LONG TERM EFFECT OF FIELD MANAGEMENT ON SOIL QUALITY IN ULTISOL

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Long Term Effect Of Field Management on Soil Quality in Ultisol"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Long term effect of field management on soil quality in Ultisol "** is a record of research work done independently by **Miss. Nithya A. M.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ABBREVIATIONS

B	Boron
BD	Bulk density
Ca	Calcium
Cu	Copper
EC	Electrical conductivity
Fe	Iron
g	Gram
ha	Hectare
K	Potassium
kg	Kilogram
m	Metre
Mg	Magnesium
Mg	Mega gram
N	Nitrogen
Nos.	Numbers
OC	Organic carbon
P	Phosphorous
pH	Hydrogen ion concentration
%	Percentage
S	Sulphur
STCR	Soil Test Crop Response Correlation
Std.	Standard
Sio_2/R_2O_3	Silica Sesquioxide ratio
t	Tonne
Zn	Zinc

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INTRODUCTION

Introduction

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate. Management that enhances soil quality will benefit cropland, rangeland, and woodland productivity.

Enhanced soil quality can help to reduce the onsite and offsite costs of soil erosion, improve water and nutrient use efficiencies, and ensure that the resource is sustained for future use. It also benefits water quality, air quality, and wildlife habitat.
Soil quality is evaluated separately for each individual soil using soil quality indicators that reflect changes in the capacity of the soil to function. Useful indicators are those that are sensitive to change, and change in response to management. The type and number of indicators used depends on the scale of the evaluation (i.e., field, farm, watershed, or region) and the soil functions of interest. For example, infiltration rate and aggregate stability help indicate the capacity of the soil to intake water and resist runoff and erosion. Changes in soil organic matter, including active organic carbon or particulate soil organic matter, may indicate changes in productivity. Increased bulk density may reflect limits to root growth, seedling emergence, and water infiltration. Measurements of indicators can be made with simple to somewhat complex field tests, or sophisticated laboratory analyses. To evaluate soil quality, indicators can be assessed at one point in time or monitored over time to establish trends.

An assessment provides information about the current functional status or quality of the soil. The assessment must start with an understanding of the standard, baseline value, or reference value to be used for comparison. Assessments can be made to help identify areas where problems occur, to identify areas of special interest, or to compare fields under different management systems. Land managers can use this information, along with data from soil surveys, fertility tests, and otherresource inventory and monitoring data, to make management decisions. Monitoring of soil quality indicators over time identifies changes or trends in the functional status or quality of the soil. Monitoring can be used to determine the success of management practices or the need for additional management changes or adjustments.

The various chemical, physical, and biological properties of a soil interact in complex ways that determine its potential fillness or capacity to produce healthy and nutritious food. The integration of these properties and the resulting level of productivity is referred to as "soil quality''. Soil quality can be defined as an inherent attribute of a soil that is inferred from its specific characteristics and observations (e.g., compactabilily, erodibilily, antifertility). The term also refers to the soil's structural integrity which imparts resistance to erosion, and to the loss of plant nutrients and soil organic matter. Soil quality is often adversely affected by soil degradative processes such as soil erosion, salinization, and desertification. Indeed, soil degradation can be defined as the time rate of change in soil quality.

There is a growing consensus that the concept of soil quality should not be limited to soil productivity, but should be extended to include the attributes of environmental quality, human and animal health, and food safety and quality. In attempting to characterize soil quality, chemical and physical properties have received much greater emphasis than biological properties because their effects are easier to measure, predict and quantify. In fact, our knowledge of how soil microorganisms affect food quality, environmental quality and human and animal health is rather limited. Future research should seek to identify and quantify reliable and meaningful biological/ecological indicators of soil quality, including total species diversity or genetic diversity of beneficial soil microorganisms. We need to know how these indicators are.affected by management inputs and how they relate to the sustainability of agricultural systems and hence the present study was proposed with the following objective :

To evaluate the soil quality under different long term field management conditions in an Ultisol (Vellanikkara series) based on physical, chemical and biological indicators.

REVIEW OF LITERATURE

2. Review of literature

2.1 Concept of soil quality and research

The concept of soil quality emerged in the literature in the early 1990s (Doran and Safely, 1997; Wienhold *et al.*, 2004) and the first official application of the term was approved by the Soil Science Society of America, Ad Hoc Committee on Soil Quality (S-581) and discussed by Karlen *et al.*, 1997. Soil quality has been defined as ''the capacity of a reference soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation'' (Doran *et al.*, 1996). The concepts of soil quality and health imply an assessment of how well soil performs the following multiple functions:

- a medium for plant growth
- a regulator of water flow in the environment
- an environmental filter
- maintenance of animal and human health
- a part of global storage and cycling of nutrients

The goal of soil quality research is to learn to manage soil for long term productivity and environmental integrity. Soil scientists have extensively examined characteristics such as organic matter, erosion rates, and nutrient availability. Focusing on soil quality has added a focus on the dynamic and biological character of soil. This means assessing soil processes such as nutrient and water cycling for clues about short- and long-term soil function (Lal and Stewart, 1993).

Studying soil quality is about site-specific land management decision making, rather than general land use assessment. The result of soil quality research is not a map of optimal land uses and a prescription for optimal land management. Instead, the result of soil quality research should be many maps of soil conditions over time, an understanding of the processes that tie management to soil performance so that managers can make better site-specific decisions, and more direct linkages between the work of farmers and researchers (Murage, 2012).

Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world. The basic assessment of soil health and soil quality is necessary to evaluate the degradation status and changing trends following different land use and small holder management interventions (Lal and Stewart,. 1995). In Asia, adverse effects on soil health and soil quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes (Hedlund *et al.*, 2003).

The concept of soil quality has consistently evolved with an increase in the understanding of soils and soil quality attributes (Karlen and Stott, 1994). Assessment of soil quality is a major challenge because it is highly dependent on management of soil through resources available in a given agroecosystem and the agroclimatic conditions (Karlen *et al.,* 2003).

2.2 Indicators of soil quality

Soil quality cannot be measured directly, but soil properties that are sensitive to changes in management can be used as indicators (Andrews, 2004). Soil quality indicators are needed that help small holder farmers understand the chain of cause and effect that links farm decisions to ultimate productivity and health of plants and animals. The soil quality approach is better applied when specific goals are defined for a desired outcome from a set of decisions.

Therefore we can think of soil quality as an evaluation process which consists of a series of actions:-

Selection of soil health indicators
Determination of a minimum data set (MDS)
Development of an interpretation scheme of indices
On-farm assessment and validation

An important debate in the literature is the selection of soil parameters as indicators of soil health. Many soil parameters may be used as indicators of terrestrial health, but would be very costly. The challenge is to find the minimum combination of parameters that will reveal a comprehensive view of the soil's condition.

Common approaches used for assessing the soil quality are either qualitative or quantitative. Qualitative indicators are often sensory descriptors like appearance, smell, feel and taste recorded through direct observations usually made by the growers (Garlynd *et al.*, 2011; Dang, 2007). Other observations include soil colour, yield response, frequency of ploughing or hoeing, and visual documentation of plant growth, selected weed species, and earthworm casts. The use of indigenous local knowledge and experience of growers provide a simple approach to characterize the status of and to diagnose any change in soil quality (Roming *et al.*, 1995; Barrios *et al.*, 2006).

Quantitative assessments of soil quality involve more sophisticated analytical approaches (Harris and Bezdicek, 1994). Generally soil quality is assessed by the combination of the physical, chemical and biological properties acting as indicators (He *et al.*, 2003), and a large number of different physical, chemical and biological properties of soil are being employed as quantitative indicators to define soil quality (Roming *et al.*, 1995).

Much work has been done to identify indicators of soil quality. More work is needed to understand how these indicators link to management practices and to soil performance, so they can be used to improve the quality of a soil. The first rule in interpreting the measurements of soil quality is to recognize the complexity of the soil system. This means that no single characteristic of soil tells it's story. Understanding the quality of soil requires several kinds of observations, at several places, at several points in time; which particular observations, places and time are relevant depend on the type of soil. The second rule in interpreting soil observations is to recognize the scale of measurement, the scale of the process related to that soil characteristic, and the scale at which solutions should be attempted. For example, a regional monitoring program needs to track long-term trends in overall soil function, while a farmer needs guidance for this season's production decisions (Weinhold, 2004).

A number of soil biological properties respond to changes in agricultural practices, showing potential use as indicators of soil quality. Other biological indicators include organic matter content; soil macrofauna like earthworms, springtails, collembulas and nematodes and the overall litter decomposition ability of living organisms (Pfiffner and Mader, 2007; Wardle *et al.*, 2011). Among biological parameters, soil microorganisms and their functions (i.e. enzyme activities such as FDA, phosphatase, amidohydrolase, nitrogen mineralization, nitrification, etc.) are also widely recognized as integral components of soil quality because of their crucial involvement in ecosystem functioning and their capability to respond quickly to environmental changes (Aseri and Tarafdar, 2006; Sharma *et al.*, 2005).

In comparison to the rapid shifts in biochemical and biological properties that occur after soil disturbance (Le Roux *et al.*, 2008), changes in physical properties may occur relatively less quickly.

Among the biological properties, soil microorganisms are very sensitive to external perturbations and can act as sensors for monitoring soil response, and more generally soil quality. Soil microbial biomass, soil enzymes and basal soil respiration are among the most important biological parameters and have proven to be powerful tools in monitoring soil quality (Karlen *et al.*, 2006; Nogueira *et al.*, 2006), although some authors have reported that soils experiencing different treatments can have similar microbial biomass whereas their functioning can markedly differ (Patra *et al.*, 2005).

2.3 Minimum data set: concept and application

A minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as soil texture, organic matter, pH, nutrient status, bulk density, electrical conductivity and rooting depth (Larson and Pierce, 1994). Collecting a minimum data set helps to identify locally relevant soil indicators and to evaluate the link between selected indicators and significant soil and plant properties (Arshad and Martin, 2002). It is a minimum set of indicators required to obtain a comprehensive understanding of the soil attributes evaluated.

More importantly, they serve as a useful tool for screening the condition, quality, and health of soil (Doran *et al.*, 2006). For smallholder farmers, these tools need to be simple measures of soil health and soil quality such as consistency, color and workability. They provide basic information needed to arrive at management decisions (Barrios *et al.*, 2006b). In the case of researchers, there is need to conduct sufficiently detailed tests while controlling for variation in order to develop meaningful assessments of soil status, often expressed as an index of soil quality (Kang *et al.*, 2005).

2.4 Soil quality index (SQI)

To determine a soil quality index, four main steps were followed: (i) define the goal, (ii) select a minimum data set (MDS) of indicators that best represent soil function, (iii) score the MDS indicators based on their performance of soil function and (iv) integrate the indicator scores into a comparative index of soil quality. In general, soil organic carbon (or organic matter) is considered to be the universal indicator of soil quality. However, the ultimate outcome of good soil quality is yield or economic produce because it serves as a plant bioassay of the interacting soil characteristics.

To select a representative minimum data set (MDS), only those soil properties that showed significant treatment differences were selected. Significant variables were chosen for the next step in MDS formation through principle component analysis (PCA) (Shukla and Ebinger, 2004).

Principal components (PC) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the no observation in p-dimensional space, subject to being orthogonal to one another. The principal components receiving high eight values and variables with high factor loading were assumed to be variables that best represented system attributes. Therefore, only the PCs with eighteen values and those that explained at least 5% of the variation in the data were examined. Within each PC, only highly weighted factors were retained for MDS. Highly weighted factor loadings were defined as having absolute values within 10% of the highest factor loading. When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and therefore eliminated from the MDS. Well-correlated variables were considered redundant and only one was considered for the MDS. The rest were eliminated from the data set. If the highly weighted variables were not correlated, each was considered important and was retained in the MDS. As a check of how well the MDS represented the management system goals, multiple regression was performed using the indicators retained in the MDS as independent variables and the end point measures like SYI, average yield of castor and average yield of sorghum as dependent variables. If any variable within the MDS did not contribute to the coefficient of determinant of multiple regressions of the variables, it was also dropped from the MDS. After determining the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method (Andrews et *al.*, 2002).

Indicators were arranged in order depending on whether a higher value was considered ''good'' or ''bad'' in terms of soil function. For 'more is better' indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. In the present study, as all the indicators that were retained in the minimum data set were considered good when in increasing order, they were scored, as ''more is better''. Once transformed, the MDS variables for each observation were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eighteen vectors >1, provided the weighted factor for variables chosen under a given PC. We then summed up the weighted MDS variables scores for each observation using the following equation:

SQI= $\sum^{n}{}_{i=1}$Wi Si, where S is the score for the subscripted variable and Wi is the weighing factor derived from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. Further, the percent contribution of each final key indicator was also calculated. The SQI values so obtained were tested for their level of significance at P = 0.05.

One or two indicators can sufficiently represent each soil function; however, indicators may be related to more than one soil function. The studies of Weil *et al.,* 1996 suggest that soil quality can be used to characterize land use/soil management and that it is better measured with several rather than by individual indicators. Therefore, it was hypothesized that a multivariate analysis of soil quality microbial indicators, such us microbial community biomass and enzyme activities, physical indicators, such as aggregate stability, and chemical indicators, such as total soil C and total soil N can be integrated. The outcome should distinguish soil quality changes resulting from defined soil management practices in Pennsylvania farms and in a long term study (HRE). Secondly, PCA was explored as a method for classifying soil quality condition of farms (or "unknown" samples) as an indication of soil management and as a way to monitor the success of a soil quality remediation study in a range of conditions.

2.5 Slope of the land

Slope is the rise or fall of the land surface. It is important for the farmer or irrigator to identify the slopes on the land. Results showed that the rainfall intensity had a small influence on nutrient concentrations in runoff, but a significant influence on the runoff flow on sloping lands. The slope length influenced the nutrient loss by soil erosion on areas that receive rainfall.

The slope gradient influenced the nutrient loss by runoff flux and velocity on sloping land. As the slope gradient decreased, the nutrient loss decreased because of the increase in infiltration. The soil texture, porosity, and water content influenced the motion of soil water and the transfer and form of nutrients in soil, through oxidation and deoxidation. Vegetative coverage influenced the infiltration coefficient of rainwater into subsurface soil, and thus influenced the runoff flow velocity. Therefore, different sloping lands need to be managed in different ways (Hebal, 2003).

2.6 Physical indicators

They are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration or movement of water within the soil profile.

Soil quality is one of the most significant factors for high agricultural productivity and sustainable agriculture. From physical standpoint, the "soil quality" could be characterized with the soil physical conditions and properties satisfying plant requirements for water, air and mechanical resistance and favouring root growth and normal physiological functions.

Soil physical properties are estimated from the soil's texture, bulk density (a measure of compaction), porosity, water-holding capacity (Hillel *et al.,* 1982). The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved through additions of organic matter to soils. Therefore, the suitability of soil for sustaining plant growth and biological activity is a function of it's physical properties (porosity, water holding capacity, structure, and tilth).

There are several criteria to consider when selecting soil health and soil quality indicators. In general, appropriate indicators should be:

- easy to asses
- able to measure changes in soil function both at plot and landscape scales
- assessed in time to make management decisions
- accessible to many farmers
- sensitive to variations in agro-ecological zone
- representative of physical, biological or chemical properties of soil
- assessed by both qualitative and/or quantitative approaches

2.6.1 Bulk density and particle density

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. Bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared to surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them. It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems.

Bulk density is also used to convert between weight and volume of soil. It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. This increases the validity of comparisons by removing error associated with differences in soil density at the time of sampling (Arshad and Grossman, 1996a).

Bulk density measurement reflects the history of management practices and affects numerous physical, chemical and biological properties of soils (Carter, 2005). Bulk density reflects the soil's ability to function for structural support, water and solute movement and soil aeration. Bulk densities above thresholds indicate impaired function.

Yadav (1996) reported that in sugarcane based cropping system, the soil under 12 years of nutrient treatments had larger aggregates than the control.

Joshi (2008) noticed that the incorporation of organic sources blended with inorganic nutrients continuously for 10 years in a rubber garden was found to decrease the bulk density of the soil.

Intrawech *et al.* (2009) conducted studies to evaluate the influence of 10 years of annual application of 4 nitrogen sources on soil physical and chemical properties and revealed that the core bulk density was not significantly affected by fertilizer treatments.

In a long-term fertilizer experiment conducted on an Aquic Hapludoll under rice-wheat-cowpea system, a declining trend was observed in rice productivity. Response to N, Zn, and farmyard manure (FYM) was quite marked both in rice and wheat. In the control, the initial status of 1.48% organic carbon reduced to one-third in two decades. However, use of 100% NPK + FYM restored the original level. Addition of 150% NPK and 100% NPK + FYM led to considerable build-up in the availability of P, K, and S. Application of 100% NPK along with FYM or Zn is suggested, to stop deterioration in crop productivity and soil fertility (Nandram, 2012).

2.6.2. Aggregate stability

Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil. The large aggregates are more sensitive to management effects on organic matter, serving as a better indicator of changes in soil quality. Greater amounts of stable aggregates suggest better soil quality. When the proportion of large to small aggregates increases, soil quality generally increases (Arshad and Grossman, 1996 b).

Soil aggregates are composed of mineral and organic particles held together by a variety of factors (Boyle *et al.*, 2009).

The physical and biological indicators of soil quality have unfavourable or adverse results and consequently show evidence of low physical and biological soil quality. Low rating scores for aggregate stability, available water content and organic matter content (20, 44 and 3 respectively) are evidences of soil degradation from long-term intensive tillage and lacking use of soil-building crops or organic matter additions (Swindale, 2008).

The aspect of soil quality consideration is especially significant and actual for now modern mechanized agriculture. In this type of agriculture, soils are subjected to an "aggressive" form of use. Often this leads to loss of organic matter and nutrient content, acidification and severe destruction of soil aggregates. The consequences are soil compaction and deterioration of other significant soil properties. Most of the Bulgarian cultivated soils are characterized by poor soil structure of the arable layer. This accounts for unstable physical conditions for root development. The main reason is the destruction of the soil aggregates by human-induced activities that cause diminishing of the soil organic matter. These effects are aggravated by the mechanical impacts of the heavy machinery and cultivation at unsuitable soil moisture conditions (Dilkova, 1998).

Only about half of soil volume is mineral and organic matter; the other half is water and air. Soil structure (how primary mineral and organic particles are bound into larger structures) determines how water and air move through the soil, bringing nutrients to microorganisms and plant roots. Structure is reflected in the amount and size of pore spaces, the size and stability of aggregates of soil particles and the density of the soil. Aggregate stability and water infiltration have attracted attention as indicators of soil quality.

2.6.3. Water retention characteristics

The result obtained from permanent observation trial on red loam soil under coconut revealed that no tillage plots improved the water retention character over cultivation alone comparable to the cultivated plots with organic and inorganic fertilization (John *et al.*, 2003).

