter could be tilled at matric potentials higher than -1000 kPa (Oswal 1983).

Bache et al. (1981) reported considerable variability in the moisture release curves between sites within the same soil series, and more so for subsoils than top soils. The reason for that variability was attributed to the core sampling (where some of the cores could sample structural cracks in subsoil while others could not), textural differences within series, differences in land management and organic matter content. The latter two were said to be the intrinsic soil properties in causing variability in measurements depending on the structure (Bache et al. 1981).

2.3 Soil Chemical Properties and Conservation Tillage Operations

Efficient soil and water management and good crop production require practical and scientific manipulation of the chemical properties of soils. Arakeri and Donahue (1985) observed that practical soil and water conservation has a significant effect on several chemical properties. Some of the chemical properties profoundly affected by conservation tillage (like terracing) have been pointed out as soil pH, cation exchange capacity, organic matter, phosphorus and nitrogen (McCalla 1978; Landon 1984; Arakeri and Danahue 1985; Shenkalwa 1989). Despite the importance of chemical data on crop production, there have been many difficulties in making generalizations from soil chemical analytical results. Barber et al. (1963) attributed these difficulties to sampling, as samples from a single site could differ in chemical properties because of the influence of some factors such as cropping history, management practices and/or time of the year when a sample was collected. Further, the quantity of an 'available' nutrient measured by a laboratory extraction does not necessarily reflect accurately or measure the availability of that nutrient to plant at the point of absorption on the root hair (Barber et al. 1963; Landon 1984). Additionally, interpretations of crop nutrient responses

are difficult due to interactions between soil chemical constituents, effect of soil conditions on movement of nutrients and their uptake by plants (Mengel 1982). Nevertheless, some of the chemical properties have been used to indicate potential excess or deficiency problems in soils, as well as comparing various soil terracing systems (Acres 1983; Landon 1984; Shenkalwa 1989). Some of the chemical properties which have been reported as being influenced by most of terracing methods are discussed in the following sections.

2.3.1 Soil reaction (pH)

Soil pH has been pointed out as one of the most important chemical property due to its effects on the availability of the 12 essential plant nutrients (McCalla 1978). pH values have further been reported to depend on localized redox states, the concentration of soluble salts in the soil solution and the concentration of CO_2 in the soil air, all of which are constantly changing due to farm management practices (Landon 1984).

The use of various terracing methods have indicated variation in soil pH on hillslope cultivated areas. A study undertaken on the slopes of Usambara mountains under different conservation tillage methods (Shenkalwa 1989)

showed that soil pH was increasing from upper to lower slopes. The reason for the increase was suggested to be the washing away of surface soil from the upper parts of the slope thus exposing the more acidic subsoil to the surface. pH variations caused by various terracing methods have further been reported to have significant effects on various crops. For most commercial crops, a neutral range (pH between 6.3 and 7.5) was asserted as most suitable (Landon 1984).

2.3.2 Cation exchange capacity (CEC)

Cation-exchange capacity measurements have been made as part of the overall assessment of the potential fertility of a soil, and possible response to fertilizer application (Landon 1984). Further, CEC results have sometimes been used as a rough guide to the types of clay minerals present (Russell 1973). CEC values often depends critically on pH, as indicated by the variable ionic adsorption, different concentrations of leaching solution and different solutions used for washing out the soil (Bohn et al. 1985).

From various studies, it has been reported that, the CEC of allophane is particularly susceptible to pH changes, a hysteresis loop being produced by subsequent acid and

alkali treatments. Studies by Jackson (1965) have for example, indicated that the CEC of allophane is near zero at pH 3.5 and over 200 cmol(+) kg^{-1} at pH 10.7. Even at constant pH, hysteresis effects could produce variations in CEC from 50 to 150 cmol(+) kg^{-1}. Corresponding values at pH 7 for other materials (in cmol(+) kg^{-1}) include: zero for kaolinite and quartz; 0.5 for gibbsite; 10 for montimorillonite; and 18 for halloysite (Aomine and Jackson 1959 quoted by Landon 1984).

FAO (1979) quoted CEC values of 8 to 10 cmol(+) kg-1 of soil as indicative values in the top 30 cm of soil for satisfactory production under irrigation, provided that other factors are favourable. CEC has been pointed out as a property of the colloidal fraction of soil, derived mainly from the clay and organic matter fraction, although the silt-sized particles sometimes contribute significantly (FAO 1979). Landon (1984) remarked that, since both CEC and water retention properties are related to soil texture, there generally exists a fair correlation between CEC and base saturation percentage particularly in soils with similar parent materials and history of formation.

2.3.3 Exchangeable cations (Ca, Mg, K and Na)

The proportion of the CEC accounted for by exchangeable bases (Ca, Mg, K and Na) has been frequently used as an indication of soil fertility. The base saturation percentage (BSP), however, does not distinguish between different bases, and imbalances in their relative proportions have been reported to cause severe plant nutrition problems (Landon 1984). According to Clark (1966) it has often been assumed that for optimum agricultural production a neutral soil is required, with all the acidity neutralized by the bases on the clay complex exchange sites. In acid soils the limiting factor has often been the concentration of aluminium ions in the soil solution which in turn depends on the concentrations of the other ions involved in the exchange reaction (Mengel 1982). It has also been shown by Clark (1966) that some soils are saturated with bases at pH 5, which may explain why acid-sensitive crops can be grown on some tropical soils with pH values about 5.5, and why liming does not increase their yield (Russell 1973).

The BSP values have been used in soil classification by FAO-UNESCO (1989) as indications of soil fertility status. Two ranges are used based on ammonium acetate extractions of samples from 20 to 50 cm depth. According

to FAO-UNESCO (1989), the values used are: > 50% - eutric (or fertile) soils and < 50% - dystric (or infertile) soils. A general interpretation of BSP values was further given as: low < 20, medium 20 - 60 and high > 60 (Varley 1983 quoted by Landon 1984).

The levels of individual exchangeable cations in the soil have been reported to have a more immediate value than the CEC in advisory work. This has been supported by the fact that exchangeable cations indicate the existing nutrient status as well as assessing the balance amongst cations (Mengel 1982; Landon 1984). It has further been reported that many effects, for example, on soil structure and on nutrient uptake by crops, are influenced by the relative concentrations as well as by their absolute levels (Landon 1984).

Exchangeable calcium (Ca)

Indices of plant available Ca have been reported to have little value in determining the fertility status of soils due to the enormous variability of its availability and great dependence on a number of other factors (Landon 1984). From previous experience, Ca deficiency has been reported to occur in soils of low CEC at pH values of 5.5 or less (Mengel 1982). Large inputs of potassium (K)

fertilizers or high natural K reserves have been found, however, to inhibit plant uptake of Ca in soils having a more neutral reaction. As a rule of thumb, some response to Ca fertilizer when applied as a plant nutrient has been observed for most crops when exchangeable Ca in the soil is less than 0.2 cmol(+) kg^{-1} of soil (Landon 1984). It has been found from various studies that high values of exchangeable Ca start from above 10 cmol(+) kg^{-1} soil (Mengel 1982; Landon 1984). Although it is known that Ca ions have an affinity for phosphate, Landon (1984) has observed that the effect of the interaction on the availability to plants is not well understood. Hence, in calcareous soils and to plants (Russell 1973; Mengel 1982; Landon 1984).

Exchangeable Magnesium (Mg)

The presence of Mg deficiency in a crop has been suggested to be associated with low Mg content in the soil as well as presence of large amounts of other cations particularly Ca and K (Mengel and Kirkby 1987). With increasing Ca:Mg ratios above about 5:1, the Mg has been reported to become progressively less available to plants, though soils could remain fertile over a very wide range of Ca:Mg ratios (Landon 1984). Deficiency symptoms resulting from low absolute values of exchangeable Mg,

rather than cation imbalance have been reported in acid, coarse textured soils having exchangeable Mg levels less than 0.2 cmol(+) kg^{-1} soil. High levels of Mg are generally taken as those above 4.0 cmol(+) kg^{-1} soil (Varley 1982 as quoted by Landon 1984).

Exchangeable Potassium (K)

Exchangeable potassium levels have been suggested to posses only limited value for predicting crop response. This is due to lack of knowledge of the capacity of the soil to release currently unavailable K over a period of time (Mengel and Busch 1982). Further, exchangeable K levels have been found to alter when the soils are dried. As a general rule, samples with large amounts of available K are known to loose some of the element by fixation, and those with low amounts have their exchangeable K released from sources that are non-available in the field (Mengel 1982; Landon 1984)

According to Landon (1984) soils can be referred to as deficient in K when exchangeable K (cmol(+) kg^{-1}) by the ammonium acetate extraction method is less than 0.05 for sands, 0.1 for sandy loams and 0.15 for typical red-brown clays respectively. In Malawi soils it was found that a response to K fertilizers was likely when a soil had an

exchangeable K value of below about 0.2 cmol(+) kg^{-1} of soil and unlikely when it was above 0.4 cmol(+) kg^{-1} of soil (Young and Brown 1962). In humid tropical soils, exchangeable K ranges of between 0.07 and 0.2 cmol(+) kg^{-1} have been quoted as minimum absolute level in order to avoid deficiency (Boyer 1972). However, Jones and Wild (1975) pointed out that the values were only approximate and would vary with crops and production levels.

Exchangeable Sodium (Na)

Although sodium has been reported in particular circumstances as being utilized by some plants as a partial substitute for K, it is not an essential plant nutrient (Mengel and Kirkby 1987). Its absence or presence in only very small quantities is therefore reported to have no detrimental effect to plant nutrition. When Na is present in the soil in significant quantities, however, it can have adverse effects on many crops as well as on the physical conditions of the soil (Landon 1984). Due to the absence of sodicity in the soils of the study area, exchangeable Na is not discussed in detail.

medium; 0.1 to 0.2 low; and less than 0.1 very low. Effects of low pH on N availability have been observed (Landon 1984) to be remarkable. Generally, microbiological activity is reduced by high acidity and available N is consequently reduced, whatever the total N.

2.3.5 Organic carbon (O.C.)

Organic carbon, like soil nitrogen, has been reported to suffer from similar difficulties of experimental determination and interpretation. The two parameters have further been made as a measure of organic matter in the soil, which in turn has been taken as a crude measure of fertility status (Landon 1984). According to Landon (1984) problems can arise experimentally due to the presence in the soil of other forms of C, notably charcoal in regions of human habitation, and undecomposed plant residues. Both carbon sources may influence the analytical results whilst contributing little to the nutrients immediately available to crops. Additionally, as with N analyses, seasonal, storage and pretreatment changes in soil organic matter are also reported to greatly affect measured values.

The importance of organic matter in improving the other soil chemical properties can not be underestimated when studying the influence of tillage operations on any soil. Wrigley (1971) asserted that organic matter compounds or humus in association with clay colloids have important effects on the buffering of soil pH. Humus and clay colloids have been reported to retain the natural fertility or hold elements from added fertilizers in a way which sandy soils can not due to the increased soil CEC (Money 1968). According to various authors, organic matter also contains most of the soils reservoir of N and in some soils phosphorus (Swift and Posner 1972; Sanchez 1976).

Although the interpretations of organic C data lacks adequate guidelines as those of N, a rough approximation has been provided. Metson (1961) using the method by Walkley and Black rated the organic carbon measurements in the order; more than 20%, 10 to 20%, 4 to 10%, 2 to 4%, and less than 2% as very high, high, medium, low and very low respectively.

2.3.6 Phosphorus (P)

Of all the major plant nutrients, phosphorus has been reported to possibly have the most complicated chemistry in the soils at least as far as assessment of P levels and the P fertilizer requirements are concerned (Fassbender 1980). Although several standard `available P' methods are in common use, their applicability depends on the soil conditions (mainly pH). For most soils with pH less than 7.0 the Bray, Truog or Morgan methods have been advocated (Dewis and Freitas 1970; Hesse 1971).

Because of the variety of methods used in determinations of available P, no one general interpretation has been given (Landon 1984). For the acid fluoride (Bray) method and, indeed, for most acid extractions, low values have been suggested to indicate deficiencies, but high values could also be ambiguously interpreted (Landon 1984). For the purpose of studying the fertility status of a given soil, the general guidelines for available P have been provided by Olsen and Dean (1965). According to Olsen and Dean (1965), and Acres (1983), indicative available P values in mg kg^{-1} as determined by Bray - dilute HFl/NH4F show that more than 50 is high and hence fertilizer response is unlikely; 50 to 15 is medium, whereby fertilizer response is probable;

and less than 15 is low, such that fertlizer response is most likely.

2.4 Influence of Bench and Ladder Terraces on Crop Performance

Bench and ladder terraces have been used with the same basic goal of conserving soil and water on steep sloped areas (Constantinesco 1976). The applicability of the two methods on soils with different depths has been compared in various parts of the world like in Africa, Asia and America. Constantinesco (1976) reported successful use of bench terraces in soils which were sufficiently deep and stable. For soils which were too shallow, crops did not grow well on the subsoil exposed, and where the soils were unstable the whole terrace collapsed. In Africa, one solution was suggested to be the laying of rows of crop residues across the slope at intervals of about one metre and to cover the rows with soil about half a metre high (Constantinesco 1976; Shenkalwa 1989). According to the two authors, the result was found to be a series of small back-sloping terraces containing a core of crop residues (somewhat similar to split ridges) and often known as ladder terraces.

There is very little information available on the effect of bench and ladder terraces on crop performance. Much, however, has been studied on the methods of their construction and their effect on the physical and chemical properties, which in turn are known to affect the crop performance (Arakeri and Donahue 1985; Shenkalwa 1989). Morgan (1986) observed that when bench terraces are constructed, much of the top fertile soil is truncated in order to make level steps. This in turn exposes the less fertile subsurface soils especially in areas with shallow soils like those of Uluguru mountains. Bench terraces, however, have been widely acceptable in Malaysia (Morgan 1986). The construction of ladder terraces has also been reported to cause a slow mechanical movement of fertile soil down the slope, which in the long run could decrease the soil fertility (Rwehumbiza and Roose 1990). Information available concerning the movement and depletion of the top fertile soil during construction of terraces by the two methods suggest that crop performance would also be affected.

Terracing on steep slopes has been reported to be very important in controlling water erosion. According to Barrows and Kilmer (1963), terracing was found to be very effective in controlling runoff rich in organic matter, phosphorus, potassium and nitrogen in many parts of the

tropics. Adejuwon and Ekanade (1987) found that terracing was very effective especially in areas where forest was removed and replaced by field and tree crops on steep slopes. Large reductions in pH, organic matter content, nitrate ions, available P, CEC, exchangeable cations and base saturation were observed in areas not well conserved (Adjuwon and Ekanade 1987). Soil erosion, if not properly controlled, has been pointed out to be the reason for crop yields to remain the same or even to decrease despite much efforts to increase yields by fertilizer application (Bennet 1947).

Shenkalwa (1989) concluded that soil physical and chemical properties are affected by the conservation practices, and the latter can be used to assess the effectiveness of erosion control measures.

CHAPTER 3

MATERIALS AND METHODS

3.1 General Characteristics of the Area

Mgeta is situated on the western upper slopes of Uluguru mountains which lie between latitudes 6° 45' and 7° 30' South and longitudes 37° 20' and 38° East (Sampson and Wright 1964) and at an altitude of 2000 m above sea level. The area receives annual rainfall of between 1000 and 2000 mm, with a temperate-like climate (Delobel et al. 1988).

The drainage of the area shows a sub-radial pattern related to the horseshoe of high mountains (Sampson and Wright 1964). This is demonstrated by some of the larger rivers like the upper reaches of part of the Ruvu river on part of Mgeta, extended on to or across the piedmont zone. This, further, probably indicates that the Uluguru Massif is an inselberg of very long standing (Sampson and Wright 1964).

The most widespread rock type is biotite gneiss, in places magmatitic, where it is generally richer in potash (Sampson and Wright, 1964). The dominant vegetation include fern, guavar, cyprus, wattle, eucalyptus and thatch

grass (Themeda spp.). The current land use is cultivation of vegetables like cabbage, cauliflower, leek and lettuce. Maize and beans are grown and all intercropped with deciduous fruit trees like peaches and citrus.

3.2 Experimental Site

Before the field work was started, a reconnaissance survey of the areas cultivated using the two conservation tillage systems (bench and ladder) was conducted. A representative site, where the two conservation tillage methods were practised was chosen at Nyandira in Mgeta division. The site chosen was under cultivation, with a uniform slope of 30% and covering a total area of about 1 ha. Half of the area was under bench terraces while the other adjacent half was under ladder terraces. A sketch of the field layout is shown on Figure 2. The two adjacent but contrasting terrace systems were made about three years ago from the time the study was conducted. Fertilizer application is the same regardless of the type of crop. The farmers usually apply sulphate of ammonia. Neither phosphorus containing fertilizer nor organic manure are applied on the terraces.

3.3 Soils

According to the soil map of the world (FAO-UNESCO 1974), the soils of the study area have been classified generally as Chromic Cambisols associated with Dystric Regosols. For a more precise information a representative profile in the study area was dug/opened at Nyandira to a depth of 120 cm and described according to the FAO Guidelines for Soil Profile Description (FAO 1977). The soils were classified up to a subgroup level according to USDA Soil Taxonomy (Soil Survey Staff 1990) and up to level two soil name under the FAO classification systems (FAO-UNESCO 1989). A summary of the field morphological and laboratory analytical data are presented in Appendix 1 and Appendix 2 respectively. The diagnostic features used for classification of the soils are presented in Appendix 3.

3.4 Soil sampling for physical and chemical analysis

Sampling sites were selected across the slopes on adjacent plots representing each of the two terracing methods. Twenty profiles were excavated at each upper, middle and lower positions of each plot as shown in Figures 1(a) and (b) for disturbed soil sample collection. The three positions were chosen in order to study the possible changes in the physical and chemical properties of the

soils down the slope. The disturbed soil samples for physical and chemical analyses were taken from 0-10, 10-20, 20-30, 30-40 and 40-50 cm depths. The 10 cm intervals to 50 cm maximum depth were chosen in an attempt to investigate the possible occurrence of vertical changes in the physical and chemical properties of the soils in the zone where most of the horticultural and other crops like maize and beans' roots obtain their mineral nutrients and water for growth. Composite samples comprised of 20 subsamples from each depth were obtained from the 20 profiles on each plot position. The composite soil samples (about 2 kg each) were thoroughly mixed and put in plastic bags. Additionally, five undisturbed core samples were taken from each plot position following the depth sequence adopted for the disturbed soil samples and these were used for water retention characteristics and bulk density determinations. A total of 90 disturbed samples and another 90 undisturbed core samples were collected for laboratory analysis for both bench and ladder terraces. The breakdown is: 5 ten centimetres intervals x 3 positions on each plot x 3 plots (or replications) per terracing method x 2 terracing methods.

3.5 Experimental Layout

The experimental layout was a 3 x 5 factorial with the two factors being position on the plot and depth of sampling respectively. A two-way factorial design was chosen to make it possible to assess the possible variations in the soil variables (physical and chemical properties of the soils) in two directions namely, down the slope following three points or positions that is upper, middle and lower, and vertically down to 50 cm depth following 10 cm intervals. The experiment was replicated three times for each terracing method. A sketch of the experimental layout is given in Figure 2 and Plate 3.

3.6. Laboratory Analytical Methods

3.6.1 Soil sample preparation

The disturbed soil samples were air dried, ground, mixed thoroughly and sieved through a 2 mm sieve and then stored in plastic bags. The core samples were taken directly to the laboratory for water retention characteristics and bulk density determinations.

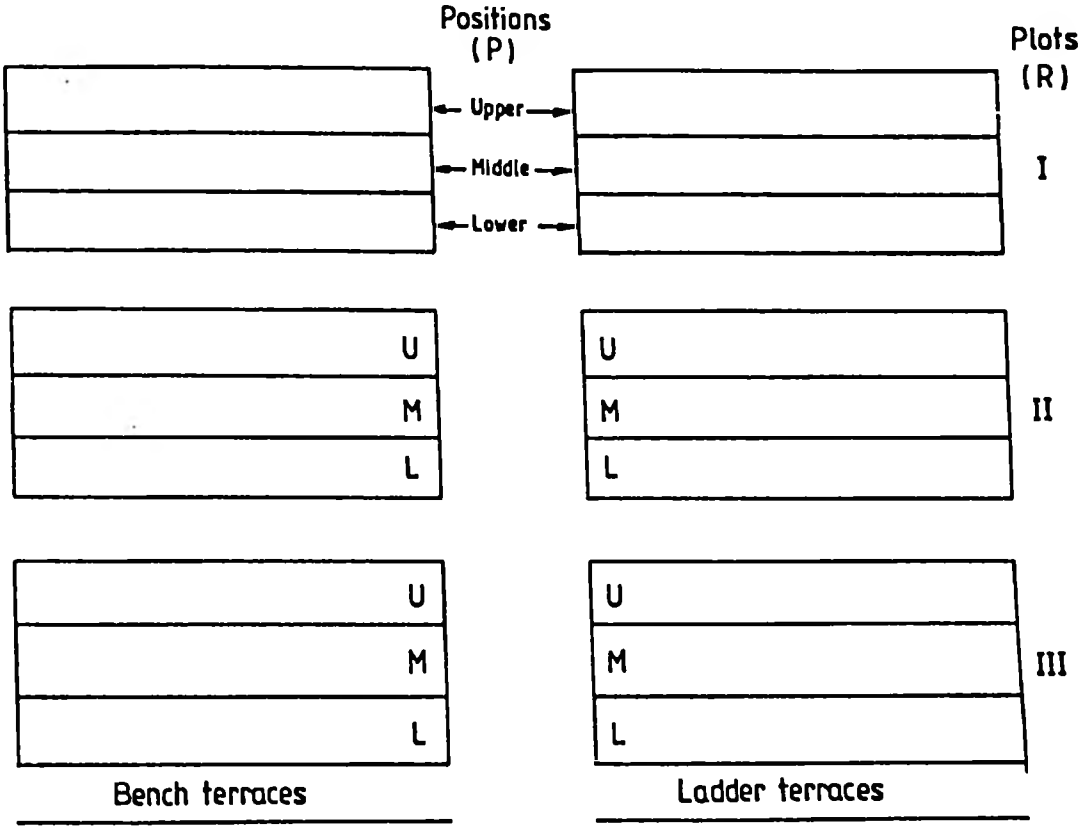

Fig. 2 . A sketch of the experimental layout showing three plots (replications) numbered I , II & III , three positions on each plot namely upper (U) , middle (M) & lower (L) & two terracing methods namely bench & ladder terraces

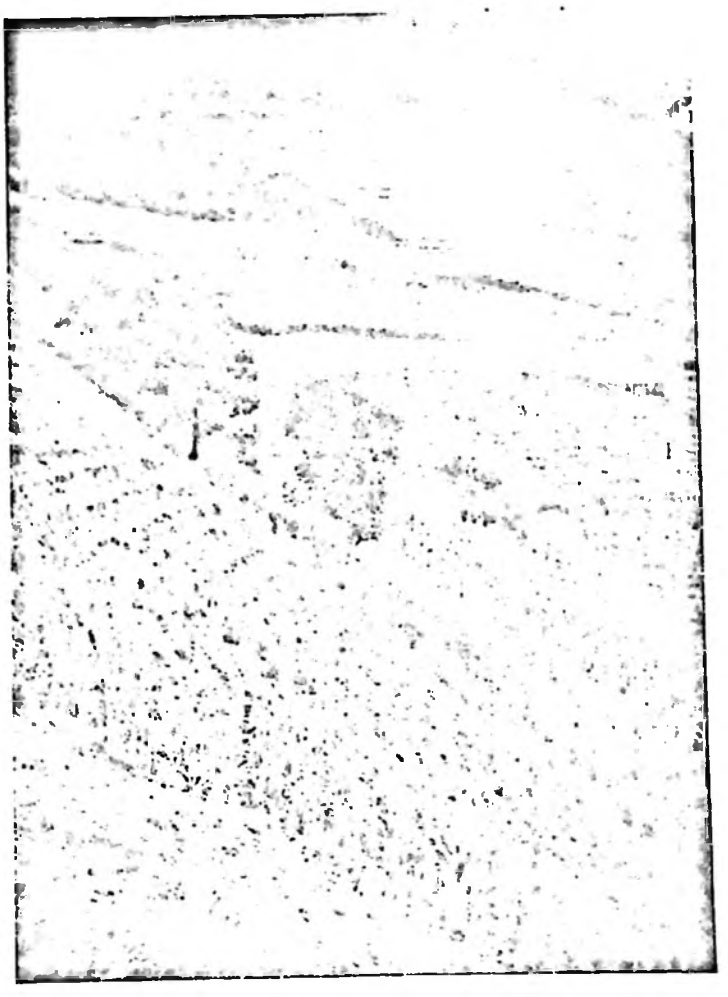

Plate 3: A photograph showing part of the field layout with bench (at left) and ladder (at right) terraces.

3.6.2 Determination of the soil physical properties

Brief accounts of the procedures used in the determinations of the selected soil physical properties are shown below:

(a) Particle-size analysis

Particle-size distribution was determined by the pipette method outlined by the National Soil Service (1987) and the textural class designation was done by following the USDA triangle (FAO 1977).

(b) Water retention characteristics

Undisturbed (core) samples were analysed to determine water retention characteristics of the soils. This was done by equilibrating the samples with water at various pressure levels (0.1, 10, 30, 50, 100, 200, 500 and 1500 kPa) using a pressure membrane (for high pressure values), plate extractor (for low pressure values) and a compressor (National Soil Service 1987).

(c) Bulk density

The bulk density was determined by the core method (Blake 1965) and expressed in g cm^{-3}.

(d) Pore-size distribution

Pore size and pore-size distribution of the soils were deduced from the moisture retention characteristic curves (Oswal 1983). The pore-size distribution was indicated by the slope of individual desorption curve of a given soil, whereby a horizontal section in the curve represented a situation where no pores were available of a size that could drain over the tension or pressure range concerned. A vertical section of the curve represented a situation where a soil contains a large number of pores of a particular size. A straight line section at intermediate slopes represented the situation where pore-size distribution resulted in uniform release of water per unit pressure change (Landon 1984; Zonn 1986).

(e) Available water capacity (AWC)

This was taken as a difference between the moisture contents in volume percentage between 10 and 1500 kPa which are referred to as the tensions at field capacity (FC) and permanent wilting points respectively (Oswal 1983; Landon 1984).

(f) Particle density

Particle density of the soils was determined by the pycnometer method (Blake 1965), and expressed in g cm^{-3}.

(g) Total porosity

The total porosity of the soils was determined by the computation involving the bulk and particle densities of the soils. The formula used was:

$$e = (1 - \frac{Db}{Dp}) \cdot 100$$

where, e = total porosity (%)

Db = bulk density (g cm^{-3}), and

Dp = particle density (g cm^{-3})

3.6.3 Determination of the soil chemical properties

Most of the soil chemical properties were determined using the standard methods with some minor modifications in some of the procedures. Soil pH (H_2O) was determined potentiometrically in a 1:2.5 soil-water suspension (National Soil Service 1987), organic carbon by the wet combustion method of Walkley and Black (Allison 1965) and total nitrogen by the semi-microkjeldahl method using a block digester as outlined by the National Soil Service (1987). Available phosphorus was determined by the Bray and Kurtz number 1 method (Olsen and Dean 1965) modified by the National Soil Service (1987) such that, a flow auto analyzer was used to read the phosphorus concentrations in mg kg^{-1} soil directly on the computer screen. Cation-exchange capacity (CEC) and exchangeable cations were determined according to the procedure given by Chapman

(1965) and modified by the National Soil Service (1987). These were determined and obtained directly from the computerized flow auto-analyzer.

3.7 Data Analysis

The data for each of the physical (except for soil moisture retention) and chemical variables were analyzed as a 2-way factorial in a randomized complete block design replicated three times. The means of the two factors - position on each plot, sampling depth and second order interaction on each of the key variables were separated by using Duncan's Multiple Range Test (Snedecor and Cochran 1989). The 2-way factorial design enabled the assessment of the changes of the soil fertility parameters (physical and chemical) down the slope (monitored through three positions - upper, middle and lower) and vertical changes of the parameters through 50 cm depth. The grand means for each variable were compared for the two treatments using a normal test to identify the superior treatment in terms of the parameters used.

The data for soil moisture retention were analyzed as a 3-way factorial design replicated three times. This design was specifically used for soil moisture retention data in order to enable incorporation of a third factor

namely soil water potential with the other two aforementioned. The means obtained were used to sketch the soil moisture characteristic curves for the soils at various positions and depths.

CHAPTER 4

RESULTS

Three dimension comparison of some soil physical and chemical properties for the two terracing methods practised at Mgeta was made. The comparison of the properties was made quantitatively between the adjacent bench and ladder terrace plots along their slope and to a depth of 50 cm. Results of the physical and chemical variables corresponding to the named dimensions are presented in Tables 1 to 8. For clarity, only data for few soil properties have been graphed. Tables 1 and 2 show the effect of the terracing methods on the physical and chemical variables based on two separate and independent factors namely, position on the plots and soil depth respectively. Tables 3 and 4 show the effect of the terracing methods on the soil water retention based on the same factors outlined above. Table 5 is a function of Table 4 which relates different kinds of soil water contents and specific water capacities to plot positions for the two terracing methods. Tables 6, 7 and 8 show the effect of the terracing methods on the soil physical and chemical variables when the two factors interact.

Table 1 : Physical and chemical variables of the soils as influenced by the terracing methods and the position within the plots and a comparison of their grand means

Variable	terracing method: Bench terraces					Ladder terraces					
Position	Upper	Middle	Lower	LSD	Grand mean	Upper	Middle	Lower	LSD	Grand mean	Grand means comparison
Physical											
Bulk density ($g\ cm^{-3}$)	1.03^{BA}	1.06^{AB}	1.12^{A}	0.03^{*}	1.07	1.06	1.02	0.99	-	1.03	*
Particle density ($g\ cm^{-3}$)	2.51	2.49	2.51	-	2.51	2.61	2.60	2.57	-	2.59	**
Total porosity (%)	58.9^{A}	57.6^{AB}	55.1^{B}	0.4^{***}	57.2	59.1	60.5	61.6	-	60.4	**
Clay content (%)	34.0^{B}	36.0^{A}	33.7^{B}	1.9^{**}	34.6	27.1	27.5	26.1	-	26.9	***
Silt content (%)	32.5	30.5	31.0	-	31.4	35.0^{B}	26.4^{AB}	26.9^{A}	1.6^{**}	26.1	**
Very coarse sand content (%)	1.7	2.0	1.8	-	1.8	2.7^{A}	1.8^{B}	2.1^{A}	0.2^{*}	2.2	*
Total sand content (%)	33.5	33.5	35.3	-	34.1	49.7	46.1	47.3	-	47.1	***
FC water content (volume %)	43.7	44.4	46.3	-	44.8	37.0	40.4	44.4	-	40.6	**
PWP water content (volume %)	19.0	17.1	19.2	-	18.6	12.8	13.0	10.9	-	12.2	***
AWC water content (volume %)	25.9	25.6	27.4	-	26.3	24.2^{B}	27.4^{AB}	33.6^{A}	7.6^{**}	28.4	*
Chemical											
Soil pH (H_2O)	5.3	5.2	5.5	-	5.3	6.2^{A}	6.1^{A}	6.0^{B}	0.1^{*}	6.1	***

Table 1 cont.

Variable	terracing method										
	Bench terraces					Ladder terraces					
Position	Upper	Middle	Lower	LSD	Grand mean	Upper	Middle	Lower	LSD	Grand mean	Grand means comparison
CEC (cmol (+) kg^{-1} of soil)	17.1^{B}	19.1^{A}	17.3^{B}	1.7^{***}	17.8	20.1	21.0	20.5	-	20.5	***
Exchangeable Ca (cmol(+) kg^{-1} of soil)	5.4^{B}	6.3^{A}	6.5^{A}	0.7^{**}	6.1	9.6^{B}	11.0^{A}	10.8^{A}	1.0^{*}	10.5	***
Exchangeable Mg (cmol(+) kg^{-1} of soil)	2.5	2.8	3.1	-	2.8	3.9^{A}	3.3^{B}	3.4^{AB}	0.6^{*}	3.5	***
Exchangeable K (cmol(+) kg^{-1} of soil)	0.17	0.16	0.16	-	0.17	0.12	0.13	0.16	-	0.14	*
Exchangeable Na (cmol(+) kg^{-1} of soil)	0.16	0.14	0.15	-	0.15	0.08	0.13	0.11	-	0.10	***
Total N (%)	0.15^{AB}	0.16^{B}	0.13^{B}	0.02^{*}	0.15	0.21^{A}	0.15^{B}	0.17^{B}	0.02^{*}	0.18	***
Organic C (%)	1.46	1.75	1.21	-	1.48	1.38^{c}	1.63^{b}	1.99^{A}	9.21^{**}	1.65	***
Available P mg/kg	0.47	0.78	0.83	-	0.69	0.36	0.46	0.67	-	0.50	NS

NB: - Means superscripted by the same letter in a given row of a given tillage method are not significantly different

* - Significant at 5% level

** - Significant at 1% level

*** - Significant at less than 1% level

4.1 Soil physical properties

4.1.1 Bulk density:

Bulk density of the soils ranged from 0.76 to 1.45 (mean 1.07) g cm^{-3} in the bench terraces and from 0.76 to 1.38 (mean 1.03) g cm^{-3}, in the ladder terraces. From Table 1 it can be observed that bulk densities for the soils of bench terraces were relatively higher than those of the ladder terraces. Moreover, bulk densities obtained in the bench terrace soils were significantly ($p < 0.05$) increasing down along the slope from 1.03, 1.06 to 1.12 g cm^{-3} in the upper, middle and lower parts of the plots respectively. There was no significant variation in bulk density along the slope with respect to the ladder terraces, though a gradual decreasing pattern can be noted down the slope. The trend was from 1.06, 1.02 to 0.99 g cm^{-3} in the respective upper, middle and lower parts of the plots.

Table 2 shows an irregular but significant variation ($p = 0.01$) in bulk density with depth in the soils of the bench terraces, but nonsignificant in the ladder terraces. From the surface soil (to 10 cm depth) of the bench terraced plots and from 20 to 30 cm depth, bulk densities were similar. Between 10 and 20 cm the bulk densities

Table 2 : Physical and chemical variables of the soils as influenced by the terracing methods and the depth of sampling

Variable	terracing method: Bench terrace						Ladder terrace					
Sampling depth (cm)	0-10	10-20	20-30	30-40	40-50	Grand mean	0-10	10-20	20-30	30-40	40-50	LSD
Physical												
Bulk density($g\ cm^{-3}$)	1.02^{BS}	0.91^{C}	1.02^{B}	1.17^{A}	1.23^{A}	$0.09^{\ddagger}$	1.04	1.03	1.07	1.01	0.98	-
Particle density ($g\ cm^{-3}$)	2.52	2.44	2.54	2.51	2.51	-	2.57	2.55	2.61	2.61	2.63	-
Total porosity (%)	59.5^{B}	62.8^{A}	59.7^{B}	53.2^{C}	50.8^{C}	$2.7^{\ddagger}$	59.4	59.8	58.8	61.3	62.8	-
Clay content (%)	35.0	35.0	34.0	35.0	33.0	-	27.0	27.0	27.0	27.0	27.0	-
Silt content (%)	30.0	31.0	31.0	32.0	32.0	-	26.0	27.0	25.0	26.0	26.0	-
Very coarse sand (%)	2.0	2.0	2.0	2.0	2.0	-	2.0	2.0	2.0	2.0	2.0	-
Total sand content (%)	34.9	34.1	34.4	32.3	34.8	-	46.9	46.7	47.8	47.0	47.1	-
FC water content(volume %)	44.5	42.3	47.3	46.9	42.8	-	41.2	37.2	40.4	42.6	41.7	-
PWP water content(volume %)	17.2^{B}	16.4^{B}	16.8^{B}	21.1^{A}	20.7^{A}	$3.4^{\ddagger\ddagger\ddagger}$	12.0	12.1	12.6	12.5	11.5	-
AWC water content (volume %)	27.3	25.9	30.5	25.8	22.0	-	29.1	25.1	27.8	30.1	29.9	-
Chemical												
Soil pH (H_2O)	5.0^{C}	5.0^{C}	5.3^{BC}	5.4^{B}	5.7^{A}	$0.3^{\ddagger\ddagger}$	6.0	6.0	6.0	6.1	6.1	-
CEC ($cmol(+)\ kg^{-1}$ of soil	19.1	17.3	17.5	17.9	17.2	-	20.7	19.7	20.3	21.3	20.9	-
Exchangeable Ca ($cmol(+)\ kg^{-1}$ of soil)	6.4	6.5	5.7	6.0	5.7	-	11.2	11.0	9.0	10.2	10.0	-
Exchangeable Mg ($cmol(+)\ kg^{-1}$ of soil)	4.0^{A}	3.8^{AB}	3.1^{B}	3.6^{AB}	3.1^{B}	$0.7^{\ddagger}$	2.8	2.9	2.7	2.8	2.8	-

Table 2 cont.