Bhriguvanishi (2008) observed that water holding capacity of soil improved significantly due to the use of farm yard manure and fertilizers, whereas in the case of chemical fertilizer treatment, the increase was negligible.

2.7. Chemical indicators

Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development. The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions such as the tendency for crust to form. In order to achieve high crop yields, small holder farmers have to provide soil nutrients in large quantities (Sanchez and Swaminathan, 2005).

Therefore it is possible to alter the pool of available nutrients by adding inorganic fertilizers, incorporating cover crops, and using other organic materials in the form of manures and composts (Stocking, 2003). Results of chemical tests are soil quality indicators which provide information on the capacity of soil to supply mineral nutrients, which is dependent on the soil pH. Soil pH is an estimate of the activity of hydrogen ions in the soil solution. It is also an indicator of plant available nutrients. High activity is not desirable and the soil may require liming with base cations, Ca or Mg in order to bring the solution back to neutral.

Long-term fertilizer experiments conducted over 30 years in different agroecological regions involving diversified cropping systems and soil types showed significant responses of crops to K applications, the effects being more pronounced in Alfisols and acidic Inceptisols . After several years of intensive cropping, response to K application occurred even in alluvial soils dominated by K bearing minerals (illite). Application of K enhanced its available status in soils and uptake by the crops. Contribution of the nonexchangeable K towards total potassium removal was above 90% in the absence of applied K which decreased to about 80% with the use of K (Swarup, 2008).

The effects of thirty of years of continuous cultivation of land after conversion from forest on soil quality were investigated by analyzing soil data from a 3-year study carried out in Sasumua catchment during 1977, 1987 and 2007. Soil pH, electrical conductivity (EC), cation exchange capacity(CEC), soil organic carbon(%C), total nitrogen(%N), exchangeable potassium(K+), magnesium(Mg^{2+}) and calcium(Ca^{2+}) were analyzed from samples taken at 0-30cm soil depth. Results showed change of soil reaction from pH 5.86 to 5.22 ($p<0.005$), Mg^{2+} changed from 3.32 mg/kg to 1.04 mg/kg ($p<0.001$), and K+ changed from 2.89 to 1.11 mg/kg ($p<0.001$) over the 30 year period. Ca^{2+} decreased by 62%, N increased by 21% and CEC increased by 27%. No change was observed in % C. Factors contributing to change of soil pH, Mg^{2+}, Ca^{2+}, and K^+ were due to overgrazing, intensive cultivation of horticultural crops and soil erosion by water. Application of farmyard manure and the practice of agro forestry have helped in retaining the levels of % C. Conventional tillage practices employed by farmers have influenced increase in CEC by encouraging decomposition of soil organic carbon (kimigo and kicheri, 2009).

The first phase of the experiment conducted for 13 years (1977-1990) revealed that for continuous cultivation of cassava, balanced application of fertilizers containing N, P_2O_5 and K_2O @ 100 kg ha^{-1} along with FYM @ 12.5 t ha^{-1} would be the best nutrient recommendation to maintain productivity of cassava in an Ultisol. Though P is important for cassava nutrition, it's uptake by the crop is less and continuous application of P containing fertilizers has resulted in a substantial build up of P in the soil hindering the availability of micronutrients especially zinc. Further research on this aspect elucidated the fact that the dosage of P can be reduced to 50 kg ha^{-1}. But cassava removes larger amounts of K followed by N. For that reason numerous long term fertility trials have shown that in continuously grown cassava, K becomes invariably the yield limiting nutrient. High and stable yields can only be sustained through the annual application of adequate levels of K and N. From this trial, the importance of secondary nutrients like calcium and magnesium and micronutrients in maintaining soil productivity for sustained tuber production was also recognized (Susan *et al.*, 2005).

Kamaldevi *et al.* (2005) observed that the pH of coconut basin soils decreased below four as a result of regular application of ammoniacal fertilizers. Consequently the availability of soil manganese increased very much which in turn enhanced the manganese uptake by palm to almost toxic levels.

Continuous use of farmyard manure and NPK fertilizers in palm over a period of 20 years had improved available phosphorous, nitrogen, zinc, iron and organic carbon status of an acidic red loam soil (Prasad and Singh, 2009).

Result of a long term experiment with bajra- wheat rotation revealed that pH of the soil remained more or less unaffected by application of chemical fertilizers as well as by farmyard manure (Chaudhary *et al* ., 2008).

Padmam (2002) reported that long term application of manures and fertilizers singly and in combination had no significant influence on soil reaction, CEC of the soil, total and available nitrogen, total and exchangeable calcium and total magnesium of the soil continuously cropped with rice.

Soil carbon content has been suggested as a soil quality indicator because decreases in this parameter can be directly related to decreased water stability of both macro- and micro-aggregates. Soil organic matter content is frequently identified as the primary attribute of soil quality assessment. Soil organic matter influences many soil properties including infiltration rate, bulk density, aggregation stability, cation exchange capacity and biological activity, all of which are related to a number of soil function (Tisdale and Oades, 1982).

Biswas *et al.* (2004) reported that long term application of phosphate in combination with other fertilizers had significantly improved the organic carbon status of red silty clay loam soils of Ranchi.

Pushpangadan (2005) reported that organic carbon status of the soil was not influenced by continued NPK fertilization in a long term fertilizer experiment under coconut at Balaramapuram,Trivandrum.

Rabindra and Gowda, (2012) revealed that continuous use of farmyard manure and judicious combination of organics and inorganics enhanced the organic carbon content from o.46 to 0.81 in a long term fertilizer trial with sugarcane.

2.8. Biological indicators

Soil organisms are assumed to be directly responsible for soil ecosystem processes, especially the decomposition of soil organic matter and the cycling of nutrients (Wardle and Giller, 2006). These processes are regarded as major components in the global cycling of materials, energy and nutrients. For example, the soil biomass (25 cm top soil layer) is known to process over 100,000 kg of fresh organic material each year per hectare in many agricultural systems.

Soil quality is strongly influenced by microbe-mediated processes, and functions can be related to diversity; it is likely that microbial community structure will have the potential to serve as an early indication of soil degradation or soil improvement. Therefore, there is growing evidence that soil microbiological and biological parameters may possess potential as early and sensitive indicators for soil ecological stress or reparation (Dick, 2002), as is the case of soil enzyme activities and exopolysaccharides, soil microbial biomass, composition of soil microflora, that were used as potential biochemical/biological indicators of soil quality.

For instance, Islam and Weil (2000) concluded that total microbial biomass, active microbial biomass and basal respiration per unit of microbial biomass showed the most promise for inclusion in an index of soil quality, based on soil samples of contrasting management systems obtained from long term replicated field experiments and pair field samples in Mid-Atlantic States.

Biological indicators of soil quality that are commonly measured include soil organic matter, respiration and microbial biomass (total bacteria and fungi) . Soil organic matter plays a key role in soil function, determining soil quality, water holding capacity and susceptibility of soil to degradation (Giller and Cadisch, 1997; Feller *et al.*, 2001). In addition, soil organic matter may serve as a source or sink to atmospheric CO_2 (Lal, 2010) and an increase in the soil C content is indicated.

Litter decomposition is a key process in elemental cycling in forest ecosystems. It depends on the interactions between soil, biota and environment. Leaves are the largest single source of soil organic matter and an important source of nutrients in soil. The role of leaf litter in the recycling of nutrients, especially nitrogen (N) and phosphorus (P), is well known. Micronutrients such as copper (Cu) and zinc (Zn) are recycled through root uptake, litter fall and decomposition (Bergkvist, 1987). Annual litter fall in the teak-gmelina stand (T2) was 2.22 Mg ha^{-1} y^{-1} on average, consisting of 89.3% for leaf, 2.5% for fruit, and 8.2% for others such as bark. Of the leaf litter, 52.8 % was counted for teak, 29.0 % for gmelina, and 18.2 % for other leaves (Itnal, 1997).

The litter fall has a vital role in recycling of nutrients since the nutrient addition through litter inputs frequently exceeds inputs from inorganic fertilizers in crops like cocoa which has lot of foliage, synchronized flushing and abundant litter fall either due to natural senescence or pruning. It has been reported that an average yield of 1000 kg $ha^{-1}yr^{-1}$ of dry cocoa beans removed 38, 6 and 77 kg of N, P and K respectively whereas the litter fall (6-7 t ha^{-1}) contributed around 88, 6 and 82 kg of N, P and K ha^{-1} yr^{-1} (Sreekala, 1997).

The litter fall in the natural forest was 2.38 Mg ha^{-1} y^{-1}, on average, consisting of 61.5% leaves, 2.3% flowers, 7.7% fruit and 28.5% for others such as branches and bark (Fig. 5). About half the leaf litter (51.7%) was bamboo leaves. The litter fall tended to peak during January to March in both the natural forest and teak plantation: during this quarter, 46% of the litter fall fell in the natural forest and 56% in the teak plantation (Sharma, 1998).

2.8.1. Microorganism

The biological activity in soil is largely concentrated in the topsoil, the depth of which may vary from a few to 30 cm. In the topsoil, the biological components occupy a tiny fraction (<0.5%) of the total soil volume and make up less than 10 % of the total organic matter in the soil. These biological components consist mainly of soil organisms, especially microorganisms. Despite their small volume in soil, microorganisms are key players in the cycling of nitrogen, sulfur, and phosphorus, and the decomposition of organic residues. They affect nutrient and carbon cycling on a global scale (Pankhurst *et al.,* 1997).

The energy input into the soil ecosystems is derived from the microbial decomposition of dead plant and animal organic matter. The organic residues are, in this way, converted to biomass or mineralized to CO_2, H_2O, mineral nitrogen, phosphorus, and other nutrients. Microorganisms are further associated with the transformation and degradation of waste materials and synthetic organic compounds (Torstensson *et al.,* 1998).

Soil reaction has a definite influence / effect on quantitative and qualitative composite on of soil microbes. Most of the soil bacteria, blue-green algae, diatoms and protozoa prefer a neutral or slightly alkaline reaction between pH 4.5 and 8.0 and fungi grow in acidic reaction between pH 4.5 and 6.5 while actinomycetes prefer slightly alkaline soil reactions. Soil reactions also influence the type of the bacteria present in soil. For example nitrifying bacteria *(Nitrosomonas and Nitrobacter)* and diazotrophs like *Azotobacter* are absent totally or inactive in acid soils, while diazotrophs like *Beijerinckia, Derxia,* and sulphur oxidizing bacteria like *Thiobacillus thiooxidans* are active in acidic soils (Sharma, 2004).

The organic matter in soil being the chief source of energy and food for most of the soil organisms, it has great influence on the microbial population. Almost all microorganisms obtain their food and energy from the plant residues or organic matter / substances added to the soil. Energy is required for the metabolic activities of microorganisms. Thus, the source of food and energy rich material is essential for the microbial activity in soil. The organic matter, therefore serves both as a source of food nutrients as well as energy required by the soil organisms (Russel, 2009).

The physical, chemical and physico-chemical nature of soil and it's nutrient status influence the microbial population both quantitatively and qualitatively. The chemical nature of soil has considerable effect on microbial population in soil. The soils in good physical condition have better aeration and moisture content which is essential for optimum microbial activity. Similarly nutrients (macro and micro) and organic constituents of humus are responsible for absence or presence of certain type of microorganisms and their activity. For example activity and presence of nitrogen fixing bacteria is greatly influenced by the availability of molybdenum and absence of available phosphate restricts the growth of *Azotobacter (Rawther, 2006).*

2.8.1.1 Soil enzymes

Enzymes are the direct mediators for biological catabolism of soil organic and mineral components. Soil enzyme activities (1) are often closely related to soil organic matter, soil physical properties and microbial activity or biomass, (2) changes much sooner than other parameters, thus providing early indications of change in soil health, and (3) involve simple procedures (Dick *et al.*, 2006). In addition, soil enzyme activities can be used as measures of microbial activity, soil productivity, and inhibiting effects of pollutants (Tate *et al.*, 2005).

Soil organism and soil enzyme only play active role in soil fertility as a result of their involvement in the cycle of nutrients like carbon and nitrogen which are required for plant growth, but also are sensitive biological indicators for soil quality evaluation, which can sensitively reflect minute changes of the soil environment (Haung, 2000). Of the many biological properties that have potential as sensitive indicators of soil quality, enzyme activities often provide a unique integrative biological assessment of soil function, especially those catalyzing a wide range of soil biological processes, such as dehydrogenase, urease, phosphatase etc.

Soil enzyme activities are very sensitive to both natural and anthropogenic disturbances and show a quick response to the induced changes.

2.8.1.2. Dehydrogenase

Soil dehydrogenase enzymes are one of the main components of soil enzymatic activities participating in and assuring the correct sequence of all the biochemical routes in soil biogeochemical cycles. Dehydrogenase activity is measured by two methods using the TTC and INT substrate; however, various authors reported poor results when TTC is used as substrate. Different biotic and abiotic factors such as incubation time and temperature, pre-incubation, soil aeration and moisture content have significant effect on dehydrogenase activity in soil. Highest dehydrogenase activity is reported from forest soil in autumn seasons while the disturbed soil from coal mine soils exhibit lowest dehydrogenase activities along the soil erosion gradient of experimental slopes. Least value of enzyme activity is reported from polluted sites than restored and undisturbed sites. Dehydrogenase enzyme is often used as a measure of any disruption caused by pesticides, trace elements or management practices to the soil, as well as a direct measure of soil microbial activity (Kumar, 2013).

Study conducted in natural and degraded soil revealed that dehydogenase activity (DHA) was greater in surface than sub surface soil which is due to accumulation of greater organic matter. It has been also found that the DHA activity was greater in natural soil than the degraded soil. The DHA activity was found greater in forest soils than grassland area. The DHA activity was also found maximum in loamy sandy soil than sandy soil (Dick *et al.*, 2006).

2.8.1.3. Urease

Urease activity influences optimum use of urea fertilizer, nitrogen volatilization, nitrogen leaching and environmental pollution related to nitrogen. Studies on evaluation of some paddy soil properties on soil urease activity revealed that urease activity is mostly controlled by organic carbon and decreases with increase in soil pH and has more suitability with acidic condition and there is no significant correlation between urease and clay percentage in soils (Hassan, 2008).

Urease enzyme is responsible for the hydrolysis of urea fertilizers applied to the soil into NH_3 and CO_2 with the concomitant rise in soil pH (Byrnes and Amberger, 2009). This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilization (Simpson *et al.*, 2004; Simpson and Freney, 2008). Due to this role, urease activities in soils have received a lot of attention since it was first reported by Rotini (1935), a process considered vital in the regulation of N supply to plants after urea fertilization. Soil urease originates mainly from plants and microorganisms found as both intra- and extra-cellular enzymes (Burns, 1986; Mobley and Hausinger, 1989). On the other hand, urease extracted from plants or microorganisms is rapidly degraded in soil by proteolytic enzymes (Pettit *et al.*, 1976; Zantua and Bremner, 1977). This suggests that a significant fraction of ureolytic activity in the soil is carried out by extracellular urease, which is stabilized by immobilization on organic and mineral soil colloids.

Urease activity in soils is influenced by many factors. These include cropping history, organic matter content of the soil, soil depth, soil amendments, heavy metals, and environmental factors such as temperatures (Tabatabai 1977; Yang *et al.*, 2006). For example, studies have shown that urease was very sensitive to toxic concentrations of heavy metals. Generally, urease activity increases with increasing temperature. It is suggested that higher temperatures increase the activity coefficient of this enzyme. Therefore, it is recommended that urea be applied at times of the day when temperatures are low. Since urease plays a vital role in the hydrolysis of urea fertilizer, it is important to uncover other unknown factors that may reduce the efficiency of this enzyme in the ecosystem.

2.8.1.4. Phosphatase

Phosphatases are a broad group of enzymes that are capable of catalyzing hydrolysis of esters and anhydrides of phosphoric acid. Apart from being good indicators of fertility, phosphatase enzymes play key role in the soil system. Acid and alkaline phosphatases are the two forms of active phosphatases. Alkaline phosphatase occurs in roots mainly after mycorrhizal colonization and has been proposed as a marker for the analyzing the symbiotic efficiency of root colonization (Tisserant *et al.*, 2003). In soil these enzymes are believed to play critical roles in P cycles as evidence shows that they are correlated to P stress and plant growth.

Phosphatases (acid and alkaline) are important in soils because these extracellular enzymes catalyze the hydrolysis of organic phosphate esters to orthophosphate; thus they form an important link between biologically unavailable and mineral phosphorous. Phosphatase activity is sensitive to environmental perturbations such as organic amendments, tillage, water logging, compaction, fertilizer additions and thus it is often used as an environmental indicator of soil quality in riparian ecosystems.

2.8.2. Earthworms

Soil fauna communities, including soil inhabiting invertebrates, are known to improve soil structure by decreasing bulk density, increasing soil pore space, soil horizon mixing, increased aeration and drainage, increased water holding capacity, litter decomposition and improving soil aggregate structure. In healthy soils invertebrates are abundant. With adequate food supply and habitat requirements, soil fauna populations will thrive with minimal maintenance. For an area with degraded soils, such as mined or intensely cultivated sites, the reestablishment of invertebrates can be simply a matter of removing the cause of degradation, or may involve more extensive site preparation techniques and reintroduction methods. There are three categories of invertebrates that live in the soil. They consist of micro-fauna, protozoa and nematoda, meso-fauna, which include mites and Diptera (fly) larvae, and macro-fauna, which include termites (Mecrotermes) and earthworms (Abbott, 1989).

Earthworms redistribute organic materials within the soil, increase soil penetrability and, under certain conditions influence ion transport in soils. Root distribution may be modified and microbial activity increased by their burrowing and feeding activities. Earthworms influence the supply of nutrients in several ways. Not only is earthworm tissue and cast material enriched in certain nutrients, relative to the soil matrix, but ingestion of organic material increases the rate of cycling. Certain farm-management practices, such as cultivation and the use of acidic fertilizers, reduce the ability of earthworm to improve plant growth. Where other inorganic fertilizers increase the growth of plants, an increase in earthworm numbers can be expected because of the increased food supply. Lime, in particular, and possibly drainage also increase earthworm activity. Further research is required on the physical and biological effects of earthworms on nutrient supply, so that suitable management practices can be developed to optimize the beneficial effects of earthworms on soil fertility (Sasider *et al.,* 2008). Nowadays, termites like earthworms are seen as very important soil organisms that effect soil functioning and ecosystem activity. In tropics, termites play an important role in nutrient recycling, transportation of soil material and soil formation (Ali, 2012).

MATERIALS & METHODS

3. MATERIALS AND METHODS

The present investigation on "Long term effect of field management on soil quality in Ultisol" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during 2012-2013.

3.1. Details of the location

Five fields from different land use systems were selected in the main campus of Kerala Agricultural University, Vellanikkara. Geographically, the area is situated at latitude 10° 32'' N, longitude ranging from 70° 17'' E and at an altitude of 72 m above mean sea level (Fig.1 and Plate 1).

3.1.1. Climate and soil

Experimental site has a humid tropical climate. In general the soil is a lateritic and acidic (Vellanikkara series) and belong to Kandiustult

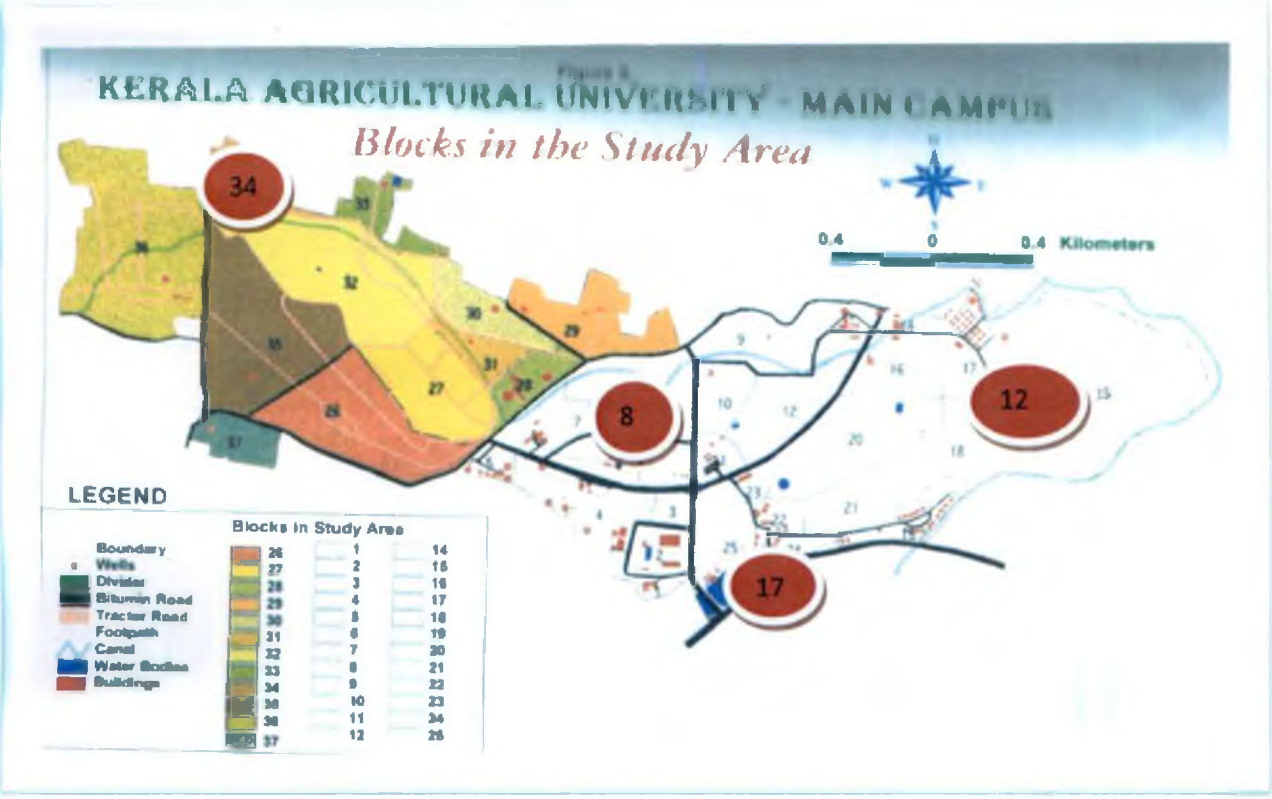
3.1.2. Season of the experiment

Soil samples were collected during summer season (Annexure- 1).

3.1.3. Details of the experiment

Location: Vellanikkara
Fields:5 (Natural forest, rubber plantation, cocoa field, STCR experimental field and tapioca field)
Area of individual field: 3600 m^2
Sampling sites per field: 5
Depths of sampling: 3 (0-15 cm, 15-30 cm and 30-60 cm)
Replications: 3
Total number of samples/ field: 45
Period of sampling: 28/12/2012 - 7/01/2013

FIGURE 1 . Location of different fields



(Sajnanath, 2000)

Natural forest- Block 8

Rubber plantation - Block 8

Tapioca field - Block 12

STCR experimental field - Block 17

Cocoa field - Block 34

PLATE 1 . General view of experimental plot

a) General view of experimental plot- Natural forest with bamboo

b) General view of experimental plot- Natural forest with mixed vgetation

c) General view of experimental plot with rubber plantation

d) General view of experimental plot with cocoa plantation

e) General view of STCR experimental field

f) General view of experimental plot with tapioca

3.2 Description of fields with notations used for study:

1. Natural forest (F) : This forest area consists of bamboo, teak, mahogany, jack, banyan and some shrubs. The area is attached to Central Nursery and Plant Propagation unit, College of Horticulture, Vellanikkara. This land is under mixed crop stand for about 25 years (Block- 8).

2. Rubber plantation (R) : This area is under rubber cultivation for the last 20 years and is maintained by the Estate, Kerala Agricultural University (Block-8).In this plot routine application of fertilizer was done based on package of practices recommendation by KAU.

3. Cocoa garden (C) : This area is under cocoa cultivation for the last 20 years and is maintained by Cadbury- KAU Collaborative Cocoa Research Project (Cadbury India Ltd) College of Horticulture Vellanikkara (Block- 34). Regular fertilizer application based on package of practices recommendation by KAU was followed here.

4. STCR experimental field(S) : This area is under continuous cultivation for STCR experiments on vegetables and other crops for the last 13 years and is maintained by the Department of Soil Science and Agricultural chemistry, College of Horticulture, Vellanikkara (Block- 17). The site has been used for the formulation of STCR fertilizer prescription equations. Crops like maize, banana, different vegetables like brinjal, chilli amaranthus, bhindi, salad cucumber and spice crops like ginger and turmeric were grown based on the STCR methodology (Ramamoorthy *et al.*, 1967) of experiments.

5. Tapioca field (T) : This area is under tapioca cultivation for the last 10 years and is maintained by the Department of Agronomy, College of Horticulture, Vellanikkara (Block -12). Here also routine application of fertilizers was done based on package of practices recommendation by KAU.

3.3 Collection of soil samples

Sampling sites were selected depending on the variation in slope in each field (Table.1). From each field, five sites were selected and from each site three spots were identified (1m apart) and composite samples were collected by sampling around each spot. Soil samples were collected from all three depths namely, 0-15 cm, 15-30 cm and 30-60 cm using spade and core sampler. Collected samples were analyzed for different physical, chemical and biological indicators.

Table 1. Categorization of sites based on slope

Fields	Slope (%)				
	Site-1	Site-2	Site-3	Site-4	Site-5
Forest	10.51	12.28	14.5	15.84	19.44
Rubber	3.39	5.24	10.5	14.05	19.44
Cocoa	8.75	10.5	12.30	15.80	19.44
STCR	3.24	5.24	6.99	8.75	14.05
Tapioca	3.49	5.24	6.99	8.75	12.30

3.4 Observations

Observations on the following properties of the soil were made

3.4.1. Physical indicators:

a. Soil texture
b. Aggregate size distribution
c. Soil temperature
d. Water holding capacity and single value constants

Table 2 . Methods of soil physical analysis

Parameter	Method	Reference
Soil texture	International pipette method	Gupta and Dakshinamoorthi (1980)
Aggregate size distribution	Yoder's wet sieving method	Yoder (1930)
Soil temperature	Soil thermometer	Jennifer (1945)
Water holding capacity and single value constants	Keen-Raczkowski brass cup	Piper (1942)

3.4.2 Chemical indicators:

a. pH and EC
b. CEC, AEC, SiO_2/R_2O_3, organic carbon and lime requirement
c. Macronutrients N, P, K, Ca, Mg and S
d. Micronutrients Fe, Mn, Zn, Cu and B

Table 3 . Method of chemical analysis

Parameter	Method	Reference
pH and electrical conductivity	1:2.5 soil water suspension- pH meter and conductivity meter	Jackson (1958)
Cation exchange capacity	Saturation with NH^{4+} ions	Jackson (1958)
Organic carbon	Wet oxidation	Walkey and Black (1934)
Available nitrogen	Alkaline permanganometry	Subbiah and Asija (1956)
Available phosphorous	Bray extract	Bray and Kurtz (1945)

Available potassium	Neutral normal ammonium acetate extraction followed by flame photometry	Jackson (1958)
Available calcium and magnesium	Neutral normal ammonium acetate extraction followed by Atomic Absorbtion spectrophotometry	Jackson (1958)
Available sulphur	$BaCl_2$ extraction followed by Nephelometry	Chesnin and Yien (1951)
Available micronutrients	DTPA extraction followed by Atomic Absorption Spectrophotometry	Lindsay and Norvell (1978)
Available boron	Hot water extraction followed by spectrophotometry	Jackson (1958)
Anion exchange capacity	Ascorbic acid blue colour method	Hesse (1971)
Silica sesquioxide ratio	Hcl extract method	Jaiswal (2003)
Lime requirement	SMP buffer method	Shoemaker *et al.* (1961)

3.4.3 Biological indicators:

Total count of bacteria, fungi and actinomycetes were found out

3.4.4. Microbial population

The method used for the enumeration was serial dilution and plate count technique as described by Agarwal and Hasija (1986).Ten grams of soil was added to 90 ml of sterile water and agitated for 20 minutes. One ml of the solution was transferred to a test tube containing 9 ml sterile water to get 10^{-2} dilution and similarly 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6} dilutions were also prepared.

Enumeration of total microbial count was carried out by using different suitable media as detailed in Appendix II. Suitable media (15-20 ml) was poured on the corresponding medium. Plates were incubated at 28+2 ^{0}C. Observations were taken as and when the colonies appeared (For bacteria-2-3 days, fungi - 5-7 days and actinomycetes-3-14 days).

3.4.5 b. Enzyme activity

Table 4 . Methods used for measuring soil enzyme activity

Enzyme	**Method**	**Reference**
Dehydrogenase	Triphenyl formazon extraction method- spectrophotometer	Tabatabai and Bremmer (1977)
Urease	Phenylmercuric acetate in 2M KCL extraction method	Pal and Chonkar (1981)
Phosphatase	P- nitrophenyl phosphate extraction method- spectrophotometer	Tabatabai and Bremmer (1977)
Asparginase	Phenylmercuric acetate in 2M KCL extraction method	Pal and Chonkar (1981)

3.4.6 Count of earth worms and termite mounds

The total number of earth worms per sqm in each field was counted and recorded. Each field was also surveyed for the presence of termite mounds (Pratab, 2004).

(Table. 5) Soil quality indicators used for evaluation of soil quality

Serial No	Soil quality indicators	Class 4 (Score- 4)	Class 3 (Score -3)	Class 2 (Score- 2)	Class 1 (Score- 1)
1	Bulk density $\mathrm{Mgm^{-3}}$	1.3-1.4	1.2-1.3	1.1-1.2	>1.1 / <1.6
2	Organic carbon	>1	1-0.75	0.50 - 0.75	<0.5
3	Soil pH	6.5-7.5	6-6.5	5.5-6	<5.5
4	Avail. N kg $\mathrm{ha^{-1}}$	>520	420-50	280-420	<280
5	Avail. P kg $\mathrm{ha^{-1}}$	>25	15-25	10-15	<10
6	Avail. K kg $\mathrm{ha^{-1}}$	>280	200-280	120-200	<120
7	Avail. S mg $\mathrm{kg^{-1}}$.	>25	15-25	10-15	<10
8	Avail. Zn mg $\mathrm{kg^{-1}}$.	>2.0	1.0-2.0	0.5-1.0	<0.5
9	Avail. Fe mg $\mathrm{kg^{-1}}$.	>10	5.5-10	2.5-5.5	<2.5
10	Avail. Mn mg $\mathrm{kg^{-1}}$.	>10.0	4.0-10	2-4	<2.0
11	Avail. Cu mg $\mathrm{kg^{-1}}$.	>2	0.5-2	.2-.50	<0.2
12	Avail. B mg $\mathrm{kg^{-1}}$.	>1.5	0.7-1.5	0.3-0.7	<0.3

(Doran and Parkin, 2004)

3.5 Statistical analysis

The data generated were analyzed by comparing with the available standard values of soil quality using suitable statistical tools like *t* – test, correlation and regression.

RESULTS

4. Results

The different sites within a field were selected based on slope percentage. The mean values of the different parameters were found and the data were arranged in tables in the increasing order of slope for the five different sites in each field.

4.1. Physical indicators

4.1.1. Bulk density

Among the different land use systems, the bulk density of soil was found to be the highest in tapioca field and lowest in rubber plantation.(Table 6)

In the forest, the bulk density of soil showed an increasing tendency with increase in depth. The value ranged from 1.46 to 1.63 Mg $m^{-3.}$ The highest value was observed in 30-60 cm depth (site-5) and lowest in 0-15 cm (site-1).

In rubber plantation too, the bulk density of sample showed a decreasing trend with increasing depth. The value ranged from 1.42 to 1.62 Mg m^{-3}. The highest value was observed in 30-60 cm depth (site-5) and lowest value in 0-15 cm (site-1).

In cocoa garden, the bulk density of soil showed a decreasing trend with increase in depth. The value ranged from 1.46 to 1.63 Mg m^{-3}. The highest value was observed in 30-60 cm depth (site-5) and lowest in 0-15 cm (site-1).

In STCR experimental field also, the trend was the same as above. The mean value ranged from 1.51 to 1.64 Mg m^{-3}. The highest value was observed in 30-60 cm depth (site-1) and lowest value observed in 0-15 cm (site-1).

In tapioca field, the bulk density of soil showed a decreasing tendency with increasing depth. Average value ranged from1.52 to 1.64 Mg m^{-3}. The highest value was observed in 0-15 cm (site- 1) and lowest value in 30-60 cm depth (site-1).

4.1.2. Water holding capacity

Among the different land use systems, water holding capacity of soil was found to be the highest in natural forest and lowest in tapioca field. In all these fields with increase in slope percentage water holding capacity decreased (Table 7).

In the forest, the water holding capacity of soil showed a decreasing tendency with increase in depth. The value ranged from 26.90 to 49.11 %· The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-4)

In rubber plantation also, water holding capacity of soil showed a decreasing tendency with increase in depth. The value ranged from 24.13 to 40.80 %· The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the cocoa garden, the water holding capacity of soil was comparatively higher range with a decreasing tendency with increase in depth. The value ranged from 28.31 to 44.61 %· The highest value was observed in 0-15 cm (site- 1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field also, the trend was the same as above. The value ranged from 22.11 to 36.44 %. The highest value was observed in 0-15cm (site- 3) and lowest value in 30-60 cm depth (site-4).

In the tapioca field the water holding capacity of soil showed a decreasing tendency with increase in depth. The value ranged from 21.81 to 36.38 %. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.1.3. Soil aggregate stability (Mean weight diameter)

The aggregate stability of soil was highest in forest field and lowest in STCR experimental field. In all these fields with increasing slope percentage, the value of soil aggregate stability decreased. (Table 8)

In the forest field, the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.61 to 0 .98 mm.The highest value was observed in 0-15cm (site- 1) and lowest value in 30-60 cm depth (site-5)

In rubber plantation also, the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.61 to 0.89 mm· The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the cocoa field, the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.72 to 0.92 mm· The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-3).

The STCR experimental field also, showed the same tendency as above. The value ranged from 0.51 to 0.72 mm· The highest value was observed in 0-15cm (site-5) and lowest value in 30-60 cm depth (site-5).

The mean weight diameter of soil in the tapioca field showed a decreasing tendency with increase in depth. The value ranged from 0.55 to 0.74 mm· The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-4).

4.1.4. Soil temperature

Among the different land use systems, soil temperature was found to the highest in tapioca field and lowest in forest field. (Table 9)

In forest, the soil temperature increased with depth in 0730 hours and it decreased with depth in 1430 hours. The value in 0730 hours ranged from26.02 to 26.81 °C and value in 1430 hours ranged from 27.01 to 27.62 °C.

In rubber plantation also, the soil temperature increased with depth in 0730 hours and it decreased with depth in 1430 hours. The value in 0730 hours ranged from 27.01 to 28.74 °C and value in 1430 hours ranged from 27.01 to 27.62 °C.

In cocoa garden, the soil temperature increased with depth in 0730 hours and it decreased with depth in 1430 hours. The value in 0730 hours ranged from 26.13 to 28.81 °C and value in 1430 hours ranged from 27.02 to 27.19 °C.

In STCR experimental field, the soil temperature of sample increased with depth in 0730 hours and it decreased with depth in 1430 hours. The value in 0730 hours ranged from 27.94 to 29.68 °C and value in 1430 hours ranged from 27.32 to 29.56 °C.

In tapioca field, the soil temperature of sample increased with depth in 0730 hours and it decreased with depth in 1430 hours. The value in 0730 hours ranged from 27.28 to 29.50 °C and value in 1430 hours ranged from 27.32 to 29.57 °C.

4.1.5. Soil texture

In the surface layer, the texture of soil in forest was clay loam while in rubber plantation, cocoa garden, STCR experimental field and tapioca field, the texture of soil was found to be sandy clay loam.