Variable	terracing method: Bench terraces					LSD	Ladder terraces					LSD
Sampling depth (cm)	0-10	10-20	20-30	30-40	40-50		0-10	10-20	20-30	30-40	40-50	
Exchangeable K (cmol(+) kg^{-1} of soil)	0.28	0.26	0.12	0.10	0.07	-	0.17	0.14	0.13	0.13	0.10	-
Exchangeable Na (cmol(+) kg^{-1} of soil)	0.19	0.18	0.13	0.13	0.13	-	0.10	0.10	0.11	0.10	0.11	-
Total N (%)	0.19^{A}	0.19^{A}	0.14^{B}	0.13^{B}	0.09^{C}	0.03^{**}	0.20^{A}	0.20^{A}	0.18^{AB}	0.16^{B}	0.16^{B}	0.03^{**}
Organic C (%)	1.96^{A}	1.99^{A}	1.38^{B}	1.22^{B}	0.83^{C}	0.26^{**}	1.99^{A}	1.84^{AB}	1.59^{BC}	1.49^{C}	1.34^{C}	0.27^{**}
Available P mg/kg	1.43^{A}	1.29^{A}	1.55^{AB}	0.17^{B}	0.01^{B}	0.009^{*}	0.87^{A}	0.74^{A}	0.04^{B}	0.67^{A}	0.17^{B}	0.005^{**}

NB: - Means in the same row of a given terrace superscripted by the same letter are not significantly different at 0.05 level of significance

* - Significant at 5% level

** - Significant at 1% level

*** - Significant at less than 1% level

decreased from 1.02 to 0.91 g cm^{-3}, while from 30 to 50 cm depth it increased from 1.02 to 1.23 g cm^{-3}. There was no significant difference when the two factors, position on the plot and soil depth interacted on the bulk density in the two terracing systems (Table 6).

4.1.2 Particle density:

Particle densities of the soils of bench terraces ranged from 2.37 to 2.73 (mean 2.51) g cm^{-3} while in ladder terraces it ranged from 2.40 to 2.91 (mean 2.59) g cm^{-3}. Particle density of the bench terrace soils were significantly lower ($p = 0.01$) than that of the adjacent ladder terraces (Table 1). From Tables 1, 2 and 6, it can be noted that there was no significant variation either along the slope, vertically down in the profile or interaction of the two parameters respectively for bench and ladder terraces.

4.1.3 Total porosity:

Total porosity values of the soils from the bench terraces were significantly lower than those of the ladder terraces ($p = 0.01$). In the bench terraces, total porosity ranged from 40.1 to 68.7 (mean 57.2) % while in ladder terraces it ranged from 47.1 to 70.5 (mean 60.4) %. Table

1 and Figure 3 show a significant decrease ($p = 0.01$) in total porosity down the slope from 58.9, 57.6 to 55.1% in the upper, middle and lower parts of bench terrace plots respectively. Ladder terraces had a non significant, but gradual increase in the soils' total porosity along the slope.

With respect to vertical changes along 50 cm soil depth (Table 2), there was only a significant variation ($p = 0.01$) in the bench terraces. In bench terraces total porosity mean values were decreasing with increase in soil depth, following the opposite trend shown by the bulk density of the same soils. In the ladder terraces there was no significant variation in total porosity with soil depth, but an opposite trend of variation to that of its bulk density values can be noted, that is an increasing total porosity down the profile.

4.1.4 Soil texture:

Generally, there were significant differences in all textural fractions between bench and ladder terrace plots ($p = 0.05$). Clay and silt contents of the soils from bench terraces were relatively higher, ranging from 27 to 40 (mean 34.6)% and 25 to 38 (mean 31.4)% respectively as compared to those of ladder terraces. In the ladder

terraces clay content ranged from 18 to 40 (mean 26.9)% and silt content from 20 to 35 (mean 26.1)%. Very coarse sand and total sand contents of bench terraces were significantly lower than those in the ladder terrace soils ($p = 0.05$ and $p = 0.01$ respectively). Very coarse sand content (%) of the bench terrace soils ranged from trace to 5 (mean 1.8) while in the ladder terrace soils it ranged from 1 to 5 (mean 2.2). Total sand content in the bench terraces ranged from 25 to 47 (mean 34.1)% and for ladder terraces from 37 to 57 (mean 47.1)%.

There was a significant increase in clay content down the slope for bench terraces ($p = 0.05$), from 34.0 to 36.0% in the upper and middle parts respectively. In the lower parts of the bench terrace plots, there was an almost similar amount of clay content to that of the upper parts. In the adjacent ladder terrace plots, clay content showed no significant variation along the slope (Figure 3). There was however a gradual increase in clay content from the upper to middle parts (27.1 to 27.5%) of the plots, followed by a slight decrease (26.1%). Silt content, there was only a significant increase down the slope ($p = 0.01$) in ladder terraces. The trend was 25.0, 26.0 to 26.9% in the upper, middle and lower parts respectively. The adjacent bench terraces did not show any significant variation along the same direction. In contrast to silt,

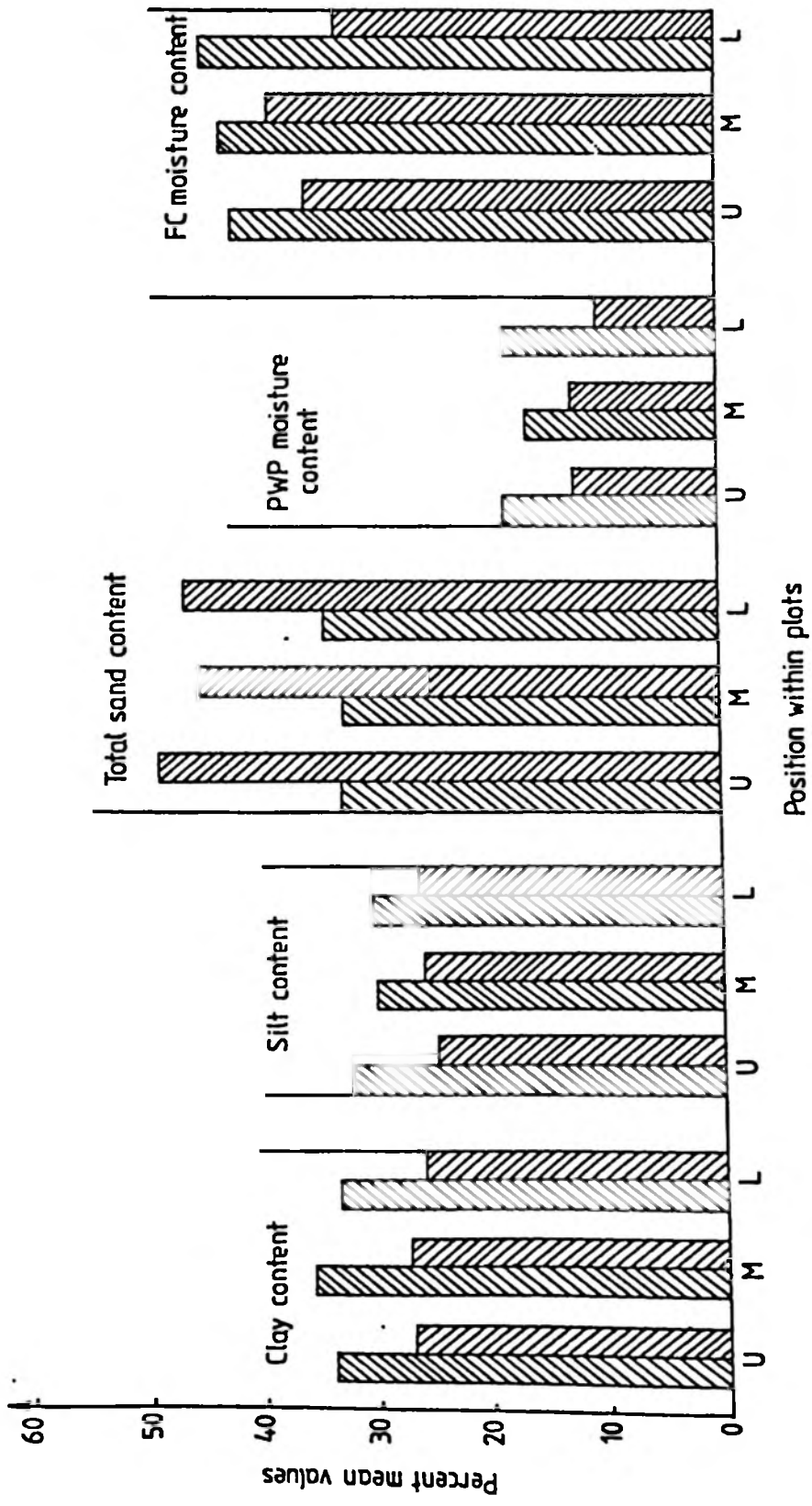

Fig. 3 . Relationship between some soil physical properties and position within the plots of bench and ladder terraces.

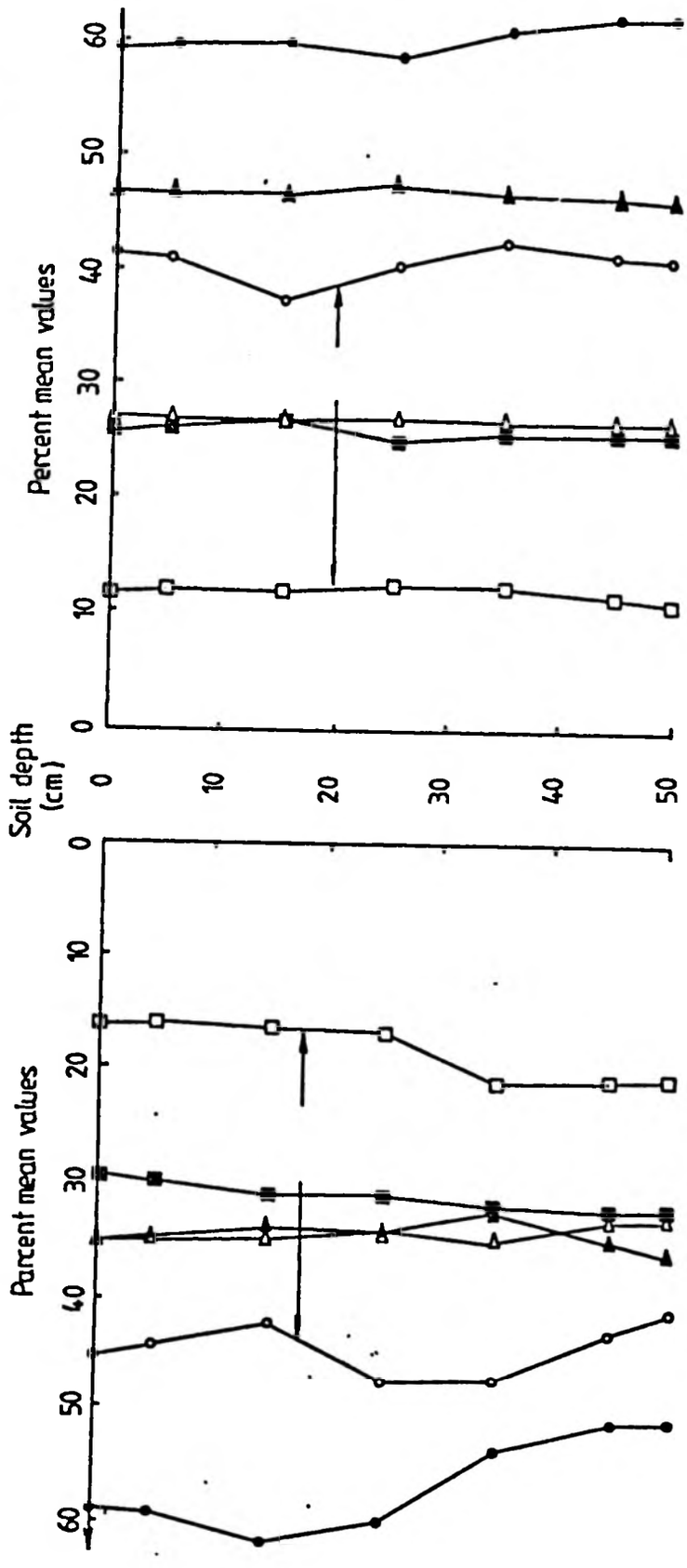

Fig. 4. Profile diagrams showing relationship between some soil physical properties and soil depth for the two terracing methods

very coarse sand content of the soils from ladder terraces decreased significantly ($p = 0.01$) down the slope, while a non significant variation was noted in the bench terrace plots along the same direction. Total sand contents for both bench and ladder terrace soils did not show any significant variation along the slope of the plots.

Generally, there was no considerable vertical variation in texture in the soils for the two terracing methods. Nevertheless, a close look at the data presented in Table 2 shows a unique phenomenon whereby the very coarse sand content for the two terracing methods are similar (2%) along the sections of 50 cm soil depth. Other textural fractions are markedly different. Further, there was no significant difference with terracing methods when considering the interaction of position on the plots and soil depth upon soil textural fractions (Table 6).

4.1.5 Soil water contents at FC, PWP and AWC

Tables 1, 4 and 5 and Figures 5(a) and (b) show the water content status for the two terracing methods. On one hand, bench terrace soils contained relatively higher moisture at both field capacity (44.8 volume % at 10 kPa matric suction) and permanent wilting point (18.6 volume

% at 1500 kPa matric suction) than the adjacent ladder terraces. The ladder terraces contained 40.6 and 12.2 volume percent at the respective matric suctions. On the other hand, soils from ladder terraces contained higher available water capacity (28.4% by volume) than soils from the bench terraces (26.2% by volume).

From the results presented in Table 1, it was observed that there was no significant variation in soil water content at field capacity as well as at permanent wilting point along the slope of both bench and ladder terrace plots. Conversely, only the ladder terrace soils had an increase in the available water capacity down along the slope. The trend of variation was 24.2, 27.4 and 33.6 volume % in the upper, middle and lower parts of the plots respectively. The available water capacity for the bench terrace soils did not vary significantly along the slope.

From Tables 2 and 3, and Figure 4 it can be noted that with the exception of the water content at permanent wilting point in the bench terraces, there was no significant variation in water contents at field capacity, permanent wilting point, water retention characteristics and available water capacity for the soils of the two terracing systems around the 50 cm depth. The permanent wilting point water content in the bench terraces showed

Table 3 : Soil water retention characteristic data for the bench and ladder terrace soils along 50 cm soil depth

Sampling depth(cm)	Soil matric suction in:		Soil water content (volume %) in :	
	kPa	(Bars)	Bench terraces	Ladder terraces
	0.1	(0.001)	61.5	55.8
	10.0	(0.100)	44.5	41.2
	30.0	(0.300)	39.4	32.7
	50.0	(0.500)	28.2	30.6
0 - 10	100.0	(1.000)	36.4	29.5
	200.0	(2.000)	34.6	28.4
	500.0	(5.000)	22.6	19.7
	1500.0	(15.000)	17.2	12.0
	0.1	(0.001)	57.6	53.5
	10.0	(0.100)	42.3	37.2
	30.0	(0.300)	36.5	30.7
	50.0	(0.500)	34.6	28.9
10 - 20	100.0	(1.000)	32.9	24.9
	200.0	(2.000)	31.7	22.6
	500.0	(5.000)	22.0	17.2
	1500.0	(15.000)	16.4	12.1
	0.1	(0.001)	60.3	55.3
	10.0	(0.100)	47.3	40.4
	30.0	(0.300)	43.5	32.6
	50.0	(0.500)	42.1	30.8
20 - 30	100.0	(1.000)	40.2	27.1
	200.0	(2.000)	38.3	26.5
	500.0	(5.000)	23.9	16.1
	1500.0	(15.000)	16.8	12.6
	0.1	(0.001)	60.4	54.1
	10.0	(0.100)	47.6	42.6
	30.0	(0.300)	42.7	36.1
	50.0	(0.500)	40.2	33.9
30 - 40	100.0	(1.000)	38.4	32.6
	200.0	(2.000)	37.2	30.8
	500.0	(5.000)	27.6	19.5
	1500.0	(15.000)	21.1	12.4
	0.1	(0.001)	55.3	57.2
	10.0	(0.100)	42.8	41.7
	30.0	(0.300)	37.5	32.6
	50.0	(0.500)	34.9	31.3
40 - 50	100.0	(1.000)	34.3	30.2
	200.0	(2.000)	32.8	28.9
	500.0	(5.000)	23.5	16.6
	1500.0	(15.000)	20.7	11.9

Table 4 : Soil water retention characteristic data for the two terracing methods through three positions on each plot

Soil matric suction in:		Soil water content(volume %) in :	
kPa	(Bars)	Bench terraces	Ladder terraces
Upper			
0.1	(0.001)	57.9	54.5)
10.0	(0.100)	43.7	37.0) Drainage
30.0	(0.300)	37.5	31.3)
50.0	(0.500)	35.5	29.1)
100.0	(1.000)	34.7	27.5)
200.0	(2.000)	33.0	26.0)AWC
500.0	(5.000)	23.5	18.8)
1500.0	(15.000)	19.0	12.8) Residual
10^{7}	10^{4}	0	0 (Unavailable)
Middle			
0.1	(0.001)	60.3	56.6)
10.0	(0.100)	44.7	40.4) Drainage
30.0	(0.300)	39.9	32.7)
50.0	(0.500)	37.8	30.6)
100.0	(1.000)	36.0	28.8) AWC
200.0	(2.000)	35.8	27.3)
500.0	(5.000)	23.7	18.9)
1500.0	(15.000)	17.1	13.0) Residual
10^{7}	10^{4}	0	0 (Unavailable)
Lower			
0.1	(0.001)	58.7	54.4)
10.0	(0.100)	46.3	44.4) Drainage
30.0	(0.300)	42.4	34.8)
50.0	(0.500)	40.8	33.6)
100.0	(1.000)	38.6	30.3) AWC
200.0	(2.000)	36.0	29.0)
500.0	(5.000)	24.6	15.7)
1500.0	(15.000)	19.2	10.9) Residual
10^{7}	10^{4}	0	0 (Unavailable)

two patterns: low contents in the 0-30 cm depth and a slight increase in the 30-50 cm depth layer (Figure 4). Interactions of the three factors, position on the plots, soil depth and different levels of applied matric suctions (Table 7) for the two terracing methods showed no significant effect on the general soil water status.

4.1.6 Soil water retention characteristics

The amount of water released per unit change in soil matric suction is referred to as the specific water capacity of a soil, and this is determined by the gradient of a given soil water retention curve (Oswal 1983). It can therefore be noted from Table 5 and Figure 5 that specific drainage water capacity was relatively higher in the ladder terraces than in bench terraces. In the case of specific water capacity in the range of the available water capacity, there was no marked difference between the two terracing methods. Specific residual water capacity for the bench terrace soils was relatively higher than that of the adjacent ladder terraces.

Specific drainage water capacity appeared to increase from upper to middle parts of bench terrace plots, then decreased in the lower parts to the same level as the upper parts (Table 5). In the ladder terraces, specific drainage

Table 5 : Soil water contents (volume %) and the respective specific water capacities (in brackets) summarized from the water retention characteristics data in Table 4 and Figures 5a and 5b for the two terracing methods

Plot's position	Terracing method					
	Bench terraces			Ladder terraces		
Kind of water content	Drainage	AWC	Residual	Drainage	AWC	Residual
Upper	14.2(7.1)	25.9(11.8)	19.0(6.8)	17.5(8.8)	24.2(11.0)	12.8(4.6)
Middle	15.6(7.8)	25.6(11.6)	17.1(6.1)	16.2(8.1)	27.4(12.5)	13.0(4.6)
Lower	12.4(6.2)	27.4(12.5)	19.2(6.9)	10.0(5.0)	33.6(15.3)	10.9(3.9)

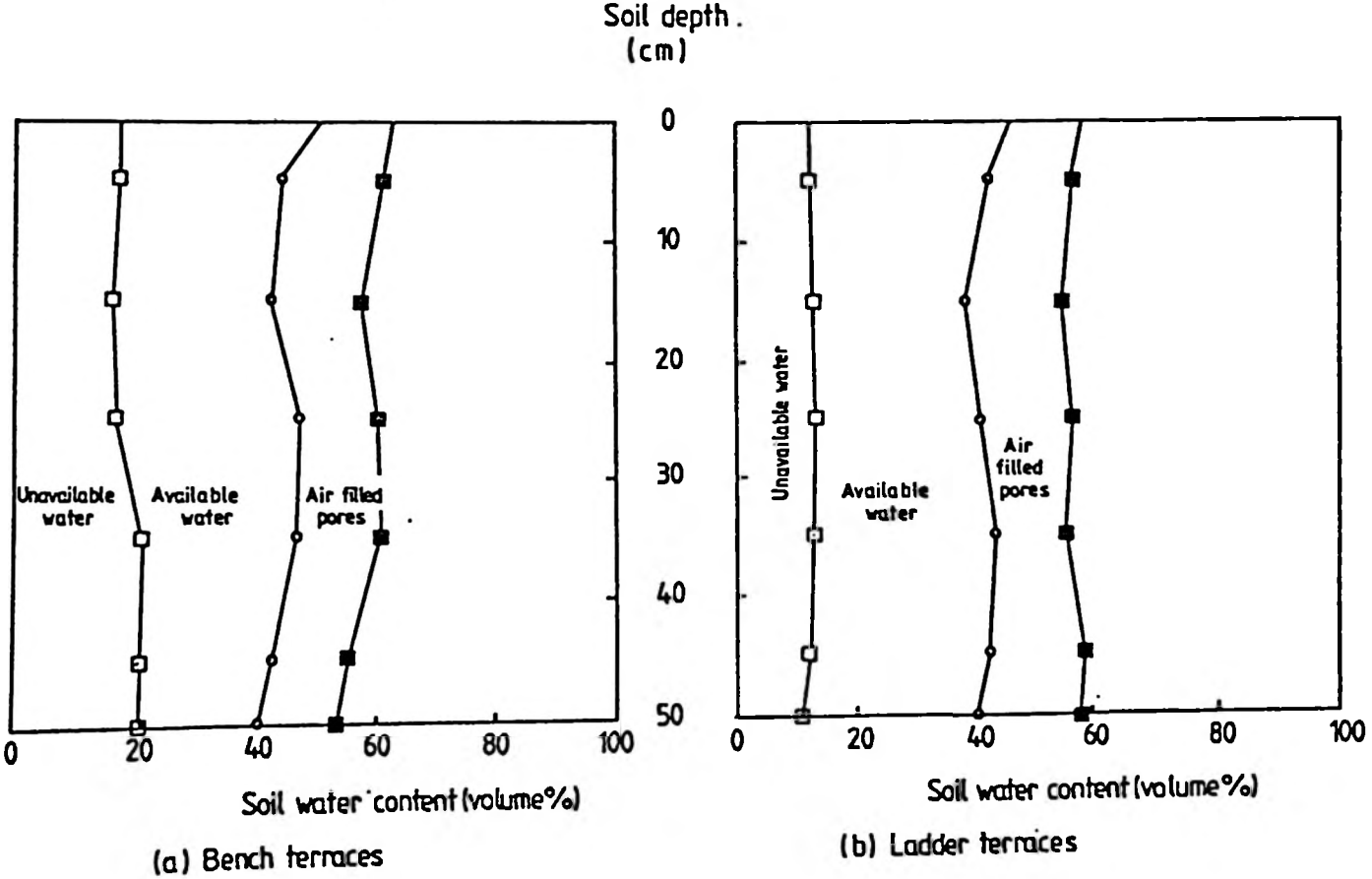

Fig. 5 . Indicative soil water volume relationships in two types of terracing methods

water capacity showed a decreasing trend from 8.8, 8.1 to 5.0% by volume per unit matric suction (Figure 6). Further, specific water capacity in the range of the available water capacity showed no considerable differences along the slope for the bench terraces, whereas in the ladder terraces, a marked increase down the slope can be noted. Specific residual water capacity of the bench terraces seems to be higher in the upper and lower parts followed by lower values in the middle parts which is contrary to the trend shown by its clay content (Table 1), but similar to its organic carbon content. Ladder terrace plots had similar values of specific residual water capacity in the upper and middle parts and least value in the lower parts corresponding to that of its clay content, water content at permanent wilting point and its particle density. Table 7 shows no significant variation in water retained by soils from the two terracing methods when the interaction of the three main factors in the present study are considered. However, from Table 7 it is apparent that bench terrace soils retained much more water at any level of matric suction compared to the adjacent ladder terraces.

Table 6: Physical variables of the soils as influenced by the terracing methods, plot position and depth of sampling

Variable Plot's position	Sampling depth (cm)	terracing methods: Bench terraces Upper	Bench terraces Middle	Bench terraces Lower	Ladder terraces Upper	Ladder terraces Middle	Ladder terraces Lower
Bulk density (g/cm^{-3})	0-10	0.96	1.02	1.09	1.06	1.01	1.02
	10-20	0.89	0.94	0.90	1.12	0.93	1.02
	20-30	1.01	0.96	1.10	1.09	1.06	1.07
	30-40	1.10	1.18	1.24	1.04	1.04	0.93
	40-50	1.20	1.20	1.29	0.99	1.06	0.88
Particle density($g\ cm^{-3}$)	0-10	2.49	2.51	2.57	2.60	2.53	2.58
	10-20	2.49	2.38	2.47	2.56	2.51	2.57
	20-30	2.54	2.49	2.60	2.74	2.56	2.55
	30-40	2.56	2.47	2.51	2.55	2.72	2.56
	40-50	2.49	2.63	2.41	2.62	2.67	2.60
Total porosity %	0-10	61.5	59.4	57.7	58.2	59.8	60.2
	10-20	64.3	60.6	63.4	56.2	62.8	60.2
	20-30	60.0	61.5	57.5	59.8	58.5	58.0
	30-40	56.9	52.2	50.5	58.9	61.6	63.6
	40-50	51.6	54.1	46.6	62.3	60.0	66.0
Clay content %	0-10	33	36	35	27	26	26
	10-20	34	37	34	24	31	25
	20-30	35	36	32	27	27	27
	30-40	34	36	36	28	28	26
	40-50	34	35	31	28	26	26
Silt content %	0-10	32	29	30	25	28	26
	10-20	32	30	31	27	25	28
	20-30	33	30	31	24	26	26
	30-40	33	31	32	24	26	29
	40-50	33	32	31	25	27	26
Very coarse sand content %	0-10	2	2	1	3	2	3
	10-20	2	2	1	2	2	2
	20-30	2	2	2	3	2	2
	30-40	2	2	2	3	1	1
	40-50	1	2	2	3	2	2
Total sand content %	0-10	35.7	34.7	34.3	47.7	45.7	47.3
	10-20	34.0	33.0	35.3	48.7	44.3	47.0
	20-30	31.7	34.7	37.0	49.3	47.3	46.7
	30-40	33.0	32.3	31.7	47.7	46.3	47.0
	40-50	33.3	33.0	38.0	46.3	46.7	48.3

NB: There is no significant difference (P = 0.05) within the terraces.

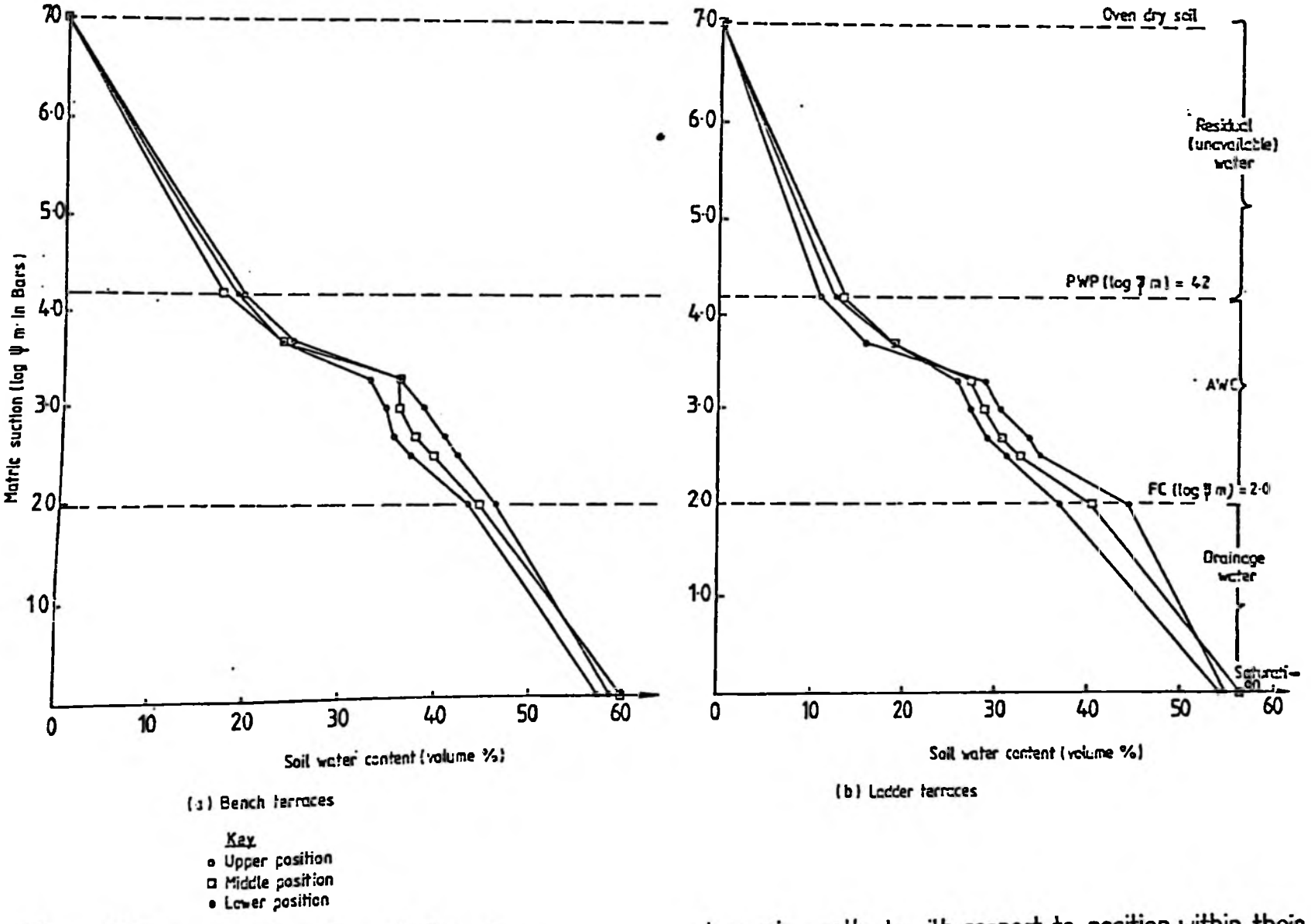

Fig.6. Water retention characteristic curves for the two terracing methods with respect to position within their respectiv plots

Table 7: Soil water of the soil as influenced by matric suction, plot position and the depth of Sampling in two terracing methods and a comparison between terraces

Matric suction		terracing methods: Bench terrace									terracing methods: Ladder terrce									
(kpa)		0.1	10	30	50	100	200	500	1500	Grand mean	0.1	10	30	50	100	200	500	1500	Grand mean	Grand means comparison
Plot position	Sampling depth (cm)																			
Upper	0-10	58.5	45.4	35.2	33.8	32.2	29.6	21.8	16.4		55.2	39.7	32.1	28.3	26.3	25.1	21.0	13.5		
	10-20	61.0	44.9	36.9	35.6	34.2	33.1	20.3	17.2		53.4	34.5	28.7	27.0	23.5	23.5	19.2	12.3		‡‡
	20-30	59.4	47.0	41.2	40.2	38.7	36.3	26.7	18.1	35.6	55.1	36.7	29.1	26.6	24.1	22.7	15.8	12.5	29.6	
	30-40	59.0	44.3	41.0	36.0	38.0	36.9	26.6	22.5		53.1	40.3	36.7	34.8	33.4	31.0	20.2	12.5		
	40-50	51.8	36.7	33.1	36.6	30.6	30.2	28.8	20.9		55.9	34.0	30.1	29.1	28.6	27.9	17.8	12.9		
Middle	0-10	60.1	40.3	37.7	36.6	34.2	34.3	23.1	16.7		58.2	40.9	34.8	33.2	32.5	31.3	22.1	12.3		
	10-20	57.6	41.9	38.0	35.6	34.2	33.3	23.9	14.1		52.9	31.8	28.2	26.7	25.3	24.0	19.3	12.9		‡
	20-30	63.7	50.8	48.6	46.8	44.8	43.3	20.8	15.6	36.9	56.3	37.8	31.7	3.00	26.3	24.3	14.8	12.6	31.0	
	30-40	63.1	48.2	39.6	38.9	34.5	37.1	28.9	21.2		53.7	41.3	30.7	27.3	25.8	24.6	20.2	13.9		
	40-50	57.3	42.4	35.8	31.0	32.3	31.2	21.7	17.9		61.7	50.4	38.0	36.0	34.0	32.1	18.1	13.3		
Lower	0-10	66.0	47.7	45.4	44.2	42.6	39.9	22.9	18.4		54.0	43.0	31.1	30.4	29.8	28.8	16.1	10.3		
	10-20	54.2	40.0	34.6	32.6	30.4	28.8	21.9	17.8		54.2	45.3	35.0	33.2	24.2	20.5	13.1	10.9		‡‡
	20-30	57.9	44.1	40.8	39.3	37.2	35.2	24.1	16.7	38.3	54.5	46.9	37.2	35.8	31.0	32.4	17.6	12.8	31.6	
	30-40	59.0	50.3	47.5	45.6	42.5	37.5	27.3	19.7		55.3	46.1	41.0	39.7	38.5	36.9	18.0	10.9		
	40-50	56.7	49.2	43.6	42.0	40.3	38.4	26.6	23.5		54.0	40.8	29.8	28.9	28.1	26.7	13.8	9.5		

NB: There is no significant difference (P = 0.05) within the terraces

‡ Grand means are significantly different at 5% level of significance

‡‡ Grand means are significantly different at 1% level of significance

4.2. Soil chemical properties

4.2.1 Soil reaction (pH)

The pH of the bench terraces was significantly lower ($p = 0.01$) than that of the ladder terraces (Table 1). In the bench terraces pH ranged from 4.0 to 6.3 (mean 5.3), while in ladder terraces the range was 5.7 to 6.3 (mean 6.1). Table 1 also shows that, there was a significant decrease in soil pH ($p = 0.01$) down along the slope of the ladder terrace plots, from 6.2, 6.1 to 6.0 in the respective upper, middle and lower parts of the plots. On the other hand, there was no significant variation in soil pH along the same direction for the bench terraces. There was also a significant increase in soil pH ($p = 0.01$) with depth in the bench terrace soils. In the ladder terraces, there was a gradual increasing trend though nonsignificant. The pH variations down the profiles of the bench terraces correspond to those of total nitrogen and organic carbon in the same terraces. Generally there was no significant variation when an interaction of the two factors - position on the plot and soil depth is considered upon soil pH for the two terracing methods (Table 8).

Table 8 : Chemical variables of the soils as influenced by the terracing methods, plot position and the depth of sampling

Variable	Sampling depth (cm)	terracing methods					
		Bench terraces			Ladder terraces		
Position on the plots		Upper	Middle	Lower	Upper	Middle	Lower
Soil pH (H_2O)	0-10	5.2	5.1	4.8	6.1	6.0	6.0
	10-20	4.9	5.0	5.2	6.2	6.0	6.0
	20-30	5.3	5.0	5.6	6.2	6.0	5.9
	30-40	5.3	5.2	5.7	6.1	6.2	6.0
	40-50	5.6	5.5	6.0	6.2	6.2	5.9
Cation exchange capacity(cmol(+) kg^{-1} soil)	0-10	17.6	20.5	19.2	19.7	21.6	20.7
	10-20	16.4	18.1	17.4	17.8	20.5	20.9
	20-30	15.5	18.8	18.2	18.6	21.4	20.8
	30-40	18.0	19.2	16.3	20.6	21.5	21.0
	40-50	17.8	18.6	15.3	23.6	19.9	19.2
Exchangeable calcium (cmol (+) kg^{-1} of soil)	0-10	5.3	6.6	7.2	10.9	11.1	11.5
	10-20	5.4	6.8	7.3	10.2	11.9	11.0
	20-30	5.1	6.0	5.9	8.4	10.4	10.8
	30-40	5.7	5.9	6.4	9.5	11.4	9.7
	40-50	5.3	6.1	5.7	8.9	10.3	10.8
Exchangeable magnesium (cmol(+) kg^{-1} of soil)	0-10	2.5	2.7	3.1	4.7	3.6	3.7
	10-20	2.4	3.2	3.0	4.1	3.9	3.4
	20-30	2.3	2.6	3.2	3.3	2.8	3.2
	30-40	2.6	2.8	3.0	4.3	3.2	3.4
	40-50	2.5	2.8	3.1	3.2	2.8	3.1
Exchangeable potassium (cmol(+) kg^{-1} soil)	0-10	0.29	0.26	0.28	0.17	0.15	0.21
	10-20	0.28	0.20	0.31	0.09	0.12	0.22
	20-30	0.11	0.15	0.10	0.09	0.14	0.17
	30-40	0.10	0.13	0.05	0.19	0.10	0.11
	40-50	0.06	0.07	0.07	0.05	0.14	0.10
Exchangeable sodium (cmol(+) kg^{-1} soil)	0-10	0.19	0.18	0.19	0.09	0.11	0.11
	10-20	0.18	0.14	0.21	0.05	0.11	0.14
	20-30	0.14	0.13	0.12	0.08	0.13	0.11
	30-40	0.12	0.14	0.12	0.12	0.11	0.09
	40-50	0.15	0.12	0.13	0.06	0.17	0.09
Total nitrogen %	0-10	0.18	0.23	0.16	0.19	0.21	0.19
	10-20	0.19	0.21	0.16	0.16	0.21	0.22
	20-30	0.14	0.15	0.12	0.16	0.18	0.19
	30-40	0.15	0.14	0.10	0.15	0.15	0.18
	40-50	0.10	0.10	0.09	0.17	0.16	0.16
Organic carbon %	0-10	1.8	2.3	1.7	1.9	2.0	2.1
	10-20	2.0	2.2	1.8	1.4	2.4	2.1
	20-30	1.3	1.8	1.1	1.1	1.6	2.0
	30-40	1.4	1.4	0.9	1.3	1.3	1.9
	40-50	0.9	1.0	0.6	1.0	1.2	1.8
Available phosphorus mg/kg	0-10	0.66	1.42	2.23	0.77	1.04	0.81
	10-20	0.14	1.52	1.21	0.42	1.00	0.80
	20-30	0.43	0.68	0.54	0.09	0.02	trace
	30-40	0.10	0.27	0.14	0.54	0.25	1.22
	40-50	trace	trace	0.02	trace	trace	0.51

NB: There is no significant difference (P = 0.05) within the terraces.