Table 6 . Bulk density (Mg m^{-3}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	1.50	1.49	1.48	1.47	1.46
F 15-30	1.56	1.55	1.53	1.51	1.50
F 30- 60	1.63	1.62	1.60	1.60	1.59
R 0-15	1.58	1.54	1.50	1.48	1.42
R 30-60	1.61	1.56	1.54	1.50	1.46
R 30-60	1.64	1.62	1.54	1.53	1.52
C 0-15	1.52	1.51	1.49	1.48	1.46
C 15- 30	1.57	1.56	1.53	1.52	1.50
C 30-60	1.63	1.61	1.59	1.58	1.56
S 0- 15	1.56	1.53	1.54	1.51	1.59
S 15-30	1.59	1.59	1.57	1.56	1.60
S 30-60	1.64	1.62	1.61	1.60	1.63
T 0-15	1.52	1.57	1.56	1.59	1.58
T 15-30	1.58	1.59	1.58	1.62	1.60
T 30- 60	1.62	1.64	1.60	1.63	1.61

F- Forest
R- Rubber plantation
C- Cocoa field
S- STCR experimental field
T- Tapioca field

Table 7 . Water holding capacity (%) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	49.11	48.01	45.32	38.64	40.34
F 15-30	42.74	41.34	38.12	32.90	33.84
F 30- 60	30.73	30.10	31.14	26.90	27.34
R 0-15	40.80	40.31	38.11	36.21	30.34
R 30-60	34.42	38.92	36.12	28.11	28.49
R 30-60	28.22	36.14	32.21	24.13	26.31
C 0-15	44.61	43.46	41.32	39.88	39.86
C 15- 30	38.92	40.12	36.92	37.42	33.46
C 30-60	34.11	38.29	29.52	33.26	28.31
S 0- 15	35.86	34.33	36.44	34.06	35.11
S 15-30	29.92	28.33	29.94	23.06	28.42
S 30-60	26.43	25.64	26.34	22.11	24.32
T 0-15	36.38	35.16	34.92	33.86	30.99
T 15-30	30.09	24.16	29.76	33.01	23.88
T 30- 60	28.11	22.11	27.32	28.56	21.81

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 8 . Soil aggregate stability (mm) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15 cm	0.93	0.98	0.86	0.94	0.82
F 15-30 cm	0.89	0.86	0.89	0.83	0.73
F 30- 60 cm	0.74	0.72	0.79	0.70	0.61
R 0-15 cm	0.89	0.84	0.72	0.83	0.70
R 30-60 cm	0.84	0.83	0.71	0.78	0.68
R 30-60 cm	0.81	0.79	0.64	0.74	0.65
C 0-15 cm	0.90	0.84	0.78	0.84	0.81
C 15- 30 cm	0.91	0.82	0.74	0.82	0.76
C 30-60 cm	0.92	0.80	0.72	0.81	0.74
S 0- 15 cm	0.60	0.54	0.59	0.68	0.72
S 15-30 cm	0.56	0.52	0.58	0.66	0.52
S 30-60 cm	0.54	0.51	0.56	0.65	0.51
T 0-15 cm	0.74	0.68	0.66	0.63	0.63
T 15-30 cm	0.73	0.65	0.65	0.62	0.59
T 30- 60 cm	0.65	0.56	0.63	0.55	0.64

F- Forest
R- Rubber plantation
C- Cocoa field
S- STCR experimental field
T- Tapioca field

Table 9 . Soil temperature (^{0}C) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-1	Site-2	Site-2	Site-3	Site-3	Site-4	Site-4	Site-5	Site-5
	7.30 hrs	1430hrs	7.30hrs	1430hrs	7.30hrs	1430hrs	7.30hrs	1430hrs	7.30hrs	1430hrs
F-15	26.12	27.40	26.31	27.54	27.01	27.62	26.31	27.34	26.51	27.56
F-30	26.51	27.20	26.24	27.24	27.14	27.60	26.42	27.20	26.54	27.54
F-60	26.81	27.01	26.02	27.02	27.17	27.49	26.56	27.12	26.58	27.52
R-15	27.68	28.56	27.26	28.33	27.70	28.64	27.03	28.36	28.75	29.83
R-30	28.41	28.56	28.29	28.38	28.63	28.59	28.03	28.45	28.74	29.85
R-60	28.68	28.54	28.34	28.38	28.69	28.54	28.34	28.68	28.74	29.85
C-15	26.13	27.41	26.32	27.56	27.04	27.64	26.33	27.36	26.52	27.58
C-30	26.54	27.22	26.25	27.26	27.16	27.60	26.44	27.22	26.56	27.56
C-60	28.81	27.02	26.04	27.04	27.19	27.49	26.58	27.14	26.59	27.52
S-15	28.32	28.96	28.04	28.74	27.94	28.94	28.31	27.32	28.10	29.38
S-30	28.93	28.94	28.92	28.72	27.96	28.89	28.81	27.35	29.51	29.43
S-60	28.95	28.92	28.94	28.69	27.99	28.88	28.89	27.39	29.68	29.56
T-15	28.30	28.94	28.02	28.72	27.93	28.94	28.30	27.34	28.08	29.38
T-30	28.91	28.92	28.90	28.70	27.94	28.90	28.78	27.32	29.47	29.45
T-60	28.93	28.90	28.92	28.62	28.96	28.88	28.79	27.28	29.50	29.57

Depths 15, 30 and 60 indicate 0-15, 15-30 and 30-60cm respectively

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2. Chemical Indicators

4.2.1. pH

In the forest, the pH of the soil sample increased with increase in depth. The value ranged from 5.11 to 5.64. The highest value was observed in 30-60 cm (Site-3) and lowest value in 0-15 cm depth (site-5) (Table 10).

In the Rubber plantation, the pH of the soil sample increased with increasing depth. The value ranged from 5.04 to 5.98. The highest value was observed in 30-60 cm (Site-2) and lowest value in 0-15 cm depth (site-4).

In the cocoa garden, the pH of the soil samples showed a increasing tendency with increasing in depth. The value ranged from 4.13 to 5.71. The highest value was observed in 30-60 cm (Site- 1) and lowest value in 0-15 cm depth (site-5).

The STCR experimental field also, showed a similar trend as above. The value ranged from 5.01 to 5.48. The highest value was observed in 30-60 cm (site-2) and lowest value in 0-15 cm depth (site-2).

In the tapioca field, the pH of the soil sample increased with increase in depth. The value ranged from 5.01 to 5.46. The highest value was observed in 30-60 cm (site-1) and lowest value in 15-30 cm depth (site-5).

4.2.2. EC

Among the different land use systems, electrical conductivity of soil was found to be the highest in cocoa garden and lowest in rubber plantation. (Table 11)

In the forest area, the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged from 0.04 to 0.09 dS m^{-1}. The highest value was observed in 0-15 cm (site-1,site-2 and site-3) and lowest value in 30-60 cm depth (site-3) .

In the Rubber plantation too, the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged from 0.02 to 0.08 dS m^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3, site-4).

In the Cocoa field, also the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged from 0.04 to 0.12dS m^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-2, site-4 and site-5).

The STCR experimental field also, showed a similar trend as above. The value ranged from 0.03 to 0.09 dS m^{-1}. The highest value was observed in 0-15 cm (site-1, site-2) and lowest value in 30-60 cm depth (site-5).

In the tapioca field, the mean electric al conductivity of soil showed a decreasing trend with increase in depth. The value ranged from 0.04 to 0.06 dS m^{-1}. The highest value was observed in 0-15 cm (site-1 and site-5) and lowest value in 30-60 cm depth (site-1, site-3 and site-5).

4.2.3. Organic carbon

Among the different land use systems, organic carbon content of soil was highest in the forest and lowest in tapioca field. In all the fields, with increase slope percentage the content of organic carbon decreased. (Table 12)

In the natural forest, the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.65 to 1.23%. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.75 to 1.21 %· The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-4).

In the cocoa field, the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.48 to 1.41%. The highest value was observed in 0-15 cm (Site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.33 to 0.98 %. The highest value was observed in 0-15 cm (Site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value ranged from 0.24 to 1.10 %. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

Table 10 . pH (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	5.32	5.18	5.14	5.12	5.11
F 15-30	5.34	5.32	5.59	5.72	5.29
F 30- 60	5.64	5.52	5.91	5.87	5.46
R 0-15	5.08	5.06	5.32	5.04	5.08
R 30-60	5.88	5.79	5.68	5.21	5.11
R 30-60	5.37	5.98	5.82	5.32	5.25
C 0-15	4.63	4.48	5.07	5.02	4.13
C 15- 30	5.61	5.61	5.21	5.24	4.87
C 30-60	5.71	5.64	5.46	5.42	5.13
S 0- 15	5.11	5.01	5.04	5.08	5.09
S 15-30	5.19	5.02	5.13	5.28	5.21
S 30-60	5.20	5.48	5.46	5.34	5.32
T 0-15	5.21	5.22	5.04	5.08	5.01
T 15-30	5.24	5.42	5.34	5.11	5.19
T 30- 60	5.46	5.44	5.42	5.34	5.25

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 11 . Electrical conductivity (dS m^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	0.09	0.09	0.09	0.08	0.08
F 15-30	0.08	0.08	0.08	0.06	0.07
F 30- 60	0.07	0.05	0.04	0.07	0.05
R 0-15	0.08	0.06	0.06	0.06	0.06
R 30-60	0.08	0.06	0.03	0.03	0.05
R 30-60	0.07	0.05	0.02	0.02	0.04
C 0-15	0.12	0.11	0.10	0.06	0.06
C 15- 30	0.08	0.07	0.08	0.06	0.06
C 30-60	0.05	0.04	0.06	0.04	0.04
S 0- 15	0.09	0.09	0.08	0.07	0.04
S 15-30	0.07	0.08	0.07	0.05	0.04
S 30-60	0.05	0.05	0.05	0.04	0.03
T 0-15	0.06	0.05	0.05	0.05	0.06
T 15-30	0.06	0.05	0.05	0.05	0.05
T 30- 60	0.04	0.05	0.04	0.04	0.05

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 12 . Organic carbon content (%) (mean) of soil samples of different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	1.23	1.16	1.09	1.04	0.97
F 15-30	0.80	1.23	0.99	0.96	0.79
F 30- 60	0.72	0.75	0.76	0.82	0.65
R 0-15	1.21	1.00	0.98	0.95	0.87
R 30-60	1.28	0.97	0.91	0.77	0.82
R 30-60	1.03	0.86	0.88	0.75	0.76
C 0-15	1.41	1.26	1.05	0.87	0.75
C 15- 30	0.98	0.78	0.95	0.55	0.54
C 30-60	0.79	0.54	0.83	0.51	0.48
S 0- 15	0.98	0.97	1.01	0.57	0.65
S 15-30	0.78	0.56	0.77	0.56	0.41
S 30-60	0.65	0.42	0.65	0.43	0.33
T 0-15	1.10	0.99	0.75	0.81	0.63
T 15-30	0.84	0.82	0.61	0.77	0.32
T 30- 60	0.72	0.66	0.58	0.62	0.24

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2.4. Available nitrogen

Among the different land use systems, the nitrogen content of soil was highest in forest and lowest in rubber plantation. (Table 13).

In the forest, the mean nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 402.11 to 614.66 kg $ha^{-1.}$ The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-1).

In the rubber plantation too, the mean nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 188.16 to 589.56 kg $ha^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-2).

In the cocoa field, the mean nitrogen content of soil showed wide range, with a decreasing trend with increase in depth. The value ranged from 250.88 to 638.69 kg ha^{-1} . The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-1).

In the STCR experimental field also, trend was the same as above. The value ranged from 266.21 to 488.86 kg $ha^{-1.}$ The highest value was observed in 0-15 cm (Site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field, the mean nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 268.32 to 488.51 kg ha^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.2.5. Available phosphorous

Among the different land use systems, phosphorous content of soil was found to be the highest in cocoa garden and lowest in forest field and rubber plantation. (Table 14)

In the forest, the mean phosphorous content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.36 to 20.96 kg ha^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too, the mean phosphorous content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.36 to 17.92 kg $ha^{-1.}$ The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-5).

In the cocoa garden, the mean phosphorous content of soil showed a wide range, with a decreasing trend with increase in depth. The value ranged from 9.0 to 18.44 kg ha^{-1}.The highest value was observed in 0-15 cm (site-2) and lowest value observed in 30-60 cm depth (site-5).

In the STCR experimental field also, the trend was same as the above. The value ranged from 5.08 to 25.68 kg ha^{-1}. The highest value was observed in 0-15cm (site-5) and lowest value in 30-60 cm depth (site-3).

In the tapioca filed the mean phosphorous content of soil showed a decreasing tendency with increase in depth. The value ranged from 8.16 to 21.68 kg ha^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-2).

4.2.6. Available Potassium

Among the different land use systems, potassium content of soil was found to be the highest in cocoa garden and lowest in rubber plantation.(Table 15).

In the forest, the mean potassium content of soil showed a decreasing tendency with increase in depth. The value ranged from 150.08 to 514.08 kg ha$^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the rubber plantation too, the mean potassium content of soil showed a decreasing tendency with increase in depth. The value ranged from 120.88 to 292.32 kg ha^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the cocoa garden, the mean potassium content of soil showed a wide range with a decreasing trend with increase in depth. The value ranged from 339.36 to 773.96 kg ha^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-1).

In STCR experimental field also, the trend was the same as above. The value ranged from 224.80 to 514.08 kg ha^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the tapioca field, the mean potassium content of soil showed a decreasing tendency with increase in depth. The value ranged from 138.88 to 487.84 kg ha^{-1}. The highest value was observed in 0-15 cm (site-2) and lowest value in 30-60 cm depth (site-5).

Table 13. Available nitrogen content (kg ha^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	451.58	602.11	589.56	614.66	564.44
F 15-30	424.12	552.64	552.68	527.20	514.66
F 30- 60	402.11	501.76	526.48	489.22	501.76
R 0-15	589.56	426.50	476.67	439.04	413.95
R 30-60	515.01	364.12	427.20	327.55	326.84
R 30-60	440.10	188.16	407.20	213.25	309.13
C 0-15	638.69	363.67	526.11	451.23	438.34
C 15- 30	363.78	321.78	326.14	351.23	338.69
C 30-60	250.88	275.97	301.06	313.60	288.51
S 0- 15	488.86	376.32	442.44	401.49	363.78
S 15-30	439.39	325.32	363.78	376.32	289.32
S 30-60	326.84	289.22	289.21	276.66	266.21
T 0-15	488.51	363.42	313.60	463.42	543.51
T 15-30	301.06	351.23	275.96	275.96	288.51
T 30- 60	291.05	308.86	288.52	301.06	268.32

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 14. Available phosphorous content (kg ha^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	18.96	16.20	14.56	20.96	14.84
F 15-30	15.68	10.88	11.20	12.80	8.08
F 30- 60	10.08	6.20	6.72	7.17	3.36
R 0-15	13.36	13.44	17.92	15.68	13.44
R 30-60	10.08	7.84	11.02	14.56	10.08
R 30-60	5.60	4.48	5.68	8.96	3.36
C 0-15	15.60	19.44	13.24	16.14	14.16
C 15- 30	12.48	16.04	10.64	13.16	10.68
C 30-60	10.64	13.88	9.44	10.68	8.04
S 0- 15	19.68	20.16	14.56	16.80	25.68
S 15-30	15.44	19.04	10.60	4.48	17.92
S 30-60	13.04	8.96	5.08	8.96	7.84
T 0-15	18.40	17.28	21.68	18.64	17.28
T 15-30	13.84	12.54	11.24	14.96	15.84
T 30- 60	11.96	8.16	8.28	9.68	8.88

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 15 . Available potassium (kg ha^{-1}) (mean) content of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	514.08	417.76	430.08	339.36	227.36
F 15-30	393.12	339.36	318.08	215.04	197.12
F 30- 60	255.36	221.76	164.64	150.08	169.12
R 0-15	292.32	281.12	206.08	273.28	283.36
R 30-60	138.88	262.08	126.56	183.68	247.52
R 30-60	122.08	184.80	120.96	120.88	125.44
C 0-15	773.96	557.64	623.28	607.28	508.92
C 15- 30	489.92	514.56	564.48	497.04	503.48
C 30-60	339.36	368.08	439.84	429.29	455.88
S 0- 15	463.68	383.36	338.56	365.12	288.96
S 15-30	315.84	368.48	284.48	329.28	272.16
S 30-60	338.24	285.28	224.80	316.96	236.32
T 0-15	411.04	487.84	384.48	374.12	362.88
T 15-30	305.76	402.08	304.64	318.08	359.52
T 30- 60	227.52	161.28	265.12	240.48	138.88

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2.7. Lime requirement

In the forest, the mean lime requirement of soil showed a decreasing tendency with increase in depth. The value ranged from1.0 to 2.3 t $ha^{-1.}$ The highest value was observed in 0-15 cm and lowest value in 30-60 cm depth (Table 16).

In the rubber plantation too, the mean lime requirement of soil showed a decreasing tendency with increase in depth. The value ranged from 1.0 to 2.3 t $ha^{-1.}$ The highest value was observed in 0-15 cm and lowest value in 30-60 cm depth.

In the cocoa garden, the mean lime requirement of soil showed a decreasing tendency with increase in depth. The value ranged from 1.0 to 2.3t $ha^{-1.}$ The highest value was observed in 0-15 cm and lowest value in 30-60 cm depth.

In the STCR experimental field also, the trend was same as the above. The value generally ranged from 1.0 to 1.8 t $ha^{-1.}$ The highest value was observed in 0-15cm and lowest value in 30-60 cm depth.

In the tapioca field, the mean lime requirement of soil showed a decreasing tendency with increase in depth. The value ranged from 1.0 to 2.3 t $ha^{-1.}$ The highest value was observed in 0-15 cm and lowest value in 30-60 cm depth.

The lime requirement of soil was found to be the highest in the cocoa garden among all the fields.

4.2.8. Available calcium

Among the different land use systems, calcium content of soil was highest in the forest and lowest in STCR experimental field. (Table 17)

In the forest ecosystem, the mean calcium content of soil showed a decreasing tendency with increase in depth. The value ranged from 89.08 to 245.67 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the rubber plantation too, the mean calcium content of soil showed a decreasing tendency with increase in depth. The value ranged from 132.62 to 236.09 mg $kg^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-2).

In cocoa garden, the mean calcium content of soil showed a decreasing tendency with increase in depth. The value ranged from 87.93 to 128.43 mg $kg^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the STCR experimental field, the mean calcium content of soil showed a decreasing tendency with increase in depth. The value ranged from 41.63 to134.83 mg $kg^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the tapioca field also, the trend was the same as above. The value ranged from 68.43 to 168.65 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.2.9. Available magnesium

The magnesium content of soil was found to be the highest in the forest and lowest in STCR experimental field after comparing different fields (Table 18).

In the forest, the magnesium content of soil showed a decreasing tendency with increase in depth. The value ranged from 52.98 to 69.09 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-1).

In the rubber plantation, the mean magnesium content of soil showed an increasing tendency with increase in depth. The value ranged from 52.90 to 66.78 mg $kg^{-1.}$ The highest value was observed in 30-60 cm (site-5) and lowest value in 0-15 cm depth (site-5).