4.2.2 Cation exchange capacity (CEC)

The CEC of the bench terrace soils was significantly lower ($p = 0.01$) than that of the ladder terraces. In the bench terraces CEC ranged from 12.4 to 22.6 (mean 17.8) cmol(+) kg^{-1} soil while in ladder terraces it was from 16.1 to 34.5 (mean 20.5) cmol(+) kg^{-1} soil (Table 1). From Table 1 it is noted that bench terrace soils had an increasing pattern in CEC from upper to middle parts of the plots with values ranging from 17.1 to 19.1 cmol(+) kg^{-1} soil respectively. From middle to lower parts of the plots the CEC remained similar to the upper part (that is 17.3 cmol kg^{-1} soil). The pattern observed in CEC for the ladder terrace plots along the slope corresponds to that of a combination of clay and silt (fine soil materials) contents of the soils from the same terraces. CEC for the ladder terrace soils showed no significant variation along the slope of the plots. Variation of CEC with depth for both bench and ladder terraces was not significant. From Table 8, it can further be noted that, there was no significant variation in CEC within terracing methods when the two main factors act together.

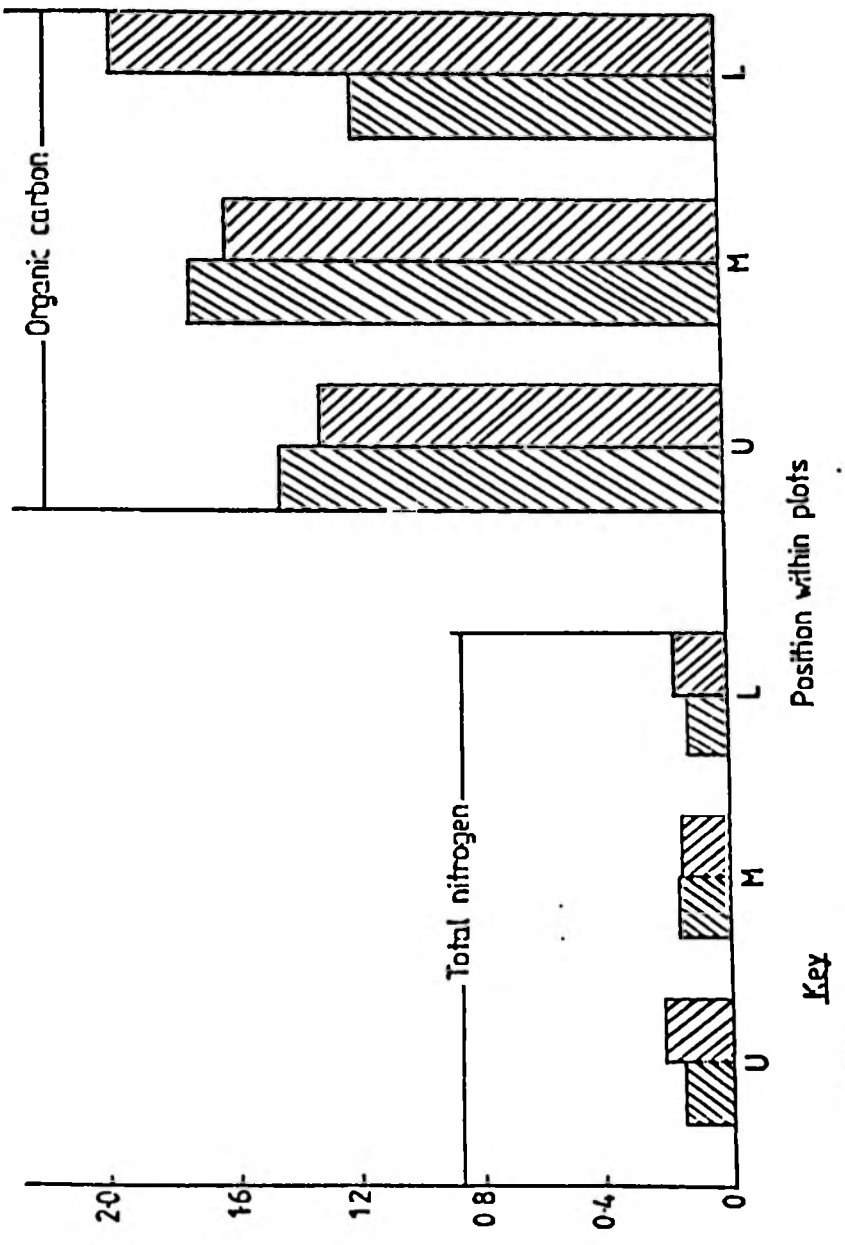

Fig.7 . Relationship between total nitrogen , organic carbon and position within plots of bench and ladder terraces.

4.2.3 Exchangeable Cations (Ca, Mg, K and Na)

Table 1 shows that there were significantly ($p = 0.01$) lower exchangeable calcium and magnesium contents in the soils of bench terraces than that of the adjacent ladder terraces. Bench terrace soils contained between 4.3 and 8.9 (mean 6.1) exchangeable calcium while there was 7.2 to 15.8 (mean 10.5) exchangeable calcium in the ladder terraces. The exchangeable magnesium in the bench terraces ranged from 1.4 to 4.7 (mean 2.8) compared to 1.1 to 6.0 (mean 3.5) in the ladder terraces. A general case was for the exchangeable potassium and sodium, in which the soils of bench terraces had slightly higher contents. Thus, the exchangeable potassium in the bench terraces ranged from 0.01 to 0.39 (mean 0.17) whereas in the ladder terraces it was from 0.04 to 0.45 (mean 0.14). The exchangeable sodium content ranged from 0.05 to 0.27 (mean 0.15) in the bench terraces and from 0.03 to 0.29 (mean 0.10) in the ladder terraces.

Table 1 also shows a significant increase ($p = 0.01$) in the exchangeable calcium content down the slope for both soils of bench and ladder terraces. The increase in both cases was sharp from upper to middle parts of the adjacent plots. The increase was from 5.4 to 6.3 and 9.6 to 11.0 soil in the bench and ladder terraces respectively.

From middle to lower parts of both bench and ladder terrace plots the exchangeable calcium contents remained statistically non significant (Table 1). In the case of exchangeable magnesium, there was only a significant variation along the slope for the ladder terrace plots and with nonsignificant variation in the bench terraces. The exchangeable magnesium for the ladder terraces decreased sharply from upper to middle parts of the plots (3.9 to 3.3), then gradually increased from middle to lower parts (3.3 to 3.4). There was no significant variation in the soils' exchangeable potassium and sodium along the slope for the two terracing methods. With the exception of exchangeable magnesium, exchangeable cations did not show significant variation with depth.

4.2.4 Total nitrogen and organic carbon

From the results presented in Table 1, it appears that there were relatively lower total nitrogen and organic carbon contents in the soils of bench terraces than in those of ladder terraces. In the bench terraces the total nitrogen (%) ranged from 0.03 to 0.25 (mean 0.15), whereas in the ladder terraces it ranged from 0.10 to 0.28 (mean 0.18). The organic carbon (%) was from 0.5 to 2.6 (mean 1.48) and 0.8 to 2.6 (mean 1.65) in the bench and ladder terrace soils respectively. A large fraction of the

organic carbon (about 40% of total) found in the ladder terrace plots was found in the lower parts (Figure 6 and Table 8). This was, however, not the case in the bench terraces.

There were significant variations ($p = 0.01$) in total nitrogen contents of soils from both bench and ladder terraces along their plot slopes (Table 1 and Figure 7). In the bench terrace plots, the soil total nitrogen showed a gradual increase from upper to middle parts (0.15 to 0.16%), followed by a sharp decrease from middle to lower parts of the plots (0.16 to 0.13%). In the ladder terrace plots, there was only sharp decrease in total nitrogen from upper to middle parts (0.21 to 0.15%), followed by a slight insignificant increase in the lower part of the plots (0.17%). In the case of organic carbon there was a clear significant ($p = 0.01$) increase down along the slope in the ladder terrace plots. The trend was 1.38, 1.63 to 1.99% organic carbon contents in the upper, middle and lower parts of ladder terrace plots, respectively.

Table 2 and Figure 8 show significant decrease ($p = 0.01$) in total nitrogen and organic carbon with depth in the soils for both bench and ladder terraces. In the bench and ladder terraces, total nitrogen started decreasing significantly from 20 cm soil depth, whereas the organic

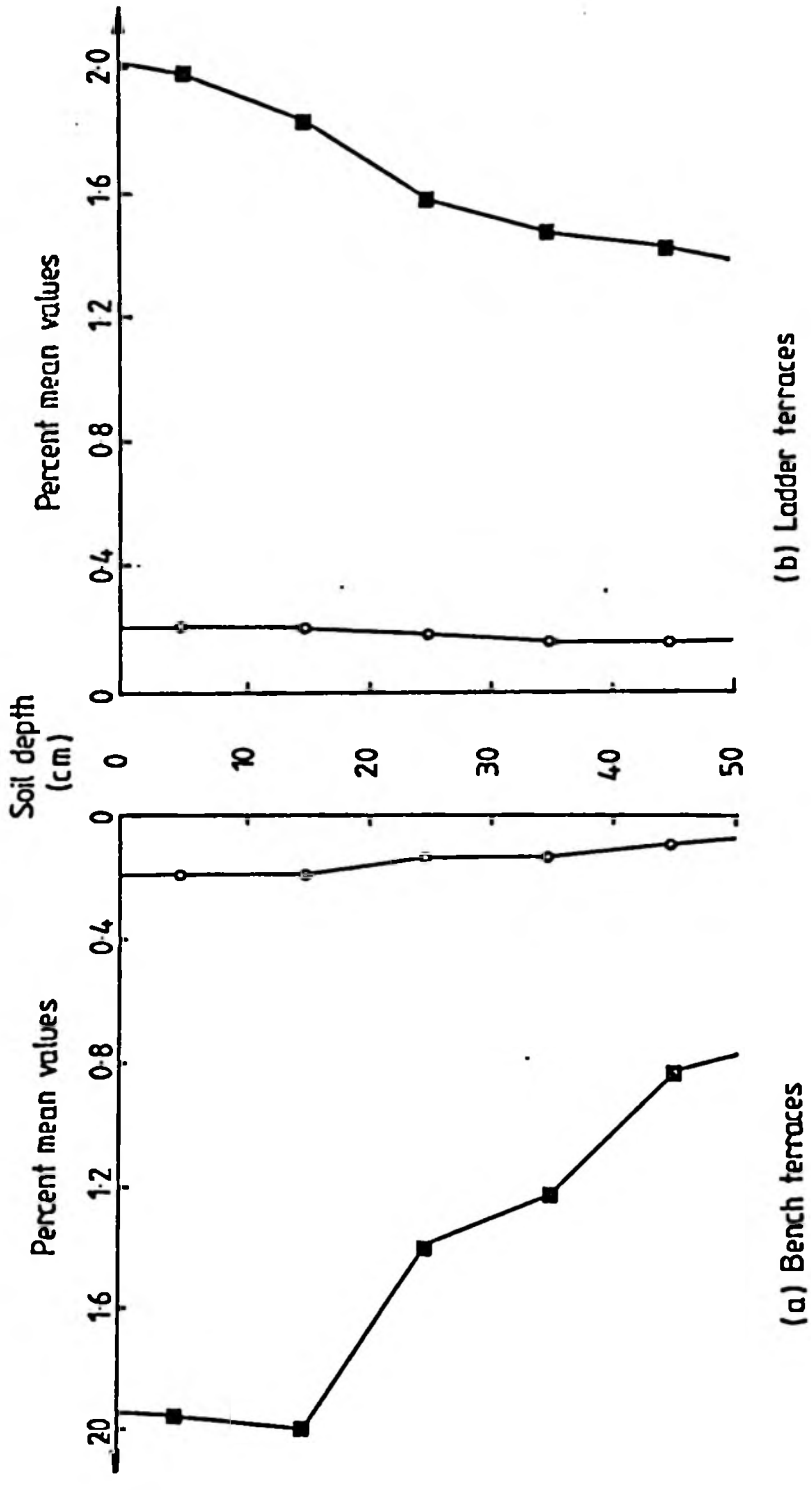

Fig. 8 . Profile diagrams showing the relationship between organic carbon , total nitrogen and soil depth for the bench and ladder terraces.

carbon content showed a similar trend in the bench terraces only. Ladder terrace soils showed a gradual decrease in soil organic carbon from the soil surface to 50 cm depth. Similar to other physical and chemical variables in the two terracing systems, total nitrogen and organic carbon contents in the soil showed no significant variation when interaction of the two main factors was considered (Table 8).

4.2.5 Available phosphorus

The available phosphorus content for bench terrace soils was relatively lower than that of the adjacent ladder terraces. In the bench terrace plots, available phosphorus ranged from trace amounts to 5.3 (mean 0.69 mg kg^{-1}) whereas the ladder terrace plots contained between trace amounts to 1.68 (mean 0.50) mg kg^{-1} values (Table 1). There was no significant variation in available phosphorus in both soils from bench and ladder terraces along their slopes. However, though nonsignificant, an increasing trend along the slope was observed for the two terracing methods (Table 1).

A similar decreasing trend with depth in available phosphorus content was noted in the two terracing systems (Table 2). From the surface to 20cm soil depth in both

adjacent plots, available phosphorus contents were statistically non significant, but from 20 to 50cm depth, there was a gradual decrease in the bench terraces while in the ladder terraces a decreasing trend was followed by an unusual increase between 30 and 40cm soil depth. Further, there was no significant variation in the available phosphorus content in the soils from the two terracing methods when the two main factors interact (Table 8).

4.3 Influence of Bench and Ladder Terraces on Crop Performance

A general relationship between the soil physical and chemical properties and crop performance observed in the field are summarized in Tale 9. From Table 9 it can be noted that the trends of the soil properties followed the pattern displayed by their corresponding crop performance.

Table 9: Influence of some soil physical and chemical properties on the observed crop performance (vegetables under beach terrace and maize, beans under ladder terrace) at Mgeta.

	Bench terraces								Ladder terraces							
Plot Position	crop performance	Soil properties[1] %C	%Si	%VCS	%vol	AWC	%O.C	%TN	Av.P(mg kg^{-1})	crop performance	soil properties[1] %C	%Si	%VCS	%vol	AWC	%O.C	%TN	Av.P(mg kg^{-1})
Upper	good	34.0	36.0	1.7	25.9	1.46	0.15	0.47		poor	27.1	25.0	2.7	24.2	1.38	0.21	0.36	
Middle	medium	36.0	30.5	2.0	25.6	1.75	0.16	0.78		medium	27.5	26.4	1.8	27.4	1.63	0.15	0.46	
Lower	good	33.7	31.0	1.8	27.4	1.21	0.13	0.83		good	26.1	26.9	2.1	33.6	1.99	0.17	0.67	

[1] C=clay: Si=silt; VCS=very coarse sand; AWC=available water capacity; O.C=organic carbon; TN=total nitrogen; Av.P=available phosphorus.

CHAPTER 5

DISCUSSION

It has been noted that interaction of the main factors, position within plots, soil depth, and matric suction (for soil moisture studies) in the present study yielded no significant effect on the chosen soil physical and chemical properties. The reason could probably be due to relatively slow and gradual occurrence of degradation processes in the soil. For instance, there was no conspicuous soil erosion by water observed in the field during presurvey of the present study, yet there was evidence of an increase down the slope of soil organic carbon and silt content in the ladder terrace plots. On the other hand, very coarse sand showed a decreasing pattern along the same direction. This suggests that the rate of transportation of fine soil particles and organic matter along the slope is very slow and gradual. The results obtained in the field were just a cumulative effect of the transpotation process. This has been exemplified by having higher total sand content in the ladder terraces compared to that of the adjacent bench terrace plots. Lack of significant levels when the main factors were considered together (Tables 7 and 8) could be due to the nature of the experimental field, such that in the bench terraces cultivation was undertaken on the subsurface soil while in

the ladder terraces only thin top soil was depleted. Practically it was impossible to obtain true statistical randomization for plots because they were already laid out systematically underneath one another in the field. Nevertheless, significant variations between the two terracing methods were ascribed to soil depths and plot positions.

5.1 Soil physical properties

5.1.1 Bulk density

Bulk density values obtained in the present study for both bench and ladder terraces were less than critical values of 1.46 and 1.63 g cm^{-3} for silts and clayey soils for many crops (Taylor et al. 1966; Landon 1984). However, critical values of bulk density at which root growth is likely to be affected need to be treated with great caution. This is because the effect of gradual increase in mechanical impedance, that is increasing bulk density, on root growth is progressive and decreases air porosity. This, in turn, restricts air supply to plant roots and facilitates the build-up of toxic products such as carbon dioxide and ethylene in the plants' root zone (deGeus 1973). For that matter, bulk density could be among the limiting factors to better crop performance in the bench terraces (Russell 1973). Further, methods used in the

construction of the two types of terraces might have led to the existing differences in the soil bulk density. In bench terraces the subsoil containing lower organic matter is exposed to the surface when the top soil is truncated and mechanically moved down the hill (Rwehumbiza and Roose 1990). In contrast, soil is mixed with crop residues and weeds when ladder terraces are made (Constantinesco 1976; Morgan 1986; Rwehumbiza and Roose 1990) which upon decomposition add organic matter to the soil and thus lower the bulk density.

Effect of the two terracing treatments on the bulk density of the soils can be noted from the trends observed along the slope as well as deep in the soil. An increasing trend in bulk density down the slope observed in the bench terrace plots (Table 1) could be caused by a decrease in organic carbon in the same direction when the terraces were constructed. On the other hand, a gradual transportation of light humic materials laterally in the same direction could have contributed to that trend. The latter is supported by the fact that organic carbon content of the soils from ladder terraces showed a similar trend to that of the bulk density. Together with humic materials, other fine soil materials (clay and silt) showed a similar increase down along the slope. This suggests that due to high mean annual rainfall of about 2000 mm (Delobel *et al.*

1988) water moving down the slope carry, on its way, some fine soil particles though no sign of water erosion was noted in the field. Moreover, a decreasing trend in bulk density observed in the ladder terraces corresponds to the findings obtained by Shenkalwa (1989). Irregular bulk density variations along the soil depth in both bench and ladder terraces might be due to differences in the nature of the soils. Bench terraces constituted subsoils with more clay and silt while ladder terraces had only few centimetres of disturbed soil moved during their construction. The soil bulk density was expected to increase with soil depth because of decreasing soil organic matter with increasing soil depth (Taylor et al., 1966; Bohn et al., 1985).

5.1.2 Particle density

Particle density values obtained from the soils of both bench and ladder terraces were slightly less than that of the common quartz mineral of 2.65 g cm^{-3}. The latter value also represents an average figure for non-ferruginous and non-humose subsoils (Blake 1965; Landon 1984). The higher values observed in the ladder terraces could be attributed to higher sand contents (Table 1) after a reduction of greater part of the soil finer materials by water. Relatively higher values of the particle density

in the ladder terraces have no direct effect on crop performance in the field, but could influence the calculations for the total porosity and judgement concerned the estimated soil aeration status and soil moisture content at field capacity (Zonn 1986). Lack of significant variation in particle density laterally along the slope and vertically deep in the profile for the bench and ladder terraces suggests that the soils could have originated from the same parent material with common chemical and mineralogical composition.

5.1.3 Total porosity

Total porosity values for bench and ladder terrace soils (Table 1) fell within a generally acceptable range of 30 to 70% suggested by Harrod (1975). According to Harrod (1975), sands with a total porosity (pore space) less than about 40% are said to be liable to restrict root growth due to excessive strength, whilst in clay soils limiting total porosities should be less than 50%.

The influence of terracing methods on the soils' total porosity was obviously noted in the two directions chosen. In bench terrace plots, total porosity decreased down the slope probably due to the decreasing pattern shown by their fine particle contents (clay and silt) as well as their

bulk density (Table 1). According to Thomson (1957), the finer the texture of a soil, the greater is its percent of total pore space. Thomson (1957) further indicated that, fine-textured soils have smaller bulk density values than do coarser - textured soils. However, an increase in clay content and total nitrogen as well as organic carbon in the middle of bench terrace plots showed no effect on their total porosity values. This could not be given an immediate possible explanation. In ladder terraces, total porosity values were generally high probably due to relatively higher total nitrogen and organic carbon together with the observed clay and silt contents (Table 1). A combination of soil organic matter and fine soil materials result into higher total porosity values (Thomson, 1957; Landon,1984). Additionally, total porosity values in ladder terraces were increasing down the slope. The increase followed a similar trend shown by clay, silt, total nitrogen and organic carbon contents in the ladder terrace soil. From the observed differences among the two terracing systems, it can be reasoned out that, methods used in the construction of bench terraces allowed only mechanical movement of soil down the slope. At the same time, when ladder terraces are constructed, small amounts of soil is moved mechanically down the slope (Figure 1(b)), but relatively larger proportion of finer soil materials including soil organic matters are gradually and continuously being transported

down the slope by water during rainy seasons. Hence, the observed variations in total porosity values along the slope in bench terrace plots could be caused by the nature of the soils after the two types of the terraces were made. The increase in total porosity down the slope in ladder terraces conforms to the results obtained by Shenkalwa (1989) on the micro contour lines on Usambara mountains. The increase was attributed to transportation by water of finer soil materials, notably humic materials along the slope. Further, there were large amounts of total sand content in the ladder terraces which could be taken as an indication of long term effects of gradual depletion of fine soil materials along the slope (Table 1).

An increase in total porosity from the surface to 20 cm soil depth could have been caused by cultivation practices which have a tendency of mixing organic matter in the soil (Thomson 1957; Adejuwon and Ekanade 1987). This has further been supported by the trend displayed by the organic carbon content vertically in the same direction (Figure 8). Continuous decrease in total porosity and bulk density with increase in soil depth under bench terraces followed the acceptable pattern suggested by Taylor et al. (1966). A slight increase in total porosity along the soil depth in ladder terraces could be attributed to the presence of greater proportion of fine soil particles

presence of greater proportion of fine soil particles together with soil organic matter. A slight difference was noted between the total porosity determined by soil saturation method (Figure 4) and the calculated one (Figure 5). This could be due to inherent errors in the procedures used in determining the total porosity. The collapse of some formed soil peds and expansion of some clay minerals (also noted in the present bench terrace soils) in the soils wetted in the cores could be another reason for the noted differences. Further, the procedures used in the determination of soil particle and bulk densities (Blake 1965; Vomocil 1965) could also attribute to the noted differences. However, the differences call for further research on the exact cause for the observed discrepancies.

5.1.4 Soil texture

While clay content of the ladder terraces fell within the acceptable range of 7 to 27% suggested to be very good for most agricultural uses (Landon 1984; Thomson and Troeh 1985), bench terraces contained slightly higher value. The soils of bench terraces were saturated with water in most times of the year (Personal observations in the field, communication with Mgeta farmers and Franco-Tanzania Horticultural Project Staff, 1990). This could be a result of simultaneous occurrence higher bulk density and lower

total nitrogen and organic carbon (organic matter) and total porosity values in the soils from bench terraces relative to those of ladder terraces (Table 1) and high mean annual rainfall (2000 mm) in the area. From the above facts, it can be suggested that occurrence of high clay and silt contents in the soils from bench terraces together with much standing water with slow or no free drainage (Figure 5) especially during rainy seasons could ultimately result could be temporary soil water logging during such seasons. The temporary water logging could affect crop performance in the bench terraces and this is supported by the higher contents of sodium and pottasium ions observed in the bench terraces than in the corresponding ladder terraces (Bohn et al. 1985; Mengel and Kirkby 1987). Higher clay and silt contents and lower very course and total sand contents both in the bench terraces than in the ladder terraces concur with the suggestion that some fine soil particles are transported by water down the slope in ladder terrace plots leaving behind the coarse particles. Trasportation of fine soil particles is supported by a decreasing trend in very coarse sand content (Figure 3) from upper to middle parts of the ladder terraces. A slight increase in very coarse sand at the lower parts of the ladder terrace plots could be due to minor mechanical movement of the particles down the slope due to gravitational force during the construction of the terraces

(Delobel et al. 1988; Rwehumbiza and Roose 1990).

Lack of significant variation for all soil fractions along the slope, down the soil profile and the interaction of the two main factors in both terraces suggest that the soils of the two types of terracing methods could have the same parent material with common chemical and mineralogical properties. This is further supported by the occurrence of similar very coarse sand content along the soil depth in both terraces (Table 2). However, due to exposure to the two different terracing systems, the current differences in physical and probably chemical properties (degradation) have occurred. Increased quantitative differences in soil physical properties like the already noted in this study can have a direct effect on the soil water status (Baver et al. 1983) and when combined with some differences in chemical properties could aggravate into some differences in soil fertility status, hence lead to clear disparity in crop performance between the terracing methods (Zonn 1986). A similarity in very coarse sand content deep in the profile, which is less easily transported by water, for both bench and ladder terraces (Table 2) can support the assumption that observed differences in soil physical properties were actually a consequence of the contrasting treatments.

5.1.5 Soil water content

Soils from bench terrace plots contained a higher water content at field capacity (-10 kPa matric potential) than those of ladder terraces. This does conform with the literature that soil dominated by fine particles can hold more water than the ones dominated with coarse particles (Hillel 1982). This implies that, since bench terraces had relatively higher clay, and silt contents compared to ladder terraces, they should be expected to have more retained water than the adjacent ladder terraces. Fine textured soils are known to possess greater surface area which contributes much energy used to retain water in the soil. Bench terrace soils for instance, contain clay particles which have the ability of expanding as they are wetted. Such a phenomenon was not observed in ladder terrace soils. The difference between the two soils could be a reason for having different water content at any given matric suction (Zonn 1986). Soil water content at permanent wilting point (PWP) in the bench terraces (-1500 kPa matric potential) was also higher than that of the ladder terraces. Greater clay content in bench terrace soils could be another possible reason due to the fact that not all water retained by soil fine particles can be drained easily below 1500 kPa matric suction (Baver *et al*.

the soil fine particles which may need over 10^5 kPa matric suction (Landon 1984). Despite the higher water contents found at field capacity and permanent wilting point in the bench terrace soils, the available water capacity (AWC) was lower than that of the ladder terraces. This, further, suggests that fine soil particles can hold much water which is not necessarily available to higher plants (Oswal 1983). If soil organic matter is combined with fine soil materials (inorganic), water held by the soils could be easily be drained out and used by higher plants which was a case in the ladder terraces (Landon 1984). This implies that, farely higher organic matter content in the ladder terraces (Table 1) might have contributed to the higher AWC. Importance of organic matter in improving soil structure and soil's water holding capacity has been discussed by many authors (Oswal 1983; Landon 1984; Zonn 1986; Shenkalwa 1989).

The effect of the two terracing methods on the soil moisture status can be noted on the differences in trends of variation of the soil water content at field capacity, permanent wilting point and available water capacity along the slope of the respective plots. From Table 1, and Figure 6, it can be suggested that an increasing available water capacity down the slope in the ladder terraces without similar trend in the adjacent bench terraces could

the soil fine particles which may need over 10^5 kPa matric suction (Landon 1984). Despite the higher water contents found at field capacity and permanent wilting point in the bench terrace soils, the available water capacity (AWC) was lower than that of the ladder terraces. This, further, suggests that fine soil particles can hold much water which is not necessarily available to higher plants (Oswal 1983). If soil organic matter is combined with fine soil materials (inorganic), water held by the soils could be easily be drained out and used by higher plants which was a case in the ladder terraces (Landon 1984). This implies that, farely higher organic matter content in the ladder terraces (Table 1) might have contributed to the higher AWC. Importance of organic matter in improving soil structure and soil's water holding capacity has been discussed by many authors (Oswal 1983; Landon 1984; Zonn 1986; Shenkalwa 1989).

The effect of the two terracing methods on the soil moisture status can be noted on the differences in trends of variation of the soil water content at field capacity, permanent wilting point and available water capacity along the slope of the respective plots. From Table 1, and Figure 6, it can be suggested that an increasing available water capacity down the slope in the ladder terraces without similar trend in the adjacent bench terraces could

be attributed to differences in clay, silt and organic matter contents in the soils (Sankaram 1980; Hillel 1982). Due to the on going cultivation practices on both bench and ladder terraces, there was no definite trend in soil water content values down the profile. A significant increase in soil water content at permanent wilting point with increase in soil depth in the bench terraces could be the consequence of increased clay and silt contents with depth. From the present study it can therefore be noted that bench terrace soils had a tendency of holding more water which was not necessarily available to plants.

5.1.6 Soil water retention characteristics

From the water characteristic curves (Table 5 and Figure 6) it can be assumed that the trends of variation shown by specific residual and drainage water capacities represent the micro- and macro- pore size distribution of the soils, respectively. Further, the specific water capacity at the available water capacity range represents distribution of medium - sized pores of the soils for the two terracing systems (Oswal 1983; Landon 1984; Burden and Seim 1989). Using the aforementioned criteria for pore-size distribution in the soil, it can be said that bench terraces had relatively less proportion of large pores compared to ladder terraces. This implies that the

capacity of the soils from bench terraces for draining excess water after the soil is saturated by rainfall at a given period of time may be lower than that for the ladder terraces. Further, a continuous rain on the bench terraces could probably lead to breakdown of any formed soil peds. The ultimate result would be destruction of soil structure, air porosity and its effect on the general soil fertility and crop performance in the field. The lower specific drainage water capacity in the bench terraces could be attributed to its soil texture because of the high contents of clay and silt as compared to the soils from the ladder terraces which are dominated by sand particles. Soils from bench terraces had lower proportion of large pores than those of ladder terraces because at field capacity the former contained more water. This leads to an argument that since at field capacity the soil structure is not disturbed, and the drainage water considered is freely drained water below 10 kPa matric suction, then there should be greater resistance for water to drain out of the soil dominated with finer particles (clay and silt) than those which are dominated by sand. This is further supported when the design of the terraces is taken into consideration [Figures 1(a) and (b)]. On the other hand, it can be noted from Table 5 that the trends shown by specific water capacities for the available water capacity and residual water capacity corresponded to the trends of

and residual water capacity corresponded to the trends of the soils' clay, silt and organic carbon and other properties derived from them such as bulk and particle densities and total porosity (Table 1) in the two terracing methods under study. This further suggests a relationship between soil texture and structure with the soil specific water capacities, hence pore-size distribution.

The higher specific drainage water capacity found in the middle of bench terrace plots than their upper or lower parts (Table 5) could be expected due to higher clay, silt and organic matter contents. Specific soil drainage water capacity of the ladder terraces showed a decreasing trend down the slope (Figure 5) probably due to lack of stable structure in the soil, an increase in clay and organic matter contents and a simultaneous decrease in total sand content along the same direction (Oswal 1983; Bohn et al. 1985).

In the case of residual water capacity for the two terracing treatments (Table 5) the soil moisture retained over 1500 kPa matric suction showed a decreasing trend towards the middle parts of the plots in the bench terraces then increased on the lower parts. In the ladder terraces it showed a decreasing trend down the slope. Such trends contradict that of soil clay content in the two terracing

methods. This is in conformity with the literature that clay particles hold water molecules very tight due to their high charges and specific surface area (Bohn et al. 1985). The organic matter at the middle part of bench terrace plots was higher, and that of the ladder terraces was increasing down the slope. A similar trend was shown by the residual water capacity along the slope as well as that of particle density in the soils from both bench and ladder terraces. It can thus be suggested that soil organic matter has much effect in releasing strongly retained soil water above 1500 kPa matric suction than clay particles.

5.2 Soil chemical properties

5.2.1 Soil reaction (pH)

The pH values obtained from the bench terrace soils were slightly lower than the range of 5.5 to 7.5 which has been suggested by Landon (1984) as good for most crops performance. In the ladder terraces the pH range obtained fell within the suggested one. For that matter therefore, pH could be taken as partly a limiting factor among several factors which cause poor crop performance in Mgeta bench terraces. Soil acidity is known to affect many plant nutrients which are essential for crop yield performance and soil fertility in general (Landon 1984; Thomson and

Troeh 1985).

Soils from bench terraces were more acidic than those of ladder terraces despite the fact that all received equal agronomic treatments in the cropping seasons. Relatively lower pH values in bench terraces (Table 1) could be caused by one or several factors. When bench terraces are constructed, the top soil rich in organic matter and major basic cations like calcium and magnesium, is mechanically moved down the slope and the subsoil which is less fertile and more acidic is left (Shenkalwa 1989). Soils with pH values less than 5.5 is reported to be weathered and that there is a possibility of obtaining some exchangeable aluminium and ferric compound ions in such soils (Drosdoff 1972; Sanchez 1976).

In the ladder terraces, loosely bound (drainage) soil water is easily drained away down the slope by gravitational force (Zonn 1986) because there are no beds *per se* like those of bench terraces which could obstruct water from flowing down the slope. This has been supported by the evident transportation of finer soil materials down the slope, namely clay, silt and organic matter.

A decrease in soil pH down the slope in the ladder terraces cannot be clearly explained due to the increase

in exchangeable calcium in the same direction. However, though statistically significant, the LSD (0.05) value of 0.1 obtained for pH values is too small to have pronounced effect in agriculture (Russell 1973). According to Russell (1973) pH readings to the nearest 0.2 of a unit is quite acceptable for most agricultural practices. Hence soil pH in ladder terraces can be considered as agronomically not variable along the slope. On the other hand, the absence of significant variation and defined pattern in soil pH along the slope for the bench terrace plots could be attributed to the nature of the soils.

Profile pH values in the bench terraces followed a similar pattern to that of clay and silt contents. This suggests that the variation is associated with the nature of the soils. For that matter, the mineralogy of the soils studied in the present research needs to be determined and related to the observed chemical properties.

5.2.2 Cation exchange capacity (CEC)

From the previous section it has been noted that the soils in the bench terraces had pH values less than 5.5 suggesting that the activity of aluminium in the soils was high (section 5.2.1) and that the soils could have some acid related infertility. Due to low pH values, aluminium

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ions could undergo hydrolysis which end up with formation of positively charged intermediate aluminium compounds, aluminium and hydrogen ions which in turn could react with the soil colloidal system and coagulate it irreversibly and consequently lowering the soil's CEC. According to Mengel and Kirkby (1987), the extent of coagulation of negatively charged colloids depends on the valency and degree of hydration of ion species concerned. Hence, the relative coagulating capacity of Na^{+}:Ca^{2+}:Al^{3+} has been reported to be in the ratio 1:20:350. This implies that, once the CEC is lowered, exchangeable calcium and magnesium are selectively replaced by aluminium and its compounds. It follows that calcium and magnesium cations can become easily taken by plants from soil solution or leached by water (Bohn et al. 1985). Ladder terraces had soils with pH values higher than 6.0, hence its CEC and exchangeable calcium and magnesium appeared relatively higher. From the observed differences between the two terracing treatments it can be noted that design of bench terraces gives chances for the soils to become more acidic and render it with a lower CEC than that for the ladder terraces.

As a rule, soils rich in clay and organic matter are known to have greater ability to adsorb more water and cations and possessing higher CEC than soils low in those variables (Mengel and Kirkby 1987). This concept supports

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As a rule, soils rich in clay and organic matter are known to have greater ability to adsorb more water and cations and possessing higher CEC than soils low in those variables (Mengel and Kirkby 1987). This concept supports

the findings obtained in the present study in which a significant variation in CEC ($p = 0.05$) noted in bench terraces (Table 1) had higher values in the middle part of the plots than upper and lower parts. In the ladder terraces too, a combination of clay, silt as well as organic matter (total nitrogen and organic carbon) contents indicated similar pattern to that of the soils' CEC along the slope. Dependence of fractions derived from clay and organic matter, and slightly from silt-sized particles has been further supported by FAO (1979) and Landon (1984).

Lack of significant variation ($p = 0.5$) in CEC with respect to soil depth could be due to the nature of the cultivated soils and methods used in their construction. Moreover, though insignificantly variable, the patterns displayed by the CEC corresponded those of clay and silt contents in the two terracing methods. Organic matter in the soils for both terracing treatments was very low, hence had relatively insignificant effect on the soils' CEC compared to clay and to lesser extent silt contents (Schnitzer and Skinner 1965; FAO 1979; Mengel and Kirkby 1987).