In the cocoa too, the mean magnesium content of soil showed a decreasing tendency with increase in depth. The value ranged from 54.02 to 69.65 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the mean magnesium content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 32.09 to 55.93 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the tapioca field also, the trend was same as the above. The mean magnesium content of soil showed a decreasing tendency with increase in depth. The value ranged from 32.50 to 59.65 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

Table 16 . Lime requirement (t/ha^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	1.8	2.3	1.8	1.8	1.8
F 15-30	1.4	1.8	1.4	1.4	1.4
F 30- 60	1.0	1.5	1.0	1.0	1.0
R 0-15	1.8	1.8	1.8	1.8	2.3
R 30-60	1.4	1.4	1.4	1.4	1.8
R 30-60	1.0	1.0	1.0	1.0	1.4
C 0-15	2.3	1.8	1.8	1.8	2.3
C 15- 30	1.8	1.4	1.4	1.4	1.8
C 30-60	1.0	1.0	1.0	1.0	1.0
S 0- 15	2.3	1.8	1.8	1.4	1.8
S 15-30	1.8	1.4	1.4	1.4	1.4
S 30-60	1.4	1.0	1.0	1.4	1.4
T 0-15	1.8	1.8	2.3	1.8	1.8
T 15-30	1.4	1.4	1.4	1.8	1.8
T 30- 60	1.0	1.0	1.0	1.8	1.8

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 17 . Available calcium content (mg kg^{-1}) **mean of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	245.67	236.62	211.52	197.08	189.87
F 15-30	176.90	118.90	89.04	98.07	93.04
F 30- 60	98.08	168.72	132.95	89.08	154.62
R 0-15	236.09	154.87	134.09	132.22	104.09
R 30-60	189.54	175.90	187.49	198.09	168.97
R 30-60	166.55	132.62	143.94	154.99	187.99
C 0-15	87.93	128.43	109.05	116.93	118.79
C 15- 30	87.90	111.99	96.98	104.96	97.55
C 30-60	68.94	104.98	82.87	88.09	93.44
S 0- 15	134.83	122.93	120.89	100.65	98.03
S 15-30	65.98	87.90	65.72	79.78	77.92
S 30-60	56.19	87.39	54.02	69.03	68.43
T 0-15	168.65	164.09	154.09	138.82	123.89
T 15-30	102.29	112.83	91.62	82.92	80.98
T 30- 60	45.92	48.35	54.92	41.63	49.28

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 18. Available magnesium content (mg kg^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	69.09	68.09	66.98	66.67	64.89
F 15-30	58.90	59.98	62.90	60.94	61.76
F 30- 60	52.98	54.09	60.76	56.90	60.02
R 0-15	56.84	56.02	55.49	55.42	52.90
R 30-60	62.84	61.04	64.98	62.32	65.90
R 30-60	64.89	65.90	65.98	66.43	66.78
C 0-15	69.65	68.09	65.11	65.09	62.93
C 15- 30	68.04	65.39	64.03	63.62	60.32
C 30-60	63.60	61.94	60.98	59.65	54.02
S 0- 15	55.93	54.09	53.28	53.29	53.03
S 15-30	53.90	52.09	51.62	51.89	51.90
S 30-60	42.76	43.02	42.84	32.50	33.98
T 0-15	59.65	59.54	59.08	58.25	56.98
T 15-30	54.82	53.09	50.94	53.01	52.90
T 30- 60	39.08	34.28	33.98	32.09	34.65

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2.10. Available boron

Among the different land use systems, boron content of soil was found to be the highest in the forest and lowest in STCR experimental field and tapioca plantation. In all the fields, with increasing slope percentage the content of boron decreased (Table 19).

In the forest, the mean boron content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.01 to 2.30 mg kg^{-1}. The highest value was observed in 0-15 cm (site-2) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too, the mean boron content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.09 to 2.80 mg $kg^{-1.}$ The highest value was observed in 15-30 cm (site-1) and lowest value in 30-60 cm depth (site-5).

The mean boron content of cocoa field decreased with increase in depth. The value ranged from 0.20 to 1.60 mg kg^{-1}. The highest value was observed in 15-30 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the STCR experimental field, the mean boron content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.00 to 1.30 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was same as the above. The value ranged from0.00–1.30 mg kg^{-1}. The highest value was observed in 15-30 cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.2.11. Available sulphur

Among the different land use systems, sulphur content of soil was highest in the cocoa garden and lowest in tapioca field (Table 20).

In the forest, the sulphur content of soil showed a decreasing tendency with increase in depth. The value ranged from 2.34 to 13.34 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

In the rubber plantation too, the sulphur content of soil showed a decreasing tendency with increase in depth. The value ranged from 2.14 to 12.31 mg kg^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-4).

In the cocoa, the sulphur content of soil showed a decreasing tendency with increase in depth. The value ranged from 2.75 to 19.32 mg kg^{-1}. The highest value was observed in 0-15 cm (Site-2) and lowest value in 30-60 cm depth (site-2).

In the STCR experimental field, the sulphur content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 4.11 to 12.14 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-2).

In the tapioca field also, the trend was the same as above. The value ranged from 1.11 to 11.01 mg kg^{-1}. The highest value was observed in 0-15 cm (site-5) and lowest value in 30-60 cm depth (site-4).

4.2.12. Available iron

Among the different land use systems, iron content of soil was found to be the highest in the forest and lowest in STCR experimental field (Table 21).

In the forest, the iron content of soil showed a decreasing tendency with increase in depth. The value ranged from 98.76 to 139.42 mg kg^{-1}. The highest value was observed in 0-15 cm (site-5) and lowest value in 30-60 cm depth (site-4).

In the rubber plantation too, the iron content of soil showed a decreasing tendency with increase in depth. The value ranged from 65.92 to 136.92 mg kg^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-2).

Under the cocoa plantation, the iron content of soil showed a decreasing tendency with increase in depth. The value ranged from 97.54 to 132.99 mg kg^{-1}. The highest value was observed in 0-15 cm (site-2) and lowest value in 30-60 cm depth (site-2).

In the STCR experimental field, the iron content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 46.65 to 109.85 mg kg^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-2). In the tapioca field also, the trend was same as the above. The value ranged from 56.98 to 146.07 mg kg^{-1}. The highest value was observed in 0-15 cm (site-5) and lowest value in 30-60 cm depth (site-4).

Table 19 . Available boron(mg kg^{-1}) (mean) content in soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	2.20	2.30	1.70	0.84	0.20
F 15-30	1.80	1.88	1.06	0.75	0.13
F 30- 60	1.40	1.20	1.04	0.39	0.11
R 0-15	0.60	0.10	0.40	0.20	0.01
R 30-60	2.80	2.10	0.50	0.30	0.21
R 30-60	1.30	0.12	0.11	0.10	0.09
C 0-15	1.01	0.02	0.80	0.33	0.44
C 15- 30	1.60	1.40	0.40	0.30	0.20
C 30-60	1.50	0.20	0.50	0.20	0.20
S 0- 15	1.30	1.02	0.20	0.10	0.30
S 15-30	0.80	0.33	1.70	0.42	0.14
S 30-60	0.30	0.20	0.60	0.14	-
T 0-15	0.11	0.08	0.10	0.02	-
T 15-30	1.30	1.10	0.70	0.84	0.30
T 30- 60	0.70	0.40	0.20	0.30	-

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 20 . Available sulphur content (mg kg^{-1}) **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	13.34	12.12	11.64	6.93	10.50
F 15-30	9.22	9.08	8.88	4.16	5.12
F 30- 60	5.12	4.96	4.32	2.34	3.02
R 0-15	10.50	8.94	12.31	6.94	9.72
R 30-60	5.14	4.32	9.04	4.06	5.19
R 30-60	3.04	2.14	4.98	2.33	2.99
C 0-15	10.12	19.32	12.10	11.32	10.08
C 15- 30	5.26	4.95	4.92	8.38	5.16
C 30-60	3.16	2.75	2.94	4.66	3.02
S 0- 15	12.14	7.36	10.51	9.32	10.15
S 15-30	7.02	5.21	5.33	5.01	6.34
S 30-60	4.36	4.11	4.94	4.22	6.12
T 0-15	10.51	9.84	7.36	8.82	11.01
T 15-30	6.21	5.34	4.32	4.56	7.32
T 30- 60	2.32	1.32	1.11	1.21	3.11

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 21 . Available iron(mg kg^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	136.23	138.43	133.98	129.56	139.42
F 15-30	130.30	131.64	129.58	127.62	132.93
F 30- 60	108.90	115.98	102.82	98.76	106.98
R 0-15	134.32	132.93	133.27	136.92	132.87
R 30-60	108.49	106.82	107.62	109.65	108.11
R 30-60	69.76	65.92	75.96	66.65	68.95
C 0-15	113.70	132.99	114.89	113.92	115.94
C 15- 30	103.99	112.78	102.96	103.98	104.54
C 30-60	98.88	100.87	97.84	98.65	97.54
S 0- 15	103.55	102.99	109.85	106.43	103.35
S 15-30	90.41	89.93	92.99	90.66	90.84
S 30-60	50.32	46.65	51.23	50.90	50.55
T 0-15	146.07	135.89	142.90	128.09	142.32
T 15-30	117.10	109.99	113.89	98.90	116.98
T 30- 60	69.76	56.98	69.09	65.98	6.66

F- Forest field

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2.13. Available manganese

Among the different land use system, manganese content of soil was found to be the highest in the forest and lowest in rubber plantation.(Table 22).

In the forest, the mean manganese content of soil showed a decreasing tendency with increase in depth. The value ranged from 43.89 to 72.76 mg kg^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-4).

In the rubber plantation too, the mean manganese content of soil showed a decreasing tendency with increase in depth. The value ranged from 18.76 to 47.17 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the cocoa, the mean manganese content of soil showed a decreasing tendency with increase in depth. The value ranged from 28.55 to 61.35 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the mean manganese content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 22.92 to 49.61 mg kg^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was same as the above. The value ranged from 30.93 to 47.35 mg kg^{-1}. The highest value was observed in 0-15cm (site-2) and lowest value observed in 30-60 cm depth (site-4).

4.2.14. Available copper

Among the different land use system, copper content of soil was found to be the highest in the forest and lowest in STCR experimental field (Table 23).

In the forest, the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 11.06 to 25.93 mg kg^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-2).

In the rubber plantation too, the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.11 to 21.11mg kg^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-3).

In the cocoa, the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 7.04 to 18.03 mg $kg^{-1.}$ The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the mean copper content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 2.01 to 12.55 mg $kg^{-1.}$ The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was same as the above. The value ranged from 4.08 to 15.26 mg kg^{-1}. The highest value was observed in 0-15 cm (site-2) and lowest value in 30-60 cm depth (site-3).

4.2.15. Available zinc

Among the different land use system, zinc content of soil was found to be the highest in the forest and lowest in tapioca field (Table 24).

In the forest, the mean zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.32 to 4.14 mg kg^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-1).

In the rubber plantation too, the mean zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.01 to 2.93mg kg^{-1}. The highest value was observed in 0-15 cm (site-5) and lowest value in 30-60 cm depth (site-1).

In the cocoa, the mean zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.01 to 3.63 mg kg^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-2).

In the STCR experimental field, the mean zinc content of soil showed a wide range of decreasing tendency with increase in depth.The value ranged from 0.65 to 1.83 mg kg^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value ranged from 0.33 to 2.49 mg kg^{-1}. The highest value was noticed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-4).

Table 22 . Available manganese content (mg Kg^{-1})(mean) **of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	68.26	60.32	61.56	72.76	69.98
F 15-30	50.10	58.65	52.98	55.89	56.87
F 30- 60	46.80	47.43	49.87	43.89	47.78
R 0-15	47.17	44.98	39.88	37.54	36.65
R 30-60	23.76	22.89	26.61	24.43	22.98
R 30-60	18.77	18.87	22.21	19.76	18.76
C 0-15	61.35	54.56	53.42	50.87	51.52
C 15- 30	51.24	42.89	49.65	33.93	33.03
C 30-60	48.90	39.65	36.93	28.94	28.55
S 0- 15	49.61	44.98	42.90	32.84	32.56
S 15-30	39.78	37.03	38.65	29.45	29.35
S 30-60	34.44	35.48	33.84	24.32	22.92
T 0-15	47.17	47.35	42.48	38.74	37.34
T 15-30	38.58	37.09	31.98	33.67	34.84
T 30- 60	33.20	34.56	30.98	30.93	31.09

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 23 . Available copper content (mg kg^{-1}) **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	24.99	24.87	23.94	25.93	25.03
F 15-30	24.94	24.09	22.86	24.44	23.83
F 30- 60	11.12	11.06	11.73	11.88	12.09
R 0-15	19.58	20.76	18.86	21.11	19.76
R 30-60	14.47	15.44	13.25	16.60	14.06
R 30-60	3.41	5.87	3.11	5.02	3.99
C 0-15	13.78	13.89	14.06	14.12	16.03
C 15- 30	17.99	17.94	18.03	18.00	16.88
C 30-60	9.93	8.04	8.78	8.35	7.04
S 0- 15	10.99	11.12	10.85	12.55	11.97
S 15-30	4.31	4.96	4.28	6.98	3.96
S 30-60	2.14	2.44	2.16	3.44	2.01
T 0-15	14.70	15.26	14.32	14.56	14.07
T 15-30	14.67	14.32	14.08	14.44	13.08
T 30- 60	4.79	4.44	4.08	4.56	4.32

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 24 . Available zinc content (mg kg^{-1}) **content of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	3.56	4.04	4.14	3.98	3.04
F 15-30	2.05	3.11	3.42	2.87	2.11
F 30- 60	1.32	2.14	2.01	1.43	1.42
R 0-15	2.24	2.25	2.05	2.32	2.93
R 30-60	1.91	1.95	1.83	1.98	1.90
R 30-60	1.01	1.04	1.11	1.07	1.13
C 0-15	3.41	3.63	3.51	3.42	2.66
C 15- 30	1.86	1.97	1.85	1.63	1.07
C 30-60	1.26	1.38	1.24	1.22	1.01
S 0- 15	1.65	1.78	1.83	1.54	1.62
S 15-30	0.90	1.25	1.29	0.87	0.97
S 30-60	0.77	0.98	0.99	0.67	0.65
T 0-15	2.49	1.69	1.92	1.52	1.67
T 15-30	1.69	1.09	1.23	0.74	0.86
T 30- 60	1.04	0.68	0.87	0.33	0.34

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.2.17. Anion exchange capacity

Among the different land use system, anion exchange capacity of soil was found to be the highest in the tapioca field and lowest in forest (Table 25).

In forest, the anion exchange capacity of soil increased with increase in depth. The mean value ranged from 1.11 to 3.03 Cmol (-) kg^{-1}. The highest value was observed in 30- 60 cm depth (site-4) and lowest value in 0-15cm (site-1).

In rubber plantation too, anion exchange capacity of soil increased with increasing in depth. The mean value ranged from 1.42- 2.98 Cmol(-)kg^{-1}. The highest value was observed in 30- 60 cm depth (site-5) and lowest value in 0-15cm (site- 1).

In cocoa garden, the anion exchange capacity of soil showed a wide range with an increased value with increase in depth. The mean value ranged from 1.14- 2.43 Cmol(-)kg^{-1} The highest value was observed in 30-60 cm depth(site-5) and lowest value in 0-15cm(site-1).

In STCR experimental field, also trend was same as the above. The mean value ranged from 1.02-3.12 Cmol(-)kg^{-1}. The highest value was observed in 30- 60 cm depth (site-5) and lowest value in 0-15 cm (site-1).

In tapioca field, the of anion exchange capacity soil showed a increasing tendency with increasing in depth. The average value ranged from 1.14- 3.88 Cmol(-)kg^{-1}. The highest value was observed in 30-60 cm (site-5) and lowest value observed in 0-15cm depth (site-1).

4.2.18. Cation exchange capacity

Among the different land use system, cation exchange capacity of soil was found to be the highest in the rubber field and lowest in cocoa garden. (Table 26).

In forest ecosystem, the cation exchange capacity of soil decreased with increase in depth. The mean value ranged from 2.02 to 3.75 Cmol (+) kg^{-1}. The highest value was observed in 0-15cm depth (site-4) and lowest value in 30-60 cm depth (site-2).

In rubber plantation too, cation exchange capacity of soil decreased with increase in depth. The mean value ranged from 2.72- 3.84 Cmol(+)kg^{-1}. The highest value was observed in 0-15 cm depth (site-2) and lowest value in 30-60 cm depth (site- 5).

In cocoa garden, the anion exchange capacity of soil showed a decreased value with increase in depth. The mean value ranged from 2.21 – 3.61 Cmol(+)kg^{-1} The highest value was observed in 0-15 cm depth(site-1) and lowest value in 30-60 cm depth (site-5).

In STCR experimental field also, trend was same as the above. The mean value ranged from 2.08-3.75 Cmol(+)kg^{-1}. The highest value was observed in 0-15 cm depth (site-1) and lowest value in 30-60 cm (site-4).

In tapioca field, the of cation exchange capacity soil showed a decreasing tendency with increasing in depth. The average value ranged from 2.41- 3.54 Cmol(+)kg^{-1}. The highest value was observed in 0-15 cm (site-2) and lowest value observed in 0-15 cm depth (site-3).

4.2.19. Silica sesquioxide ratio

Among the different land use sytem, silica sesquioxide ratio of soil was found to be the highest in the natural forest and lowest in tapioca field. In all these fields with increasing slope percentage the value of silica sesquioxide ratio decreased (Table 27).

In the forest, the silica sesquioxide ratio of soil showed a decreasing tendency with increase in depth. The value ranged from 1.34 to 2.73. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too, the silica sesquioxide ratio of soil showed a decreasing tendency with increase in depth. The value ranged from1.43 to 1.88. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the cocoa field, the silica sesquioxide ratio of soil showed a decreasing tendency with increase in depth. The value ranged from 1.33 to 1.77. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field too, the silica sesquioxide ratio of soil showed a decreasing tendency with increase in depth. The value ranged from 1.31 to 1.71. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value ranged from 1.22 to 1.77. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

Table 25 . Anion exchange capacity (cmol(-) kg^{-1})(mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	1.11	1.88	2.04	2.11	2.52
F 15-30	1.61	2.29	2.05	2.41	2.61
F 30- 60	1.98	2.33	2.04	3.03	2.30
R 0-15	1.42	1.91	2.14	2.24	3.41
R 30-60	2.31	1.08	2.64	2.06	3.04
R 30-60	2.91	0.93	2.02	2.11	2.98
C 0-15	1.14	1.74	2.01	2.01	2.14
C 15- 30	1.16	1.93	1.98	2.40	2.64
C 30-60	1.32	2.04	2.33	2.55	2.01
S 0- 15	1.02	2.04	2.34	2.64	3.04
S 15-30	1.11	2.05	2.26	2.68	3.06
S 30-60	1.41	1.98	3.01	3.07	3.12
T 0-15	1.14	1.99	1.98	2.04	2.31
T 15-30	1.32	2.35	2.04	2.98	2.64
T 30- 60	1.91	2.09	2.11	3.04	3.88

F- Forest

R- Rubber plantatin

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 26 . Cation exchange capacity (Cmol(+)kg^{-1} **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	3.61	2.28	3.05	3.75	2.88
F 15-30	3.69	2.14	2.95	3.58	2.69
F 30- 60	3.54	2.02	2.26	3.14	2.46
R 0-15	3.81	3.84	3.40	3.37	3.05
R 30-60	3.80	3.80	3.16	3.35	2.85
R 30-60	3.81	3.75	2.98	3.28	2.72
C 0-15	3.61	3.10	3.28	3.37	2.78
C 15- 30	3.24	3.11	3.35	3.35	2.45
C 30-60	2.81	3.01	3.41	3.32	2.21
S 0- 15	3.79	3.35	3.61	3.09	2.89
S 15-30	3.75	3.23	3.45	2.71	2.98
S 30-60	3.64	2.72	3.25	2.08	2.95
T 0-15	3.52	3.54	3.31	3.09	3.41
T 15-30	3.10	3.52	2.69	2.93	3.29
T 30- 60	2.88	3.49	2.41	2.87	3.13

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 27 . Silica sesquioxide ratio (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	2.73	2.52	2.01	1.98	1.97
F 15-30	2.22	2.01	1.96	1.95	1.88
F 30- 60	2.01	1.65	1.73	1.73	1.34
R 0-15	1.88	1.84	1.72	1.65	1.61
R 30-60	1.73	1.71	1.68	1.64	1.52
R 30-60	1.64	1.62	1.52	1.41	1.43
C 0-15	1.77	1.72	1.70	1.68	1.48
C 15- 30	1.41	1.66	1.63	1.54	1.37
C 30-60	1.63	1.53	1.47	1.39	1.33
S 0- 15	1.71	1.69	1.64	1.62	1.61
S 15-30	1.58	1.51	1.58	1.50	1.43
S 30-60	1.44	1.37	1.38	1.48	1.31
T 0-15	1.77	1.71	1.67	1.52	1.48
T 15-30	1.68	1.68	1.48	1.42	1.38
T 30- 60	1.66	1.37	1.33	1.34	1.22

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.3. Biological parameters

4.3.1. Fungal population

Among the different land use system, fungal count of soil was found to be the highest in the cocoa garden and lowest in forest and rubber plantation (Table 28).

In the forest, the fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from 6 to 71 x 10^{-4} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too, the fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from 6 to 75 x10^{-4} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the cocoa field, the fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from14-79 x10^{-4} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from11- 62 x 10^{-4} cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value ranged from 8-73 x10^{-4} cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.3.2. Bacterial population

Among the different land use system, bacterial count of soil was found to be the highest in the natural forest and lowest in cocoa garden (Table 29).

In forest, the bacterial count of soil showed a decreasing tendency with increase in depth. The value ranged from 8 to 61 x10^{-6} cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too the bacterial count of soil showed a decreasing tendency with increase in depth. The value ranged from 9 to 44 x 10^{-6} cfu g^{-1}. The highest value was observed in 15-30 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In cocoa field, the bacterial count of soil showed a decreasing tendency with increase in depth. The value ranged from 3 to 42 x 10^{-6} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value o in 30-60 cm depth (site-5).

In the STCR experimental field, the bacterial count of soil showed a decreasing tendency with increase in depth. The value ranged from12 to 46 x10^{-6} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value generally ranged from 8 to 39 x 10^{-6} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

4.3.4. Actinomycetes population

The count of actinomycetes of soil was found to be the highest in the forest and lowest in rubber plantation, cocoa garden and tapioca field (Table 30).

In the forest field, the actinomycetes count of soil showed a decreasing tendency with increase in depth. The value ranged from 12 to 75x10^{-5} cfu g^{-1}. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the rubber plantation too, the actinomycetes count of soil showed a decreasing tendency with increase in depth. The value ranged from 9 to 70 x10^{-5}. cfu g^{-1} The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the cocoa field, the actinomycetes count of soil showed a decreasing tendency with increase in depth. The value ranged from 9 to 68 x 10^{-5} cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from 11 to 60 x10^{-5} cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5).

In the tapioca field also, the trend was the same as above. The value ranged from 9 to 62 x10^{-5} cfu g^{-1}. The highest value was observed in 15-30 cm (site-1) and lowest value in 30-60 cm depth (site-5).

Table 28 . Fungal population (x 10^4 cfu g^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	71	70	68	61	60
F 15-30	42	40	30	33	28
F 30- 60	12	9	8	6	6
R 0-15	75	64	61	60	58
R 30-60	33	25	23	21	18
R 30-60	12	12	11	8	6
C 0-15	79	72	71	70	68
C 15- 30	32	29	24	21	23
C 30-60	18	12	11	16	14
S 0- 15	62	58	56	54	51
S 15-30	46	49	42	41	40
S 30-60	24	22	21	18	11
T 0-15	73	71	68	62	58
T 15-30	31	29	27	24	19
T 30- 60	14	11	8	13	8

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 29 . Bacterial population(x 10^6 cfu g^{-1}) **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	61	58	56	54	42
F 15-30	39	39	38	34	31
F 30- 60	14	11	13	9	8
R 0-15	44	42	39	38	31
R 30-60	29	28	24	21	18
R 30-60	16	14	12	9	8
C 0-15	42	41	40	39	36
C 15- 30	39	32	33	15	22
C 30-60	10	10	8	3	6
S 0- 15	46	41	33	32	30
S 15-30	26	24	23	22	21
S 30-60	19	16	15	14	12
T 0-15	39	38	38	36	34
T 15-30	24	26	22	22	21
T 30- 60	13	17	11	9	8

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 30. Actinomycetes population (x 10^5 cfu g^{-1}) (mean) of soil samples of the different fields

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	75	72	69	66	60
F 15-30	42	40	39	38	25
F 30- 60	20	21	18	17	12
R 0-15	70	69	67	64	58
R 30-60	42	39	34	29	24
R 30-60	25	18	14	12	9
C 0-15	68	66	62	58	54
C 15- 30	28	26	23	21	20
C 30-60	16	14	11	11	9
S 0- 15	60	54	52	43	42
S 15-30	26	24	22	19	19
S 30-60	17	12	11	15	16
T 0-15	62	58	58	54	53
T 15-30	24	22	21	21	19
T 30- 60	13	12	14	11	9

F- Forest
R- Rubber plantation
C- Cocoa field
S- STCR experimental field
T- Tapioca field

4.3.5. Enzyme activity

4.3.5.1 Asparginase

Among the different land use systems, asparginase enzyme activity of soil was found to be the highest in the forest and lowest in tapioca field (Table 31).

In the forest ecosystem, the mean asparginase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 20.11 to 79.1 (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1})2. The highest value was observed in 0-15 cm (site-1) and lowest value in 30-60 cm depth (site-3).

In the rubber plantation too, the mean asparginase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 11.23 to 68.29 (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1}). The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-2).

In the cocoa field, the mean asparginase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from14.22 to 75.25 (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1}). The highest value was observed in 0-15 cm (site-5) and lowest value in 30-60 cm depth (site-2).

In the STCR experimental field, the mean asparginase enzyme activity of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from12.74 to 68.19 (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1}). The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-1).

In the tapioca field also the trend was the same as above. The value ranged from10.18 to 52.29 (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1}). The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-2).

4.3.5.2 Dehydrogenase

Among the different land use systems, dehydrogenase enzyme activity of soil was found to be the highest in the natural forest and lowest in STCR experimental field (Table 32).

In the forest ecosystem, the mean dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 211.65 to 462.14

μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1}. The highest value was observed in 0-15cm (Site-2) and lowest value in 30-60 cm depth (site-3).

In the rubber plantation too the mean dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 234.56 to 464.96 μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1}. The highest value was observed in 15-30 cm (Site-3) and lowest value in 30-60 cm depth (site-5).

In the cocoa field, the mean dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 104.14 to 486.0614 μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1}. The highest value was observed in 0-15 cm (Site-5) and lowest value in 30-60 cm depth (site-3).

In the STCR experimental field, the mean dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 83.76 to 434.14 μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1}. The highest value was observed in 0-15cm (site-5) and lowest value observed in 30-60 cm depth (site-3).

In the tapioca field also, the trend was same as the above. The value ranged from 98.36 to 449.37 μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1}. The highest value was observed in 0-15 cm (site-5) and lowest value observed in 30-60 cm depth (site-2).

4.3.5.3 Urease

Among the different land use systems, urease enzyme activity of soil was found to be the highest in the natural forest and lowest in rubber plantation (Table 33).

In the forest, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 401.76 to 664.65ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The highest value was observed in 0-15cm (site-4) and lowest value observed in 30-60 cm depth (site-5).

In the rubber plantation too, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 168.16 to 588.54 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (Site-3) and lowest value in 30-60 cm depth (site-2).

In the cocoa, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 249.09 to 639.88. The highest value was observed in 0-15 cm (Site-5) and lowest value in 30-60 cm depth (site-5).

In the STCR experimental field, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 272.64 to 484.86 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The highest value was observed in 0-15cm (Site-3) and lowest value in 30-60 cm depth (site-4).

In the tapioca field also, the trend was the same as above. The value ranged from 272.14 to 588.41 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (Site-5) and lowest value in 15-30 cm depth (site-4).

4.3.5.4 Phosphatase

Among the different land use systems, phosphatase enzyme activity was found to be highest in cocoa garden and lowest in tapioca field (Table 34).

In the forest field, the mean phosphatase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 13.92 to 54.88 of P-nitrophenol released g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-4).

In the rubber plantation, the mean phosphatase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 24.22 to 46.89 of P-nitrophenol released g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (site-4) and lowest value in 30-60 cm depth (site-4).

In the cocoa garden, the mean phosphatase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 13.98 to 55.98 of P-nitrophenol released g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-1).

In the STCR experimental field, the mean phosphatase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 23.01 to 46.63 of P-nitrophenol released g^{-1} of soil hr^{-1}. The highest value was observed in 0-15 cm (site-3) and lowest value in 30-60 cm depth (site-4).

In the tapioca field, the mean phosphatase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 9.67 to 23.98 of P- nitrophenol released g^{-1} of soil hr^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-3).

Table 31 . Asparginase enzyme activity (phenyl mercuric acetate hydrolysed g^{-1} of soil hr^{-1}) **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	79.12	76.34	77.44	82.32	69.11
F 15-30	42.29	38.37	34.39	38.23	30.33
F 30- 60	24.39	21.2	20.11	26.8	21.19
R 0-15	31.19	52.19	56.64	68.29	64.2
R 30-60	27.28	28.67	29.12	35.13	33.33
R 30-60	17.29	11.23	18.21	13.35	12.09
C 0-15	75.19	65.23	68.29	73.09	75.25
C 15- 30	38.11	35.9	36.19	36.13	36.07
C 30-60	22.84	14.22	27.20	19.96	21.22
S 0- 15	53.29	56.28	68.19	62.54	42.02
S 15-30	32.11	34.21	42.11	39.18	26.66
S 30-60	12.74	15.78	12.49	20.9	14.23
T 0-15	48.19	43.09	52.29	50.33	39.09
T 15-30	26.11	24.23	30.12	29.19	22.23
T 30- 60	13.22	10.18	13.11	14.22	11.55

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 32 . Dehydrogenase enzyme activity (μg of TPF hydrolysed g^{-1} of soil 24 hrs^{-1} **(mean)of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	454.12	462.14	420.97	449.04	451.63
F 15-30	399.32	340.82	273.14	398.96	463.14
F 30- 60	276.14	273.14	211.65	301.41	309.99
R 0-15	398.41	398.03	459.34	432.14	364.32
R 30-60	378.91	273.81	464.96	383.36	294.14
R 30-60	340.14	268.39	443.41	371.14	234.56
C 0-15	449.34	281.41	465.39	384.63	486.06
C 15- 30	384.23	194.54	273.14	193.41	452.14
C 30-60	339.41	104.48	104.14	189.46	398.14
S 0- 15	387.98	387.37	434.17	194.32	233.41
S 15-30	274.14	198.46	278.34	182.36	193.07
S 30-60	224.13	108.39	274.14	99.38	83.76
T 0-15	398.14	214.64	275.32	378.36	449.37
T 15-30	468.34	104.34	241.47	240.75	381.08
T 30- 60	343.09	98.36	98.75	198.99	246.75

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 33. Urease enzyme activity (urea hydrolysed g^{-1} of soil hr^{-1}) **(mean) of soil samples of different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	454.11	624.16	589.36	664.65	568.44
F 15-30	444.62	531.43	552.68	527.38	515.65
F 30- 60	408.41	426.14	427.48	409.21	401.76
R 0-15	414.95	429.49	588.54	479.67	438.04
R 30-60	326.84	365.02	525.08	447.22	327.52
R 30-60	264.12	168.16	441.09	408.14	214.64
C 0-15	439.31	339.41	524.72	452.32	639.88
C 15- 30	348.68	367.14	326.88	351.09	341.76
C 30-60	288.51	265.92	303.29	314.64	249.09
S 0- 15	404.14	372.32	484.86	403.84	367.76
S 15-30	364.76	374.12	444.39	374.23	378.23
S 30-60	292.21	291.41	314.89	272.64	291.61
T 0-15	483.51	365.41	314.65	464.24	588.41
T 15-30	306.15	356.23	274.32	272.14	287.14
T 30- 60	308.14	389.41	289.14	304.05	289.32

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

Table 34 . Phosphatase enzyme activity (P- nitrophenol released g^{-1} of soil hr^{-1}) **(mean) of soil samples of the different fields**

Depth (cm)	Site-1	Site-2	Site-3	Site-4	Site-5
F 0-15	25.20	45.11	54.88	44.92	34.34
F 15-30	16.82	36.33	35.98	36.01	25.64
F 30- 60	15.34	24.96	24.76	13.92	13.99
R 0-15	46.89	46.33	37.30	35.96	36.34
R 30-60	35.34	45.90	34.98	34.87	34.45
R 30-60	24.66	24.43	24.54	24.22	24.94
C 0-15	45.32	55.98	55.43	55.04	45.33
C 15- 30	34.56	34.33	44.67	44.39	34.98
C 30-60	24.11	14.02	23.19	23.33	13.98
S 0- 15	34.67	34.87	44.63	35.03	25.22
S 15-30	23.67	33.78	33.45	33.98	23.98
S 30-60	23.01	23.65	32.88	32.98	23.21
T 0-15	23.98	13.98	14.02	13.56	22.89
T 15-30	12.78	13.03	13.22	12.98	12.65
T 30- 60	11.09	10.69	9.67	10.34	15.87

F- Forest

R- Rubber plantation

C- Cocoa field

S- STCR experimental field

T- Tapioca field

4.3.9. Earth worm count

The highest number of earth worms was found in forest field (38 nos m^{-2}) followed by cocoa garden (26 nos. m^{-2}), rubber plantation (22 nos m^{-2}), STCR experimental field (16 nos. m^{-2}) and tapioca field (15 nos. m^{-2}) (Table 35) (Plate 2).

4.3.10. Termite mound

On surveying the whole area under each field, it was found that the highest number of termite mounds was in forest field (12) followed by cocoa garden (6), rubber plantation (5), STCR experimental field (nil) and tapioca field (nil) (Table 36) (Plate 3).

Table 35. Count of earthworms of different fields under investigation

No: of earthworms/m^2				
Forest	Cocoa field	Rubber plantation	STCR experimental field	Tapioca field
38	26	22	16	15

Table 36. Count of termite mounds of different fields under investigation

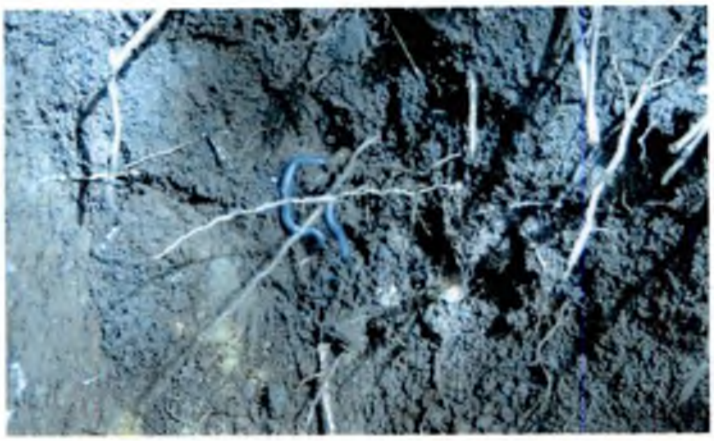
Termite mounds/field				
Forest	Cocoa field	Rubber plantation	STCR experimental field	Tapioca field
12	6	5	Nil	Nil

PLATE 2 . **Photograph showing the presence of earthworms in different fields**

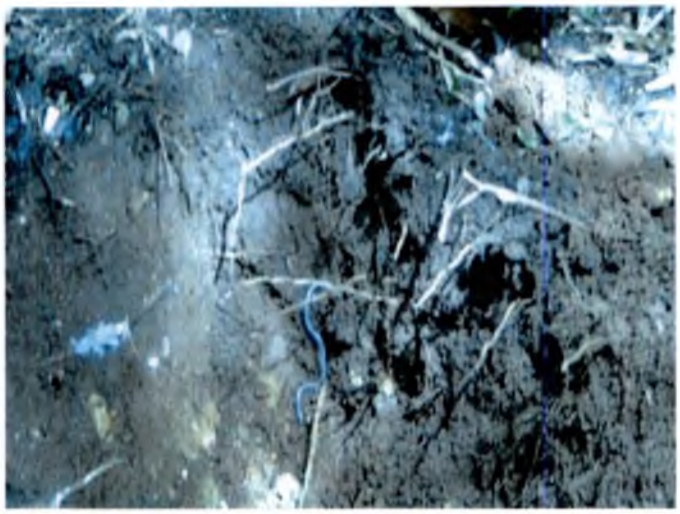
a) **Forest field**

b) **Rubber plantation**

PLATE 2 . Photograph showing the presence of earthworms in different fields



a) Forest field



b) Rubber plantation

PLATE 3 . View of termite mounds

a) Under bamboo trees

b) Under mixed vegetation

Evaluation based on soil quality indicators

Table 37. Scoring based on soil quality indicators

Field	Indicators												
	pH	OC (%)	BD Mg m^{-3}	N Kg ha^{-1}	P Kg ha^{-1}	K Kg ha^{-1}	S mg Kg^{-1}	B mg Kg^{-1}	Fe mg Kg^{-1}	Mn mg Kg^{-1}	Zn mg Kg^{-1}	Cu mg Kg^{-1}	Total score
Forest	1	3	2	4	3	4	1	3	4	4	4	4	37
Rubber	1	3	2	2	2	4	1	2	4	4	3	4	32
Cocoa	1	3	2	2	3	4	1	2	4	4	4	4	34
STCR	1	2	2	2	2	4	1	1	4	4	3	4	30
Tapioca	1	2	1	2	3	4	1	2	4	4	3	4	31

The maximum score which can be obtained is 48. Among the different fields, the forest was rated superior with a score of 37 followed by cocoa garden with a score of 34.The scores obtained for rubber plantation, tapioca field and STCR experimental fields were almost similar.

the tapioca field fell under class 2 (280- 420 kg ha^{-1}). The t-test revealed significant difference from the standard value.