5.2.3 Exchangeable cations (Ca, Mg, K and Na)

Exchangeable calcium and magnesium obtained in the

soils for the two terracing systems ranged from adequate to high with respect to most crop requirements. This is in agreement with various researchers who suggested that exchangeable calcium or magnesium less than 0.2 cmol kg^{-1} soil show deficiency symptoms to most crops, while levels above 10 and 4 cmol kg^{-1} soil respectively were considered high (Mengel 1982; Landon 1984; Mengel and Kirkby 1987). Calcium:magnesium ratios of the soils for both bench and ladder terraces did not reach 5:1 in which magnesium could be less available to plants (Landon 1984). Values of exchangeable potassium and sodium fell within a range of 0.05 to 0.25 cmol kg^{-1} of soil which was also suggested to be adequate for most crops (Boyer 1972; Landon 1984). The exchangeable cations as plant nutrients were not among the possible limiting factors for crop performance at Mgeta in the present study. Nevertheless the values for the exchangeable calcium and magnesium of the bench terrace soils were lower than those in the ladder terraces. As it was noted in section 5.2.2, this could be a result of low pH and organic matter in the bench terrace soils. On the other hand, relatively higher contents of exchangeable potassium and sodium observed in bench terraces than in the adjacent ladder terrace plots could be attributed to the temporary water logging observed in the soils, which has been associated with higher clay and silt and lower organic matter contents in the former (Baver *et al*. 1983; Mengel

and Kirkiby, 1987). In the bench terraces, as it was noted in most of its physical properties, no free movement of water or fine soil materials down the slope, so even if potassium and sodium ions are dispersed in soil solution could not find a way out of the beds, rather they just remain in the soils unless they are taken up by plants.

The influence of the terracing methods on the exchangeable cations can be depicted from the variations in cation contents along the two directions selected, along the slope and vertically in the soil. As noted earlier, the method used in the construction of bench terraces led to mechanical movement of the top soil rich in organic matter and exchangeable calcium and magnesium down the slope (Adejuwon and Ekanade 1987; Shenkalwa 1989; Rwehumbiza and Roose 1990) with the consequence that the exchangeable calcium seemed to increase significantly ($p = 0.1$) down the slope. In the ladder terraces, the changes observed could be a result of a combination of mechanical movement of the soils down the slope during cultivation and the lateral transportation of inorganic and organic fine soil materials. Since most of the fine soil materials are negatively charged (Sanchez 1976; Mengel and Kirkby 1987), when they are moved down the slope by water, they carry with them adsorbed calcium and magnesium ions. Furthermore, the absence of significant variation in all

exchangeable cations deep in the soil (Table 2) and considering lack of significance for second order interaction (Table 8), is sufficient evidence to suggest minimal movement of fine soil materials, notably clay in the two directions for both bench and ladder terraces.

5.2.4 Total nitrogen and organic carbon

Generally, total nitrogen and organic carbon (organic matter) content of the soils from bench and ladder terraces, were very low in the present study. According to Metson (1961) total nitrogen content between 0.1 and 0.2% and organic carbon less than 2% are considered low for agricultural and microbiological activities whatever the sources of total nitrogen in the soil. Low organic matter content in soils can lead to some set backs in the general fertility status of such soils.

The amounts and patterns of variations in soil total nitrogen and organic carbon (Figure 7) can be taken as important factors among others which might have led to poor crop performance in Mgeta. This may be a valid reason because if, for instance, there could be enough organic matter in the bench terraces down to a depth of 50 cm the structure of the soils would have improved, increasing soil aeration, total porosity and other properties such that no

water would have temporarily been stagnating on the beds (Mengel and Kirkby 1987). Cation exchange capacity would be high and more plant nutrients would be available for better crop performance in the bench terraces (Schnitzer and Skinner 1965; Drosdoff 1972; Sanchez 1976). In the case of ladder terraces, it seems that addition of organic materials in the soil without proper management and conservation could not help because most losses of its fine soil materials appeared to be by gradual transportation by water down the slope rather than soil erosion *per se*. Hence growing of grass or small fruit trees across the slope to prevent soil from moving down the slope together with frequent additions of organic matter could probably improve crop performance in Mgeta (Lal 1979; Morgan 1986). Several authors have stressed the overwhelming importance of organic matter conservation in soils as a means for improving and maintaining soil fertility (Schnitzer and Skinner 1965; Greenland and Dart 1972; Sanchez 1976; Adejuwon and Ekanade 1987; Shenkalwa 1989).

Slightly lower quantities of total nitrogen observed in bench than in the ladder terraces could be due to relatively lower soil pH found in the former terraces. Landon (1984) commented that lower nitrogen content in the soils with low pH is mostly attributed to reduced

microbiological activities among other factors. Additionally, low total nitrogen observed in the bench terraces could be associated with the method used in the construction of the terraces whereby the top soil, normally rich in organic matter is truncated and mechanically moved down the slope (Rwehumbiza and Roose 1990). In ladder terraces, low organic matter content (total nitrogen and organic carbon) observed could be caused by transportation and depletion of fine humic compounds together with other fine soil materials which are moved by water down the slope during the rainy seasons. The evidence of transportation of such particles down the slope can be deduced from Table 1 and Figure 7. From Table 1 and Figure 7, clay, silt and organic matter content of ladder terrace soils seemed to increase down the slope while very coarse sand decrease down the same slopes. Transportation of fine soil materials down the slope move together with adsorbed plant nutrients like calcium, magnesium, potassium, nitrogen and others.

Similar patterns for total nitrogen and organic carbon variations observed in bench terrace soils could be expected because there was no depletion of organic matter by moving water as it was suggested in the ladder terraces. Further, there is a strong relationship between total nitrogen and organic carbon, in which about 99% of the

former is said to be bound in organic matter (Mengel and Kirkby 1987; Shenkalwa 1989). However, from Table 1 it can be noted that there is no straight forward pattern in the trends for total nitrogen and organic carbon, probably due to differences in the rate of mineralization or other chemical processes caused by differences in chemical properties like soil pH and C:N ratio of the organic matters in the soils (Verloo 1980). The significant increase in organic carbon content ($p = 0.01$) for ladder terrace soils down the slope support the suggestion that there is a lateral movement of fine soil materials transported by water down the slope. The organic carbon content of the bench terraces did not show any significant variation along the slope, suggesting absence of fine materials' movement in the soils. A clear decrease in total nitrogen and organic carbon with increase in soil depth was expected due to the fact that most of the organic matter is found in the top soils and it is incorporated into deeper layers (to plough layer depth of about 30 cm) by cultivation practices (Sanchez 1976; Bohn et al. 1985; Mengel and Kirkby 1987).

5.2.5 Available phosphorus

The available phosphorus for both bench and ladder terrace soils were extreme, being lower than the lowest

value of 15 mg kg^{-1} which is viewed as the minimum value at which fertilizer response is most likely (Olsen and Dean 1965; Acres 1983). Although available phosphorus was very low in the present study, such values may not necessarily be associated with any terracing system due to the fact that, even in the profile which was dug on uncultivated land (Appendix 2) showed low values too. Hence it could be attributed to other factors including inherent low phosphorus content in the parent materials (Mengel and Kirkby 1987). Further, when the soil pH is considered, it can be suggested that soils from bench and ladder terraces had commonly low available phosphorus for different reasons. In the bench terraces predominant phosphorus species could be $H_2PO_4^-$ whereas in the ladder terraces both $H_2PO_4^-$ and HPO_4^{2-} could be dominant (Bohn *et al*. 1985). Since exchangeable aluminium and ferric ions were presumed to exist in the soil solution, and organic matter content of the soils was very low, most of the phosphorus in the soil could be precipitated (fixed) as $AlPO_4$ or $FePO_4$ and consequently lead to the observed low available phosphorus in the soils. From the same reason, it would be expected to have more available phosphorus in the ladder than in the bench terraces. However, this was not the case (Table 1) probably because of the extremely low content of soil organic matter (Sanchez 1976) which has been thought to be transported together with other fine

soil materials down the slope by rain water. Additionally, the observed lower values in the cultivated land in bench and ladder terraces could be due to the fact that most farmers at Mgeta do not apply phosphorus - containing fertilizers and organic matter to their farms regardless of the crop grown (Personal communication with Mgeta farmers 1990). They just apply sulphate of ammonia fertilizers for all crops. It can generally be suggested that the observed and reported decline in crop performance in Mgeta could be aggravated by several factors. these may include inherently low phosphorus content in the soil, lack of application of phosphorus - containing fertilizers and organic matter as well as phosphorus fixation by heavy metals found in acid soils (with pH less than 5.5) particularly when organic matter content of the soils is very low (Schnitzer and Skinner 1965; Greenland and Dart 1972; Mengel and Kirkby 1987).

Despite the low amounts of phosphorus in the soils, the effect of terracing methods on the available phosphorus can be noted in Tables 1 and 2. The trend shown by the trends of variation for the available phosphorus corresponds to that of organic carbon along the slope and deep in the soil for both terracing methods. Since it is known that phosphorus mobility in the soil is very low (Mengel and Kirkby 1987; Shenkalwa 1989), and that soil

organic matter supplies 50 to 60% of the phosphate in the soil (Barrower and Kilmer 1963; Sanchez 1976; Bohn et al. 1985), it can be suggested that the factors which affect the organic matter in the soil could also affect the available phosphorus in the soil. Consequently, the addition and management of organic matters in the soils would also be beneficial to phosphorus status in the soils, provided phosphorus-containing fertilizers are added to the soils. For most soils, the recommended phosphorus containing fertilizers include water soluble, basic slags and rock phosphate (Kucey and Bole 1984; Mengel and Kirkby 1987).

5.3 Influence of Bench and Ladder Terraces on Crop Performance.

The results summarized in Table 9 concur with the suggestions provided in the preceding sections that soils under bench terraces are relatively infertile when compared to those of the ladder terraces. This has been attributed to the construction process in which most of fertile topsoil is truncated. Furthermore, the observed pattern in crop performance in the ladder terraces assumed the same trend as for the fine soil materials, which goes together with the suggestion that the latter are transported by water down the slope during rain seasons.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 Soil physical properties

The results of this study indicate that bench terrace plots had slightly higher ($p = 0.05$) bulk density, moderately higher ($p = 0.01$) silt and very high ($p < 0.01$) clay contents compared to the adjacent ladder terrace plots. Further, bench terrace soils had slightly lower AWC as well as very coarse sand content, moderately lower particle density and total porosity whereas total sand content was relatively very low when compared to those of the ladder terrace soils. The effects of higher clay and silt content and relatively low organic matter levels had negative consequences in the soil water status (low AWC) in the bench terraces.

Some effects of the treatments on the soil physical properties were noted in the present study. In bench terraces, there was a slight increase ($p = 0.05$) in bulk density; no well defined pattern in clay content; and a decreasing pattern for the soil total porosity down the slope. Other soil physical variables studied did not show

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significant variation along the slope in bench terrace plots. In the ladder terraces, there was a slight increase ($p = 0.05$) in silt content and AWC of the soils.

The methods used in construction of bench and ladder terraces contributed to the observed differences in soil physical properties. The bench terraces' topsoil, which is rich in organic matter and most mineral plant nutrients (notably Ca and Mg), is truncated and mechanically moved down the slope. This process leaves behind the subsoil which is generally less fertile. Due to high clay and silt content with little organic matter of the soils and very high mean annual rainfall at Mgeta, most of the rain water stagnates on the beds of the bench terraces and cause temporary water-logging. This happens due to the fact that water infiltration and leaching in the soil occur very slowly. In the ladder terraces movement of fine soil particles, namely clay, silt and some humic compounds of the soil organic matter are transported by rain water along the slope gradually but continuously. Long term effect of gradual transportation of fine soil materials was associated with highest total sand content found in ladder terrace soils compared to those of bench terraces. Within the profile there was generally no significant variation in the soil physical properties.

:hemical properties

Ladder terraces had quite higher ($p < 0.01$) values .l pH, CEC, exchangeable Ca and Mg and total nitrogen. .c carbon was moderately higher ($p = 0.01$) in the : compared to those of the adjacent bench terraces. terrace soils contained relatively higher ($p < 0.01$) geable sodium and slightly higher ($p = 0.05$) geable potassium compared to those of ladder es. Available phosphorus content of the soils from bench and ladder terraces did not differ icantly.

ost of the chemical variables studied in the present ch gave values well above the recommended range ted for better crop performances. The CEC for both and ladder terraces and the exchangeable calcium for terraces were relatively higher than the recommended . The exchangeable magnesium, potassium, sodium, and nitrogen for both bench and ladder terraces had within the recommended ranges as well as eable calcium for bench terrace soils. The soil : carbon for both bench and ladder terraces were .y lower than the recommended values while values of l available phosphorus for both terraces were lower e suggested value of 15 mg kg^{-1}.

than the suggested value of 15 mg kg^{-1}.

Most of the chemical variables, with significant variations along the slope in bench terraces, lacked defined patterns. This was attributed to the method used in the construction of the terraces such that, after the bench terrace beds have stabilized, no more free movement of soil or water down the slope. Organic carbon and exchangeable calcium and magnesium showed an obvious increase down the slope in the ladder terrace plots. The study showed that most of the physical (clay, silt and AWC) and soil chemical properties (organic matter, exchangeable calcium and magnesium) had an increasing pattern down the slope. This was attributed to the gradual and continuous transportation of fine soil materials along the slope by water, probably accompanied with minor mechanical movement of soil in the ladder terraces during their construction. Lower values of soil pH (less than 5.5) were observed in bench terraces. Such low values render plant nutrients unavailable. Many acid soil related properties such as lower CEC, exchangeable cations (example calcium and magnesium) and available phosphorus were noted in bench terrace soils. Low values of the available phosphorus in the bench and ladder terraces were associated with depletion of the organic matter in the soil as well as lack of application of phosphorus - containing fertilizers and

Deep in the profile, for both bench and ladder terraces there was no noticeable differences in soil chemical properties. The observed soil chemical properties (total nitrogen, organic carbon, and available phosphorus) indicated a decreasing trend with soil depth.

6.3 General conclusion and recommendation

It has been found that the two methods of terraces practised at Mgeta have some positive and negative effects on the physical and chemical properties of the soils. Bench terraces, drastically reduce soil and water movement down the slope. Most of the bench terrace plots tended to have poor soil structure because of high clay and silt content and low organic matter. The poor structure could result in reduced soil infiltration, low available water capacity, poor aeration and reduced root penetration. Application of organic matter in a form of animal, green or compost manures together with inorganic fertilizers in bench terrace plots followed by mulching would improve crop performance.

The ladder terraces are made such that when cultivating , vegetation and crop residues are spread and covered with soil cut from the face of the terraces above. Other crop residues are taken out as animal feeds. This

together with reduction of the fine soil materials lead to poor soil fertility and hence poor crop performance. To improve crop performance on ladder teraces, pastures like guatemala or elephant grass and deciduous fruit trees like peaches should be grown by single line intervals across the slope on each individual plot. In advantage, pastures could be used to feed the tamed animals like cattle and milk goats while fruits would be used as food for human beings. The plants grown on the terraces across the slope would check the movement of fine soil materials. The drainage systems should be designed so that rain water can follow predetermined channels rather than flowing down the slope through the ladder terraces.

REFERENCES

Acres, B.D. 1983. Tanzania Tabora rural integrated development project land use component. Soils of Tabora region Volume 1 main report. Land resource development centre, Tolworth Tower Subiton, Surrey KT6 7DY, England. 114 pp

Adejuwon, J.O. and O. Ekanade 1987. Edaphic component of the environmental degradation resulting from the replacement of tropical rainforest by field and tree crops in S.W. Nigeria. International Tree Crops Journal 4(4). 269-282.

Ahn, P.M. (1975). Erosion Hazard and Farming Systems in East Africa. In: Soil conservation and management in the humid tropics (Edited by Greenland,D.J. and R.Lal) NewYork, USA. Wiley Interscience Publications. p. 172-174.

Allison, L.E. (1965). Organic carbon. In: Methods of soil analysis Part 2.(Edited by C.A. Black) Madison, Wisconsin, USA. America Society of Agronomy, Inc. Publishers. p. 1367-1378.

Arakeri, H.R. and R. Donahue (1985). Principles of soil conservation and water management. New Delhi, India. Oxford and IBH Publishing company. p. 85-121.

Archer, J.R. and P.D. Smith 1972. The relation between bulk density and 'available water capacity' and air capacity of soils. Journal of Soil Science 23, 475-480.

Avery, B.W. and C.L. Bascomb (1974). Soil Survey Laboratory Methods. Soil Survey Technical Monogrph No.6 Rothamsted, Harpenden. 132pp

Bache, B.W.; C.A. Frost and R.H.E. Inkson 1981. Moisture release characteristics and porosity of twelve Scottish soil series and their variability. Journal of Soil Science 32, 505-520.

Barrows, H.L. and V.J. Kilmer (1963). Nutrient losses by erosion. In: Advances in agronomy volume 15. (Edited by A.G. Norman) New York, USA. Academic press. p.303-316.

Baver, L.D., W.H. Gardner and W.R. Gardner (1983). Soil physics. Fourth edition. NewYork, USA. Wiley eastern limited. p. 446-473.

Bear, F.E. (1965). Soils in Relation to Crop Growth. Agricultural college and experimental station rutgers - The state university new brunswick, New Jersey. Reinhold Publishing Corporation. 297pp.

Bennet,H.H. (1947) Elements of soil conservation. New York, USA. McGraw-Hill book company Inc. 358pp.

Blake, G.R. (1965). Particle density and bulk density. In: Methods of soil analysis Part 2.(Edited by C.A. Black) Madison, Wisconsin, USA. American Society of Agronomy,Inc. Publishers. p. 371-390.

Bohn, H.L., B.L. McNeal and G.A. O'connor (1985). Soil Chemistry Second edition. New York, USA. A Wiley Interscience Publication. 341pp.

Boyer, J. (1972). Soil Potassium, IN: Soils of the humid tropics.(Edited by Drosdoff, M.) Washington,D.C. USA. National Academic Science. p.102 - 135.

Breimer, T. and J.H.G. Slangen 1981. Treatment of soil samples before NO_3-N analysis. Netherlands Journal of Agriculture Science. 29(1), 15-22.

British Standard Institutions (1975). Methods of testing soils for civil engineering purposes. London, England. British standard 1377. 94p.

Burden, D.S. and H.M. Seim 1989. Correlation of spatial variable soil water retention for a surface soil. Soil Science. 148(6), 436-447.

Buringh, P. (1979). Introduction to the study of soils in tropical and subtropical regions. Third edition. Wageningen,The Netherlands. p.47-48.

Chapman, H.D. (1965). Cation exchange capacity; and total exchangeable bases. In: Methods of soil analysis Part 2. (Edited by C.A. Black) Madison, Wisconsin, USA. American Society of Agronomy, Inc. Publishers. p.891-904.

Cheong, C.L. (1971). Integrated farm water management. Irrigation and drainage paper. Rome, Italy. FAO of the united nations. 75pp.

Clark, J.S. 1966. The lime potential and percent base saturation in some representative podzolic and brunizolic soils in Canada. Soil Science Society of America Proceeding 30, 93-96.

America Proceeding 30, 93-96.

Constantinesco, I. (1976). Soil conservation for developing countries. Soil resources development and conservation service, land and water development division. Rome, Italy. FAO of the United Nations. 80pp.

de Geus, J.G. (1973). Fertilizer guide for the tropics and subtropics. Zurich, Centre d' Etude de I'Azote, 68p.