4.4.4. Available phosphorous

The phosphorous content in forest soil came under class 3 (15-25 kg ha^{-1}). The t-test revealed significant difference from the standard values (Table 41).The phosphorous content in rubber plantation fell under class 2 (10-15 kg ha^{-1}). The t test revealed significant difference from the standard value. The phosphorous content in cocoa garden soil fell under class 3 (15-25 kg ha^{-1}). The t-test revealed significant difference from the standard values. The phosphorous content in STCR experimental field fell under class 2 (10-15kg ha^{-1}). The t test revealed significant difference from the standard value. The phosphorous content in tapioca field came under class 3(15-25kg ha^{-1}). The t-test revealed significant difference from the standard values.

4.4.5. Available potassium

The potassium content in forest soils fell under class 4 (>280 kg ha^{-1}). The t-test revealed significant difference from the standard value and it was found to be high (Table 42). The potassium content in rubber plantation comes under class 4 (>280 kg ha^{-1}). The t-test revealed significant difference from the standard value and it was found to be high. The potassium content in cocoa garden fell under class 4 (>280 kg ha^{-1}). The potassium content STCR experimental field fell under class 4 (>280 kg ha^{-1}). The t-test revealed significant difference from the standard value and it was found to be high. The potassium content in tapioca field soils fell under class 4 (>280 kg ha^{-1}). The t-test revealed significant difference from the standard value and it was found to be high.

4.4.6. Available boron

The boron content in forest soil fell under class 3 (0.7-1.5 mg kg^{-1}).The t test revealed that there is significant difference from the standard value (Table 43).The boron content in rubber plantation fell under class 2 (0.3-0.7 mg kg^{-1}).The t test revealed that there is significant difference from the standard value. The boron content in cocoa garden falls under class 2(0.3-0.7 mg kg^{-1}). The t test revealed that there is significant difference from the standard value. The boron content in STCR experimental field fell under class1 (< 0.3 mg kg^{-1}). The t test revealed that there is significant difference from the standard value and it was found to be high. The boron content in tapioca field fell under class 2 (0.3-0.7 mg kg^{-1}). The t test revealed that there is significant difference from the standard value content in tapioca field fell under class 4 (>10 mg kg^{-1}).The t test revealed that there is significant difference from the standard values and it was found to be high.

4.4.10. Available zinc

The zinc content in forest soil fell under class 4 category (>2.00 mg kg^{-1}). The t test revealed that there is significant difference from standard values and it was found to be higher (Table 47).The zinc content in rubber plantation fell under class 3 (1.00- 2.00 mg kg^{-1}).The t test revealed significant difference from standard value and it was found to be higher. The zinc content in cocoa garden fell under class 4 (>2.00 mg kg^{-1}). The zinc content in STCR experimental field fell under class 3 (1.00- 2.00 mg kg^{-1}). The zinc content in tapioca fell under class 3 (1.00- 2.00 mg kg^{-1}).The t test revealed significant difference from standard value and it was found to be higher.

4.4.11. Available iron

The iron content in forest soil came under class 4 (>10 mg kg^{-1}). The t test revealed that there is significant difference from the standard values and it was found to be high (Table 48). The iron content in rubber plantation fell under class 4 (>10 mg kg^{-1}). The t test revealed that there is significant difference from the standard values and it was found to be high. The iron content in cocoa garden fell under class 4 (>10 mg kg^{-1}). The t test revealed that there is significant difference from the standard values and it was found to be high. The iron content in STCR experimental field fell under class 4 (>10 mg kg^{-1}). The t test revealed that there is significant difference from the standard values and it was found to be high. The iron content in tapioca field fell under class 4 (>10 mg kg^{-1}) and it was found to be high.

4.4.12. Bulk density

The bulk density in forest soil came under class 2 (1.5 - 1.6 Mg m^{-3}). The t test revealed that there is significant difference from standard values and it was found to be in between (Table 49). The bulk density in rubber plantation fell under class 2 (1.5 - 1.6 Mg m^{-3}). The t test revealed that there is significant difference from standard values and it was found to be in between. The bulk density in cocoa garden came under class 2 (1.5 - 1.6 Mg m^{-3}). The t test revealed that there is significant difference from standard values and it was found to be in between. The bulk density in STCR experimental field came under class 2 (1.5 - 1.6 Mg m^{-3}). The t test revealed that there is significant difference from standard values and it was found to be in between.

Table 38 Comparison using t test for pH based on soil quality standards

Field	Observed value	Std. Value	t value	Std. value	t value	Std. value	t value	Std value	t value	Std Value	t value
Forest	5.63	5.5	1.33	6	3.76**	6.5	8.854**	7	13.95**	7.5	19.03**
Rubber	5.5	5.5	0.49	6	9.14**	6.5	18.33**	7	27.52**	7.5	36.71**
Cocoa	5.01	5.5	5.46**	6	11.06**	6.5	16.67**	7	22.27**	7.5	27.87**
STCR	5.1	5.5	8.56**	6	19.28**	6.5	30.01**	7	40.75**	7.5	51.48**
Tapioca	5.25	5.5	11.73**	6	35.77**	6.5	59.81**	7	83.84**	7.5	107.89**

Table 39 Comparison using t test for organic carbon (%) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. Value	t value
Forest	0.93	0.5	15.49**	0.75	6.49**	1	2.49*
Rubber	0.94	0.5	19.54**	0.75	8.35**	1	2.83**
Cocoa	0.82	0.5	7.88**	0.75	1.72	1	4.43**
STCR	0.65	0.5	4.73**	0.75	3.19**	1	11.14**
Tapioca	0.69	0.5	6.1**	0.75	1.61	1	9.34**

Table 40 Comparison using t test for available nitrogen (kg ha^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. Value	t value
Forest	520.99	280	26.61**	420	11.15**	560	4.31**
Rubber	390.97	280	7.15**	420	1.87	560	10.90**
Cocoa	369.98	280	5.95**	420	3.306**	560	12.56**
STCR	354.34	280	7.52**	420	6.63**	560	20.79**
Tapioca	341.27	280	4.84**	420	6.228**	560	17.29**

Table 41 Comparison using t test for available phophorus (kg ha^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. value	t value
Forest	18.42	10	1.46	15	0.593	25	1.14
Rubber	10.37	10	0.569	15	7.19**	25	22.70**
Cocoa	22.16	10	11.46**	15	6.75**	25	2.69*
STCR	15.22	10	4.12**	15	0.171	25	7.73**
Tapioca	23.6	10	7.08	15	4.48**	25	0.727

Table 42 Camparison using t test for available potassium (kg ha^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. Value	t value	Std. value	t value
Forest	290.15	120	10.41**	200	5.52**	280	0.621
Rubber	197.94	120	7.72**	200	0.204	280	8.13**
Cocoa	511.53	120	25.04**	200	19.92**	280	14.81**
STCR	320.84	120	22.68**	200	13.65**	280	4.61**
Tapioca	316.25	120	13.99**	200	8.29**	280	2.59*

Table 43 Comparison using t test for available boron (mg kg^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. Value	t value	Std. value	t value
Forest	0.85	0.3	4.89**	0.7	1.31	1.5	5.85**
Rubber	0.52	0.3	1.64	0.7	1.35	1.5	7.35**
Cocoa	0.63	0.3	4.02**	0.7	0.883	1.5	10.69**
STCR	0.26	0.3	0.59	0.7	5.43**	1.5	15.24**
Tapioca	0.42	0.3	1.42	0.7	3.21**	1.5	12.46**

Table 44 Comparison using t test for available sulphur (mg kg^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. Value	t value
Forest	7.38	5	4.63**	7.5	0.227	12.5	9.94**
Rubber	6.11	5	2.35**	7.5	2.94**	12.5	13.51**
Cocoa	6.34	5	3.04**	7.5	2.62*	12.5	13.94**
STCR	6.81	5	4.84**	7.5	1.85	12.5	15.23**
Tapioca	5.62	5	1.24	7.5	3.74**	12.5	13.72**

Table 45 Comparison using t test for available copper based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. value	t value
Forest	20.19	0.2	21.63**	0.5	21.31**	2	20.19**
Rubber	13.01	0.2	12.81**	0.5	12.51**	2	11.01**
Cocoa	13.54	0.2	22.43**	0.5	21.92**	2	19.41**
STCR	6.21	0.2	10.32**	0.5	9.81**	2	7.23**
Tapioca	11.05	0.2	15.62**	0.5	14.84**	2	12.73**

Table 46 Comparison using t test for available manganese (mg kg^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. value	t value
Forest	73.14	2	17.95**	4	17.45**	10	15.93**
Rubber	28.41	2	18.16**	4	16.78**	10	12.60**
Cocoa	44.36	2	28.33**	4	27.00**	10	22.98**
STCR	35.21	2	31.05**	4	29.18**	10	23.57**
Tapioca	36.32	2	43.32**	4	40.82**	10	33.32**

Table 47 Comparison using t test for available zinc (mg kg^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std. value	t value	Std. value	t value
Forest	2.73	0.5	15.28**	1	11.82**	2	4.90**
Rubber	1.78	0.5	15.12**	1	9.22**	2	2.58**
Cocoa	2.07	0.5	11.04**	1	7.53**	2	0.519
STCR	1.18	0.5	11.47**	1	3.08**	2	13.68**
Tapioca	1.21	0.5	7.98**	1	2.37**	2	8.87**

Table 48 Comparison using t test for available iron (mg kg^{-1}) based on soil quality standards

Field	Observed value	Std. value	t value	Std.value	t value	Std. value	t value
Forest	124.27	2.5	60.82 **	5.5	59.32**	10	57.072**
Rubber	103.89	2.5	25.23 **	5.5	24.49**	10	23.37**
Cocoa	107.56	2.5	73.93**	5.5	71.82**	10	68.65**
STCR	82.04	2.5	22.43**	5.5	21.58**	10	20.31**
Tapioca	105.37	2.5	22.13**	5.5	21.48**	10	20.52**

Table 49 Comparison using t test for bulk density (Mg m^{-3}) based on soil quality standards

Field	Observed value	Std value	t value	Std value	t value	Std value	t value	Std value	t value	Std value	t value
Forest	2.37	1.1	38.75**	1.2	35.71**	1.3	32.67**	1.4	29.62**	1.5	26.58**
Rubber	2.45	1.1	46.81**	1.2	43.35**	1.3	39.89**	1.4	36.43**	1.5	32.97**
Cocoa	2.37	1.1	44.56**	1.2	41.04**	1.3	37.53**	1.4	34.03**	1.5	30.52**
STCR	2.39	1.1	133.33**	1.2	123.01**	1.3	112.69**	1.4	102.37**	1.5	92.05**
Tapioca	2.58	1.1	207.71**	1.2	193.71**	1.3	179.69**	1.4	165.89**	1.5	151.67**

4.5. Results of correlation analysis

4.5.1. Forest field

All intercorrelations between the different parameters namely pH, OC, N, P, K ,CEC, Fe, Cu, bacterial count, fungal count, urease activity and dehydrogenase activity were found to be highly significant except the correlations of N with P and K and CEC with Fe, Cu and urease (Table 50).

4.5.2. Rubber plantation

All intercorrelations between the different parameters namely pH, OC, N, P, K, CEC, Fe, Cu, bacterial count, fungal count, urease activity and dehydrogenase activity were found to be highly significant except the correlations of N with P and K and CEC with Fe, Cu and urease (Table 51).

4.5.3. Cocoa field

All intercorrelations between the different parameters namely pH, OC, N, P, K, CEC, Fe, Cu, bacterial count, fungal count, urease activity and dehydrogenase activity were found to be highly significant except the correlations of OC with Cu ,P with Fe and CEC with Fe and Cu (Table 52).

4.5.4. STCR experimental field

All intercorrelations between the different parameters namely pH,OC, N, P, K, CEC, Fe, Cu ,bacterial count, fungal count, urease activity and dehydrogenase activity were found to be highly significant except the correlations of P with CEC and CEC with Fe and Cu (Table 53).

4.5.5. Tapioca field

All intercorrelations between the different parameters namely pH, OC, N, P, K, CEC, Fe, Cu, bacterial count, fungal count, urease activity and dehydrogenase activity were found to be highly significant except the correlations OC with urease enzyme activity and CEC with Fe and Cu (Table 54).

Table 50 . Correlation between different chemical and biological parameters in forest field

Parameters	pH	OC	N	P	K	CEC	Fe	Cu	Bacteria	Fungi	Urease	Dehydrogenase
pH		.551**	.342**	.603**	.601**	.204	.713**	.646**	.728**	.707**	.586**	.526**
OC			.495**	.722**	.753**	.085	.722**	.734**	.826**	.821**	.661**	.543**
N				.531	.486	-.313*	.406**	.440**	.463**	.464**	.842**	.326*
P					.821**	.579**	.669**	.693**	.848**	.844**	.459**	.667**
K						.310*	.690**	.644**	.854**	.819**	.430**	.528**
CEC							.332	.296	.309*	.322*	.090	.350*
Fe								.929**	.885**	.871**	.726**	.807**
Cu									.898**	.854**	.767**	.819**
Bacteria										.975**	.773**	.787**
Fungi											.743**	.758**
Urease												.633**
Dehydrogenase												

Table 51 . Correlation between different chemical and biological parameters in rubber field

Parameters	pH	OC	N	P	K	CEC	Fe	Cu	Bacteria	Fungi	Urease	Dehydrogenase
Ph		.683**	.612**	.631**	.696**	.376*	.729**	.788**	.917**	.710**	.509**	.407**
OC			.675**	.671**	.724**	.584**	.650**	.283	.768**	.735**	.346*	.311*
N				.721**	.906**	.448**	.529**	.305*	.710**	.852**	.716**	.596**
P					.663**	.401**	.271	.329*	.664**	.625**	.716**	.506**
K						.458**	.583**	.452**	.774**	.789**	.542**	.625**
CEC							.191	.298	.345*	.308*	.190	-.307*
Fe								.401**	.774**	.841**	.543**	.324*
Cu									.347*	.678**	.428**	.308*
Bacteria										.840**	.652**	.548**
Fungi											.771**	.611**
Urease												.601**
Dehydrogenase												

Table 52 . Correlation between different chemical and biological parameters in cocoa field

Parameters	pH	OC	N	P	K	CEC	Fe	Cu	Bacteria	Fungi	Urease	Dehydrogenase
pH		.592**	.367*	.423**	.359**	.422**	.308*	.386*	.570**	.421**	.272	.611**
OC			.816**	.402**	.586**	.731**	.619**	.569**	.724**	.754**	.658**	.934**
N				.428**	.709**	.650**	.766**	.686**	.839**	.828**	.720**	.718**
P					.503**	.294	.613**	.647**	.705**	.675**	.339*	.377*
K						.373*	.546**	.584**	.804**	.708**	.380*	.441**
CEC							.401	.181	.366**	.789**	.513**	.712**
Fe								.835**	.818**	.995**	.879**	.602**
Cu									.827**	.838**	.638**	.512**
Bacteria										.919**	.814**	.659**
Fungi											.814**	.650**
Urease												.676**
Dehydrogenase												

Table 53 . Correlation between different chemical and biological parameters in STCR experimental field

Parameters	pH	OC	N	P	K	CEC	Fe	Cu	Bacteria	Fungi	Urease	Dehydrogenase
pH		.808**	.480**	.517**	.767**	.428**	.735**	.706**	.852**	.803**	.403**	.097
OC			.458**	.508**	.622**	.721**	.615**	.504**	.670**	.669**	.377	.121
N				.598**	.514**	.413**	.627**	.434**	.697**	.724**	.969**	.472**
P					.781**	.506**	.733**	.651**	.742**	.781**	.502**	.391**
K						.366**	.877**	.845**	.852**	.810**	.358*	.269
CEC							.406	.379	.451**	.494**	.549**	.535**
Fe								.912**	.875	.989**	.498**	.566**
Cu									.831**	.731**	.306**	.460**
Bacteria										.964**	.603**	.410**
Fungi											.622**	.434**
Urease												.400**
Dehydrogenase												

Table 54 . Correlation between different chemical and biological parameters in tapioca field

Parameters	pH	OC	N	P	K	CEC	Fe	Cu	Bacteria	Fungi	Urease	Dehydrogenase
pH		.551**	.342**	.173	.675**	.472**	.526**	.543**	.728**	.707**	.586**	.526**
OC			.800**	.214	.218	.688**	.407**	.358*	.621**	.526**	.063	.272
N				.485**	.304*	.304*	.654**	.530**	.731**	.691**	.459**	.555**
P					.562**	.120	.876**	.867**	.731**	.691**	.798**	.646**
K						.241	.781**	.811**	.750	.771	.241	.003
CEC							.175	.242	.473**	.336*	1.100	.053
Fe								.975**	.923**	.906**	.662**	.488**
Cu									.975**	.897**	.863**	.384**
Bacteria										.958**	.554**	.480**
Fungi											.548**	.480**
Urease												.863**
Dehydrogenase												

Regression Analysis

Step wise regression analysis was carried out keeping organic carbon as dependent variable. It was found that the available nitrogen, available phosphorous and cation exchange capacity contributed significantly to organic carbon status in all the fields. Data is shown in Table 55 .

Table 55 .Regression between organic carbon and soil quality indicators

Dependent variable- organic carbon

	Fields				
	Forest	Rubber	Cocoa	STCR	Tapioca
Adjusted R square	.806	.918	.913	.802	.868
N	2.72**	2.94**	.85*	3.07**	3.87**
P	3.92**	6.34**	3.37**	0.37*	7.08**
CEC	3.09**	5.69**	2.04*	1.24*	0.42*

DISCUSSION

The results obtained during the present investigation are discussed and the interpretations are made under the following sections.

5.1. Physical characteristics

5.1.1. Bulk density

In the natural forest, the bulk density of soil showed an increasing tendency with increase depth. The value ranged from 1.46 to 1.63 Mg m$^{-3\cdot}$ In rubber plantation too the particle density of sample showed a decreasing trend with increasing depth. The value ranged from 1.42 to 1.62 Mg m^{-3}. In cocoa garden, the bulk density of soil showed a wide range with a decreasing trend with increasing depth. The value ranged from 1.46 to 1.63 Mg m^{-3}. In STCR experimental field also the trend was the same as the above. The mean value ranged from 1.51 to 1.64 Mg m^{-3}.In tapioca field the bulk density of soil showed a decreasing tendency with increasing depth. The average value ranged from1.52 to 1.64 Mg m^{-3}.

The bulk density of soil samples increased with increase in depth and low values for bulk density were observed in forest soil. The low value of bulk density in soil samples is due to the high organic carbon content in this soil compared to others. The high organic carbon content in forest sites decreased the bulk density by diluting the soil matrix with less denser material as well improving soil aggregation (Roa, 2008, Bell, 1977 and Prasad, 1987).