Delobel, T.C.; G.R. Evers and A.P. Maerere 1988. Position and functions of deciduous fruit trees in the farming systems at upper Mgeta, Uluguru mountains, Tanzania. Franco-Tanzania Horticulture Project, SUA (Unpublished).

Dewis, J. and F.Freitas 1970. Physical and chemical methods of soil and water analysis. Soils Bulletin number 10. Rome, Italy. FAO. 275pp.

Drosdoff, M. (1972). Soils of the humid tropics. Committee on tropical soils agricultural board.Washington, D.C. National research council, National Academy of Sciences. 587pp.

seedling root growth. 1.Mechanical impedance, aeration,and moisture availability as influenced by bulk density and moisture in a sandy loam soil. Plant and Soil 36, 613-622.

FAO (1977). Guidelines for profile description. Second edition. Rome, Italy. Publications Division of the FAO. 66p.

FAO (1978). Report on the FAO/UNEP expert consultation on methodology for assessing soil degradation. Rome, Italy. Food and Agriculture Organisation of the United Nations. 92pp.

FAO 1979. Soil survey investigations for irrigation. Soils Bulletin number 42. FAO, Rome. 188p.

FAO-UNESCO (1974). Soil map of the world. volume. I. Legend. Paris, France. Unesco-Paris. 59pp.

FAO-UNESCO (1989). Soil map of the world. Revised legend. Technical paper 20.Wageningen, The Netherlands. Published by ISRIC. 160p.

Fassbender, H.W. (1980). Problems connected with soil testing for phosphorus and potassium. In: Soil and plant testing and analysis. Rome, Italy. FAO p. 93-108.

Fauck, R.(1977). Erosion and mechanization. In: Soil conservationand management in the humid tropics. (Edited by Greenland,D.J. and R. Lal). New York, USA. A Wiley Interscience Publications p. 189-194.

Gill, W.R. and G.E. VandernBerg (1971). Soil dynamics in tillage and traction. Washington, D.C. Handbook volume 316, Agricultural research service, US Department of Agriculture. United states Government Printing Office. 511pp.

Greenland, D.J. and P.J. Dart 1972. Biological and organic aspect of plant nutrition in relation to needed research in tropical soils. Tropical soils research seminar. International Institute for Tropical Agriculture, Ibadan, Nigeria (Mimeo). 469p.

Greenwood, D.J. 1975. Measurement of soil aeration. Soil physical conditions and crop production. MAFF Technical Bulletin number 29. HMSO, London, p.261-272.

Hansen, V.E., O.W. Israelsen and G.E. Stringham (1980). Irrigation principles and practices. Fourth edition. Chichester, New York, USA. John Wiley. 417pp.

Harper, H.J. (1951). Soil Conservation. In: Advances in agronomy. (Edited by A.G. Norman) New York, USA. American Society of Agronomy volume III. Academic Press. 630pp.

Harrold, M.F. 1975. Field experience on light soils. Soil physical conditions and crop production. MAFF Technical Bulletin number 29, HMSO, London p. 22-51.

Heald, W.R. (1965). Calcium and Magnesium. In: Methods of soil analysis Part 2. (Edited by C.A.Black). Madison, Wisconsin, USA. American Society of Agronomy, Inc. Publishers. p.999-1009.

Hesse, P.R. (1971). A Text book of soil chemical analysis. London, England. John Murray. 520pp.

Hillel, D. (1982). Introduction to soil physics. New York, USA. Academic Press. p. 200-207.

Hudson, N. (1971). Soil conservation. London, England. B.T. Batsford limited. 320pp.

Jackson, M.L. (1965). Free Oxides, Hydroxides and Amorphous Aluminosilicates. In: Methods of soil analysis Part 2. (Edited by C.A. Black) Madison, Wisconsin, USA. American Society of Agronomy Inc. p. 578-603.

Jones, M.J. and A. Wild 1975. Soils of the west african savanna. Technical Communication number. 55. Commonwealth Bureau of Soils, Harpenden. 246pp.

Ketcheson, J.W. and L.R. Weber 1978. Effects of soil erosion on yield of corn. Canadian Journal of Soil Science. 58, 459-463.

Kucey, R.M.N and J.B. Bole. 1984. Availability of phosphorus from 17 rock phosphate in moderately and weakly acidic soils as determined by ^{32}P dilution and total P uptake methods. Soil Science. 138, 180-188.

Lal, R. (1979). Physical characteristics of soils of the tropics: Determination and management. In: Soil physical properties and crop production in the tropics. (Edited by R. Lal and D.J. Greenland) Chichester, England. John Wiley. p.7-36.

Lal, R. 1985. A suitability guide for different tillage systems in the tropics. Soil Tillage Research 5, 179-196.

Landon, J.R. (1984). Booker tropical manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agriculture International Limited. 450p.

McCall, W.W. 1978. The pH reference of plants. University of Hawaii, Honolulu, Jamaica. General Home-Garden Series number. 18. 78pp.

McLean, E.O. (1965). Aluminium. In: Methods of soil analsis. Part 2.(Edited by C.A. Black) Madison, Wisconsin, USA.American Society of Agronomy Inc. Publishers. p.978-997.

Mengel, K. 1982. Factors of plant nutrient availability relevant to soil testing. Plant and Soil. 64, 129-138.

Mengel, K. and E.A. Kirkby (1987). Principles of plant nutrition Bern, Switzerland. International Potash Institute. 579pp.

Mengel, K. and R. Busch 1982. The importance of the potassium buffer power on the critical potassium level in soils. Soil Science. 133(1), 27-32.

Metson, A.J. 1961. Methods of chemical analysis for soil survey samples. New Zealand Department Science Independence Research Soil Bureau Bulletin number. 12. Government Printer, Wellington, New Zealand. 243pp.

Milthorpe, F. (1960). Plant-water relationships in arid and semi-arid conditions. Paris, France. Unesco. 98p.

Money, D.C. (1968). Climate, soils and vegetation. London, England. University Tutorial Press. 459pp.

Morgan, R.P.C. (1986). Soil erosion and conservation. Revised edition. New York, USA A Hutchison Ross Publication. p. 226-243.

National Soil Service (1987). Laboratory procedures for routine soil analysis. second edition.Mlingano, Tanga Tanzania. TARO-Agricultural Research Institute. 59pp.

Negi, S.S. (1983). Soil conservation: Fundamentals of forestry volume. VII Dehra Dun, Bishen Singh, Mahendra Pal Singh, India. p. 7.

Ngatunga, F.L.N. (1981). Soil Erosion Studies at Mlingano on the Eastern Usambara Uplands. M.Sc. (Agric.) Thesis, University of Dar es Salaam, Tanzania. 145pp.

Olsen, S.R. and L.A. Dean (1965). Phosphorus. In: Methods of soil analysis Part 2. (Edited by C.A, Black). Madison, Wisconsin, USA. American Society of Agronomy Inc. Publishers. p.1035-1048.

Oswal, M.C. (1983). A textbook of soil physics. New Delhi, India. Vikas Publishing House. PVT limited. p. 34-55.

Peters, D.B. (1965). Water availability. In: Methods of soil analysis. Part 1. (Edited by C.A. Black). Madison, Wisconsin, USA. American Society of Agronomy Inc. Publishers. p.279-285.

Rapp, A., L. Berry and P.H. Temple 1972a. Studies of soil erosion and sedimentation in Tanzania. Geografiska Annaler 54, 105-379.

Rapp, A., L. Berry and P.H. Temple 1972b. Soil erosion and sedimentation in Tanzania - The project, Geografiska Annaler. 54 (3-4), 105-109.

Richards, L.A. (1965). Physical condition of water in soil. In: Methods of soil analysis Part I. (Edited by C.A. Black) Madison, Wisconsin, USA. American Society of Agronomy Inc. Publishers. p. 128-151

Rogers, H.T. 1941. Plant nutrient losses by erosion from a corn, wheat and clover rotation on dunmore silt loam. Soil Science Society of America Proceeding. 6, 263-271.

Roose, E.J. (1977). Application of the universal soil loss equation of wischmeier and smith in west Africa. In: Soil conservation and management in the humid tropics. (Edited by Greenland D.J. and R. Lal) New York, USA. Wiley Interscience Publications.p.1777-188.

Russell, E.W. (1973). Soil conditions and plant growth. Tenth edition. London, England. Longman. 991pp.

Rwehumbiza, F.B.R. and E. Roose 1990. `Land Husbandry.' A New Strategy for Soil and Water Management in the Farming Systems at Upper Mgeta, Uluguru Mountains, Morogoro. Soil Science Department, SUA, Morogoro, Tanzania. (Unpublished).5pp

Salter, P.J. and J.B. Williams 1965. The influence of texture on the moisture characteristics of soils. II. Available water capacity and moisture release characteristics. Journal of Soil Science. 16, 310-317.

Sampson, D.N. and A.E. Wright 1964. The Geology of the Uluguru mountains. Geology Survey of Tanzania Bulletin. No. 37. 77pp.

Sanchez, P. (1976). Properties and management of soils in the tropics. New York, USA. John Wiley and Sons. 618pp.

Sankaram, A. (1980). Soil science - physical properties textbook series in agricultural chemistry. Bangalore, The Bangalore Printing and Publishing Company. p. 50-121.

Scheinmann, D. 1986. Caring for the land of Usambara. A guide to preserving the environment through agriculture, agroforestry and zero grazing. SECAP, Lushoto, Tanzania. Published by GTZ, Eschborn, West German. 58pp.

Schmitzer, M. and S.I.M. Skinner 1965. Organo-metallic interactions in soils. IV carboxyl and hydroxyl groups in organic matter and metal retention. Soil Science. 99, 278-284.

Shenkalwa, E.M. (1989). Evaluation of erosion control in Tanzania by soil physical-chemical analysis. M.Sc. Thesis. State University of Ghent, Belgium. International training centre for postgraduate soil science. 75pp.

Slater, C.S. and E.A. Carleton 1938. The effect of erosion losses of soil organic matter. Soil Science Society of America Proceeding. 123-128.

Snedecor, G.W. and W.G. Cochran (1989). Statistical methods. Eighth edition, Iowa, USA. Iowa State University Press/Ames. p. 301-311.

Scheinmann, D. 1986. Caring for the land of Usambara. A guide to preserving the environment through agriculture, agroforestry and zero grazing. SECAP, Lushoto, Tanzania. Published by GTZ, Eschborn, West German. 58pp.

Schmitzer, M. and S.I.M. Skinner 1965. Organo-metallic interactions in soils. IV carboxyl and hydroxyl groups in organic matter and metal retention. Soil Science. 99, 278-284.

Shenkalwa, E.M. (1989). Evaluation of erosion control in Tanzania by soil physical-chemical analysis. M.Sc. Thesis. State University of Ghent, Belgium. International training centre for postgraduate soil science. 75pp.

Slater, C.S. and E.A. Carleton 1938. The effect of erosion losses of soil organic matter. Soil Science Society of America Proceeding. 123-128.

Snedecor, G.W. and W.G. Cochran (1989). Statistical methods. Eighth edition, Iowa, USA. Iowa State University Press/Ames. p. 301-311.

Soane, B.D., D.J. Campbel and S.M. Herkes 1972. The characterization of some Scotish arable topsoils by agricultural and engineering methods. Journal of Soil Science. 23, 93-104.

Swift, R.S. and A.M. Posner 1972. Nitrogen, phosphorus and sulphur contents of humic acid fractionated with respect to molecular weight. Journal of Soil Science. 23, 50-57.

Taylor, H.M., G.M. Roberson and J.J. Parker 1966. Soil strength - root penetration relations for medium to course textured soil materials. Soil Science. 102, 18-22.

Taylor, S.A. and G.L. Ashcroft (1972). Physical edaphology. San Fransisco, USA. W.H. Freeman and Company. 533pp.

Temple, P.H. 1972a. Soil and water conservation policies in the Uluguru mountains, Tanzania. Geografiska Annaler 54-A, 110-123.

Temple, P.H. 1972b. Measurements of runoff and soil erosion plot scale with particular reference to Tanzania. Geografiska Annaler 54 - A(3-4), 203-220.

Temple, P.H. and D.H. Murray-Rust 1972. Sheet wash measurements on erosion plots at Mfumbwe, eastern Uluguru mountains, Tanzania. Geografiska Annaler. 54 A, 3-4.

Temple, P.H. and A. Rapp (1972). Landslides in the Mgeta area, western Uluguru mountains, geomorphological effects of sudan heavy rainfall. Geografiska Annaler. 54-A, 157-193.

Thomson, L.M. (1957). Soils and soil fertility. Second edition. New York, USA, London, England. McGraw-Hill Book Company. p. 1-13.

Thomson, L.M. and F.R. Troeh (1985). Soils and soil fertility. Fourth edition.New York, USA. Tata McGran-Hill Publishing Company Limited. p. 42-78.

Unger, P.W. and T.M. McCalla (1980). Conservation tillage systems. In: Advances in agronomy. (Edited by N.C. Brady). New York, USA. Macmillan Publishing Company. p. 2-52.

Veihmeyer, F.J. and A.H. Hendrickson 1931. The moisture equivalent as a measure of the field capacity of soils. Soil Science. 32, 181-193.

Vareecken, H., Maes and P. Darius 1989. Estimating the soil moisture retention characteristics. Soil Science. 148(6), 389-403.

Verloo, M. (1988) Soil Chemistry. Ghent, Belgium. International training centre for postgraduate soil scientists. 57 p.

Vomicil, J.A. (1965) Porosity. In: Methods of soil analysis Part I. (Edited by C.A. Black) Madison, Wisconsin, USA. American Society of Agronomy Inc. Publishers. p. 299-314

Webster, R. and P.H.T. Beckett 1972. Matric suctions to which soils in south-central England drain. Journal of Agriculture Science. 78, 379-387.

Whitson, A.R. and T.J. Dunnewald 1916. Soil conservation. Wisconsin Agricultural Experimental Station Bulletin. 272. 58pp.

Williams, C.N. and K.T. Joseph (1970). Climate, soil and crop production in the humid tropics. Kuala Lumpur, Singapore. Oxford University Press. 177pp.

Wrigley, G. (1971). Tropical agriculture. London, England. Faber and Faber. 376pp.

Young A. and P. Brown (1962). The physical environment of northern Nyasaland. Zomba, Malawi. Government Printer. p.38-52.

Zonn, S.V. (1986). Tropical and subtropical soil science. Moscow, USSR. Mir Publishers. p. 47-76.

APPENDIX 1

General Information on Site and Soil

LOCATION: 1.5 km on the road to Tchenzema from Nyandira

LAND FORM: Mountain RELIEF: Mountainous

SLOPE OF SITE: 30% ELEVATION: 1800 m a.s.l.

PARENT MATERIAL: Colluvial

VEGETATION: Fern, guava, cyperus, wattle, eucalyptus, thatch grass *Themeda* spp. Cultivation of cabbage, maize and beans

SOIL: Deep, well drained with sandy clay loam texture

Higher category classification:

FAO - Chromic Cambisols

USDA - Typic Eutropept

AUTHORS: The profile was described on 21.1.1991 with the assistance of Dr. B.M. Msanya (of S.U.A.) and Mr. D.N. Kimaro (of National Soil Service, Mlingano, Tanzania)

SOIL PROFILE DESCRIPTION:

Horizon	Depth	Description
Ah	0-18cm	Dark brown (7.5YR 4/4) moist; sandy clay loam ; weak fine and medium crumby; friable when moist, sticky and plastic when wet; many fine pores; fine medium and many fine roots; clear smooth boundary.
BA	18-46cm	Strong brown (7.5YR 5/6) moist; sandy clay loam; weak fine and medium subangular blocky; firm when moist, sticky and plastic when wet; many fine pores; few medium roots; gradual smooth boundary.
Bw1	46-60cm	Strong brown (7.5YR 5/6) moist; sandy clay loam; strong fine and medium subangular blocky; firm when moist, stick and plastic when wet; many fine and few medium pores; few course roots; thin broken cutans; 2.5%

		irregular quartz; gradual smooth boundary.
Bw2	60-85cm	Strong brown (7.5YR 5/8) moist; sandy clay loam; moderate fine and medium subangular blocky; firm when moist, sticky and plastic when wet; many fine pores; few fine roots; gradual smooth boundary.
Bw3	85-104cm	Strong brown (7.5YR 5/8) moist; sandy clay loam; many fine and medium subangular blocky; slightly firm when moist, sticky and plastic when wet; many fine pores; very fine and very few roots; clear smooth boundary.
Bw4	104-120cm	Reddish yellow (5YR 6/6) moist; sandy clay loam; moderate fine and medium subangular blocky; friable when moist, sticky and plastic when wet; many fine pores; very fine and very few roots.

APPENDIX 2

The analytical laboratory results for the profile described at Nyandira

Horizon	Depth (cm)	Particle size analysis[1] Cl.	Si.	VFS	FS	MS	CS	VCS %	pH (H_2O)	Organic carbon	Total N%	C/N	available Bray 1 P (ug/kg)	CEC (cmol (+)kg^{-1} soil)	Exchangeable cations (cmol(+) kg^{-1} soil) Ca	Mg	K	Na	Base saturation (%)
Ah	0-18	32	29	6	11	8	12	2	6.1	3.7	0.24	15	4.0	18.6	11.0	3.6	0.17	0.17	80.3
BA	18-46	33	30	6	10	9	10	2	5.9	1.4	0.13	11	2.0	19.8	10.7	4.9	0.25	0.12	80.7
Bw1	46-60	35	31	5	7	10	10	2	6.0	0.9	0.07	13	2.0	17.3	10.7	3.4	0.06	0.14	82.7
Bw2	60-85	34	29	9	6	9	11	2	5.7	0.6	0.05	12	2.0	16.0	9.8	3.2	0.10	0.18	83.0
Bw3	85-104	35	31	6	5	11	10	2	5.8	0.3	-	-	-	17.5	10.2	3.5	0.09	0.09	79.3
BW4	104-120	33	30	6	9	12	8	2	5.7	0.2	-	-	-	15.8	9.5	2.9	0.04	0.15	79.7

24/11/96

[1] CL = Clay; Si = Silt; VFS = very fine sand; FS = fine sand; MS = medium sand; CS = coarse sand; VSC = very coarse sand.

Appendix 3 : A summary showing the classification of the soils from Nyandira

Diagnostic epipedon	Diagnostic sub-surface horizon	Other diagnostic features	Soil name	
			USDA Soil Taxonomy	FAO-UNESCO
Ochric A	Cambic B	- High organic matter content particularly in the surface horizons (up to 46 cm depth)	order:Inceptisol suborder:Tropept Great group: Untropept	level I:Cambisol
		- High base saturation throughout	subgroup:Typic Eutropept	level 2:Chromic Cambisol
		- Iso-mesic (8-15°C mean annual) soil temperature regime		
		- Strong brown to red (7.5 YR and chroma of more than 4 or 9 hue redder than 7.5 YR) soil colour		