5.1.2. Aggregate stability

In the forest ecosystem, the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.61 to 0.98 mm. The highest value was observed in 0-15cm (site- 1) and lowest value in 30-60 cm depth (site-5). In Rubber plantation also the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.61 to 0.89 mm. In the cocoa garden also exhibited a similar trend of the mean weight diameter of soil. The value ranged from 0.72 to 0.92 mm$^{\cdot}$ In the STCR experimental field, the value ranged from 0.51 to 0.72 mm$^{\cdot}$ In the tapioca field too the mean weight diameter of soil showed a decreasing tendency with increase in depth. The value ranged from 0.55 to 0.74 mm$^{\cdot}$

Based on mean weight diameter, it was found that the aggregate stability of soil was found to be the highest in the forest among all the five fields with a range of

0.61 to 0.98 mm. The highest value was observed in 0-15cm (site-1) and lowest value observed in 30-60 cm depth (site-5).The greater stability of soil aggregates of forest soils is due to the action of organic matter and root which act as binding agent between particles. Similar mechanism in soil system has been reported by Hayne (1990), Carter (1993) and Cakmark (1997).

5.1.3. Soil temperature

The soil temperature increased with depth during early morning hours and it decreased with depth in the afternoon hours in almost all fields.

Comparing the results of soil temperature, the lowest soil temperature was recorded in the forest followed by cocoa garden. An increased soil temperature was reported in STCR experimental field and tapioca field. The increase in soil temperature was due to the less shading and lower canopy cover in these fields. This was in accordance of finding of Carten (1998), Miller (1999), Chaudari (2003).

5.2. Chemical characteristics

5.2.1. Organic carbon

In the forest ecosystem, the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.65 to 1.23 %. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60 cm depth (site-5). In the rubber plantation too the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.75 to 1.21 %· In the cocoa the mean organic carbon content of soil showed a decreasing tendency with increase in depth. The value ranged from 0.48– 1.41%· In the STCR experimental field too the mean organic carbon content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 0.33 to 0.98 %· In the tapioca field also the trend was same as the above. The value ranged from 0.24 to1.10%.

The organic carbon content in forest soil was found to be the highest among the different fields. The value ranged from 0.65 to 1.23 %. The highest value was observed in 0-15cm depth (site-1) and the lowest in the subsurface layer in 30-60 cm depth (Site-5).The organic carbon content was high in forest soil due to the high annual litter fall return to the soil. This was in accordance to the finding of Kumar *et al.* (1989), Gupta and Badanur (1990).

5.2.2. pH

In the forest, the pH of the soil sample increased with increase in depth. The value ranged from 5.11 to 5.64. The highest value was observed in a depth of 30-60cm (site-3) and lowest value in 0-15 cm depth (site-5). In the rubber plantation the pH of the soil samples increased with increase in depth. The value ranged from 5.04 to 5.98. In the Cocoa garden also the pH of the soil samples showed a increasing tendency with increasing in depth. The value ranged from 4.13 to 5.71. The STCR experimental field also followed the same pattern. The value ranged from 5.01 to 5.48. In the tapioca field also the pH of the soil sample increased with increasing in depth. The value ranged from 5.01 to 5.46.

The pH of soil in the surface layers of forest, rubber plantation and cocoa garden was found to be low compared to the subsurface layers. The pH of soil generally decreased with depths in all the ecosystems due to the higher accumulation of organic matter in the surface soil leading to the further decomposition and release of organic acids which resulted in the higher acidity in surface soils. This was in accordance with the finding of Biswas (1998) and Hou et *al.* (1990).

5.2.3. EC

In the forest, the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged from 0.04 to 0.09 dS $m^{-1.}$ The highest value was observed in surface layer (site-1, site-2, site-3) and lowest value observed in subsurface layer (site-3). In the rubber plantation too the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged from 0.02 to 0.08 dS m^{-1}. In the cocoa garden also, the mean electrical conductivity of soil showed a decreasing tendency with increase in depth. The value ranged between 0.04 to 0.12 dS $m^{-1.}$ The highest value was observed in 0-15cm (Site-1) and lowest value observed in 30-60cm depth (site-2, site-4 and site-5).The STCR experimental field also showed similar results. The value ranged from 0.03 to

0.09 dS m$^{-1.}$ In the tapioca field, the mean electrical conductivity of soil showed a decreasing trend with increase in depth. The value ranged from 0.04 to 0.06 dS m$^{-1.}$

There is not much difference in the values of electrical conductivity in different ecosystems. This indicated that there was no remarkable accumulation of soluble salts in soil profile which might be due to the sufficient leaching and flushing of soluble salts from the soil profile due to the high rain fall of the study area and similar finding have also been reported by Jackson *et al.* (1997), Huetell *et al.* (1998).

5.2.4. Available phosphorous

In forest ecosystem, the mean phosphorous content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.36- 20.96 kg ha^{-1}. The highest value was observed at a depth of 0-15cm (site-4) and lowest value at 30-60 cm depth (site-5). In the rubber plantation too the mean phosphorous content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.36 to 17.92 kg ha^{-1}. In the cocoa garden also the mean potassium content of soil showed a wide range, with a decreasing trend with increase in depth. The value ranged from 18.44 to 9.04 kg ha^{-1}. In the STCR experimental field also the trend was the same as above. The value ranged from 5.08- 25.68 kg ha^{-1}. The highest value was observed in 0-15cm (Site-5) and lowest value observed at 30-60cm depth (site-3). In the tapioca field the mean potassium content of soil showed a decreasing tendency with increase in depth. The value ranged from 8.16 to 21.68 kg ha^{-1}.

The phosphorous content in cropped lands like STCR and tapioca fields were significantly higher than that of the forest land. The higher content of available phosphorous in those fields were due to the carry over effect of continuous fertilizer application. This was in accordance with finding of Deshmuk and Birdar (1998), Keren *et al.* (1996).

5.2.5. Available nitrogen

In the forest ecosystem, the available nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 402.11 to 614.66 kg $ha^{-1.}$ In the rubber plantation too the mean nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 188.16to 589.56 kg ha^{-1}. In the cocoa field the mean nitrogen content of soil showed wide range, with a decreasing trend with increase in depth. The value generally ranged from 250.88 to 638.69 kg $ha^{-1.}$ In the STCR experimental field also trend was same as the above. The value ranged from 488.86 to 266.21 kg ha^{-1} and in the tapioca field the mean nitrogen content of soil showed a decreasing tendency with increase in depth. The value ranged from 488.51 to 268.32 kg ha^{-1}.

Available nitrogen content of soil under all fields were low compared to that of forest soils. The results were in accordance with finding of Saviozz *et al.* (2001) and Lewis (2003).

5.2.6. Available zinc

The mean zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.32 to 4.14 mg kg $^{-1}$. The highest value was observed in forest ecosystem at 0-15 cm (Site-4) and lowest value in 30-60 cm depth (site-1). In rubber plantation too the zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.01 to 2.93 mg kg $^{-1}$. In cocoa garden also the zinc content of soil showed a decreasing tendency with increase in depth. The value ranged from 1.01 to 3.63 mg kg $^{-1}$. In the STCR experimental field the mean zinc content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 0.65 to 1.83 mg kg $^{-1}$ and in the tapioca field also the trend was the same as above. The value generally ranged from 0.33 to 2.49 mg kg $^{-1}$.

The available zinc content was found to be the highest in the forest among all ecosystems. The zinc content in the surface layer was high but there was a regular decrease in its content with depth. The accumulation of zinc in surface layer is due to the addition through plant residues left over by preceding crop and also due to high leaf litter addition. This was in accordance with finding of Kumarara (1996), Sharma (1999), Keren *et al.* (2003).

5.2.7. Available copper

In the forest ecosystem, the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 11.06 to 25.93 mg kg^{-1}. The highest value was observed in 0-15cm (site-4) and lowest value in 30-60 cm depth (site-2). In the rubber plantation too the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 3.11 to 21.11 mg kg^{-1}. In the cocoa the mean copper content of soil showed a decreasing tendency with increase in depth. The value ranged from 7.04 to 18.03 mg $kg^{-1.}$ In the STCR experimental field the mean copper content of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 2.01 to 12.55 mg kg^{-1} and in the tapioca field also the trend was the same as above. The value ranged from 15.26 to 4.08 mg kg^{-1}.

The copper content of soil in all fields markedly decreased with increasing depth, which may be attributed to the accumulation of biomass in the surface layer of soil leading to high organic carbon in the surface layer leading to the high organic carbon content in surface layer than subsurface. This was in accordance of finding of Speir *et al.* (1987) and Ryan *et al.* (1994).

5.3. Biological characteristics

5.3.1. Microbial population

The bacteria, fungi and actinomycetes population was found to be decreasing with increase in depths in almost all the ecosystems studied Mukherji *et al.* (1989) and Mishra *et al.* (1983).

In the forest ecosystem, the mean fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from 6 to 71×10^{-4} cfu g^{-1}. The highest value was observed in 0-15cm (Site-1) and lowest value in 30-60 cm depth (site-5). In the rubber plantation too the mean fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from 6 to 75 $\times 10^{-4}$ cfu g^{-1}. In cocoa garden the mean fungal count of soil showed a decreasing tendency with increase in depth. The value ranged from14 to 79 x10^{-4}cfu g^{-1}. In the STCR experimental field the mean fungal count of soil showed a decreasing tendency with increasing depth. The value ranged from11 to 62 x10^{-4}cfu g^{-1} and in the tapioca field also the trend was same as the above. The value ranged from 8 to 73x10^{-4}cfu g^{-1}. The highest value was observed in 0-15cm (site-1) and lowest value in 30-60cm depth (site-5).

Fungal population was always higher in surface soil, which might be due to high amounts of C_{org}(carbon organic), higher aeration and favourable moisture. The decline in fungal population numbers with increasing depth observed in this study agreed with the findings of Yamamoto (1993) and variation in physico-chemical properties of soil might play an important role in this feature (Bossio *et al.*, 2005, Kennedy *et al.*, 2005). According to Dkhar (1983), fungi grow slowly with increasing depths due to shortage of mineral nutrients and compaction of soil. Significant decrease in C_{org}(carbon organic) and N_{tot} (nitrogen total) with increasing depth might be due to low organic matter availability at greater depths. The predominanance of microbes in different fields were found out. The actinomycetes population was found to be high in forest field and rubber plantation and fungi was found to be highest in cocoa field, STCR experimental field and tapioca field.

Table 56 . Predominance of microbes in the different fields

Field	Predominant microflora
Forest	Actinomycetes
Rubber plantation	Actinomycetes
Cocoa field	Fungi
STCR field	Fungi
Tapioca field	Fungi

5.3.2. Urease activity

Urease is unique among soil enzymes because it affects the fate and performance of fertilizer urea. Urea when added to the soil as fertilizer, is rapidly hydrolyzed to ammonium carbonate in most soil through the activity of soil urease and is responsible for the rapid release of ammonia when urea is applied. Urease is a constitutive enzyme found in large number of microorganisms especially in ureolytic bacteria and fungi (Bremner and Mulvancy, 1978).

In the forest field, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 401.76 to 664.65ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The highest value was observed in 0-15cm (site-4) and lowest value in 30-60 cm depth (site-5). In the rubber plantation too the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 168.16 to 588.54 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. In the cocoa garden also, the mean urease enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 249.09 to 639.88 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. In the STCR experimental field the mean urease enzyme activity of soil showed a wide range of decreasing tendency with increase in depth. The value ranged between 272.64 to 484.86 ppm of urea hydrolysed g^{-1} of soil hr^{-1}. The tapioca field also the trend was the same as above. The value ranged from 272.14 to 588.41 ppm of urea hydrolysed g^{-1} of soil hr^{-1}.

The study showed that an increased urease activity was prevalent in the forest ecosystem followed by cocoa garden. This increase in urease activity may be attributed to desirable soil characteristics and associated beneficial elements.

A significant and positive correlation of urease with CEC, available N, available P and available K also indicated the role of organic manures in the availability of nutrients which ultimately resulted in higher activity of urease.This was evidently due to the higher activity of substrate nitrogen (urea), which promoted urease activity. The higher values registered for urease under different ecosystems could be attributed to the high organic matter addition through litter fall, which served as a good source of energy, carbon and nutrients for ureolytic microorganisms. In general, there was a decrease in urease activity with higher dose of fertilizer addition except for nitrogen.Since nitrogen was supplied as urea, an increase in urease activity was generally expected as the substrate concentration was high. Further addition of nitrogen might have increased the population of ureolytic organism initially which resulted in high urease synthesis. Fauci and Dick (1994) reported increase in the activity of urease with addition of urea.

5.3.4. Phosphatase activity

It was noted that under the forest ecosystem, where there was lack of a fertilizer programme, a higher phosphatase activity was noticed. This could be attributed to the release of P from organic matter by acid phosphates associated with the dead and living cells through internal cell metabolism and energy transformation reaction. This was in accordance with the finding of Burns *et al.* (1982).

The high activity observed in rubber plantation and cocoa garden might be due to the protection of phosphatase produced by the adsorption and stabilization mechanism brought about by a higher level of organic colloids than the other ecosystems studied. Similar mechanism of enzyme protection in soil sytem by organic fraction had been reported by Hayano *et al.* (1977).

The decrease in phosphatase enzyme activity in STCR experimental field and tapioca field could be attributed to the reduced activity of phosphorous solubilising organisms in response to a high available P. Thus the maximal activity of phosphatase could be observed only in fields receiving maximum organic phosphatase.This was in accordance of result obtained by Patil, *et al.*, (1997).The decrease in phosphatase activity observed at high dose of K application might be attributed to the higher sensitivity of active P- solublizing flora to the higher concentration of K.

5.3.5. Dehydrogenase activity

In forest ecosystem, the dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 211.65 to 462.14µg. The highest value was observed at 0-15 cm depth (Site-2) and lowest value in 30-60 cm depth (site-3). In the rubber plantation too the mean dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from234.56 to 464.96 µg of P- nitrophenol released g^{-1} of soil hr^{-1}. In cocoa field the enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 104.14 to 486.06 µg of P- nitrophenol released g^{-1} of soil hr^{-1}. In the STCR experimental field also the mean dehydrogenase enzyme activity of soil showed a wide range of decreasing tendency with increase in depth. The value ranged from 83.76 to 434.17 µg of P- nitrophenol released g^{-1} of soil hr^{-1} and in the tapioca field also the trend was the same as above. The value ranged from 98.36 to 449.37 µg of P-nitrophenol released g^{-1} of soil hr^{-1} .

The dehydrogenase enzyme activity of soil was found to be the highest in the natural forest when the different fields were compared. In the forest ecosystem the dehydrogenase enzyme activity of soil showed a decreasing tendency with increase in depth. The value ranged from 211.65 to 462.14 µg of P- nitrophenol released g^{-1} of soil hr^{-1}.The highest value was observed in 0-15 cm (Site-2) and lowest value observed in 30-60 cm depth (site-3).The dehydrogenase acitivity has been often linked with the levels of available organic carbon substrates in the soil, as they serve as the source of electrons and H^+ for accomplishing reduction reaction. The higher level of dehydrogenase activity observed under forest, might be due to high organic carbon, litter accumulation, and nutrient status (Murthy et *al.*, 1990).

The activities of enzymes in almost all fields markedly decreased with depth. This decrease in enzyme activity with depth was associated with decrease in organic matter. The level of enzyme activity increased with increase in organic carbon content in soil. This may be related to the population dynamics of microflora. The decrease in dehydrogenase and phosphatase activity with depth is important because dehydrogenase is considered as an indicator of total microbial activity and phosphatase as the indicator of the rate of hydrolysis of organic P (Nannipieri *et al.,* 1990).

SUMMARY

6. Summary

Assessment of soil quality is essential for determining the sustainability of land management systems. It is generally accepted that intensive agricultural production leads to a decline in soil quality. For this reason, it is highly essential to monitor soil quality to avoid soil degradation and in doing so, preserve the production capabilities of the land and protect environment.

In this investigation, an attempt has been made to evaluate the the soil quality under different long term field management conditions in an Ultisol (Vellanikkara series) based on physical, chemical and biological indicators. The samples were taken from different blocks in KAU campus identified as different fields. Altogether 225 samples were collected from 3 depths from five different ecosystems. The salient results obtained in the present work are summarized below

1. The mechanical analysis of the soil samples revealed that most of the samples were sandy clay loam. The data obtained on the soil components were used for their textural classification.

2. The soil reaction of the samples had shown that the soil is acidic in nature. It may be due to the considerable extent of leaching of cations due to high rainfall.

3. The electrical conductivity of almost all the samples were found to be very low in all the fields. There was no significant difference in this parameter between surface and subsurface samples.

4. The contents of organic carbon were medium in most of the soil samples. It is higher in surface layers than the subsurface layers.

5. Available phosphorus content was high in most of the soil samples. It is due to high phosphorus fertilizer application in most of the fields.

6. Available potassium content was medium to high in most of the samples and it is higher in surface layer.

7. Among the secondary nutrients, available calcium showed a wide range in all the ecosystems. There was slight variation in the content of surface and subsurface layers. Available magnesium was low in the samples. There was a decreasing trend in subsurface layers compared to surface layers.

8. Among the micronutrients, iron was the highest followed by manganese. In case of zinc, the concentration was low.

9. The total microbial population was found to be highest in forest followed by cocoa. The count was highest in surface samples and it was due to the high organic matter content in the surface layer.

10. The enzyme activity was also found to be highest in forest field followed by cocoa field. The activity was highest in surface samples and it was due to the high organic matter content in the surface soil layers.

11. The earthworm activity and termite activity was found to be the highest in forest field followed by cocoa garden.

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APPENDICES

Appendix I. Meteorological data during the soil sample collection

Date	Max. Temp. (^{0}C)	Min. Temp. (^{0}C)	Mean RH (%)	Wind speed (km/hr)	Mean sun shine hrs	Rain fall (mm)	Rainy days	Mean evaporation (cm)	Soil Temperature (^{0}C)					
									Morning			Evening		
									5cm	10cm	15cm	5cm	10cm	15cm
24/12-31/12	33.2	23.6	060	6.1	7.1	013.6	1	5.2	26.0	26.9	27.9	35.8	32.2	31.4
1/1-7/1	34.4	23.0	061	3.6	8.4	000.0	0	4.0	25.7	26.5	27.5	39.2	33.7	32.3
8/1-14/1	33.9	23.0	052	5.4	7.0	000.0	0	4.3	25.9	26.9	27.8	38.3	33.3	31.9
15/1-21/1	33.5	21	048	5.5	9.7	000.0	0	5.2	24.5	25.9	27.0	39.1	33.4	32.0
22/1-28/1	34.5	22.2	041	6.6	9.7	000.0	0	5.9	25.5	26.7	27.9	39.7	33.8	32.5
29/1-4/2	34.2	23.5	051	3.5	9.5	000.0	0	5.4	25.9	27.2	28.3	40.0	34.5	32.6

Appendix II. Media used for enumeration of Soil microorganisms

SI No	Microbe	Dilution for plating	Medium
1	Bacteria	10^{-6}	Nutrient agar
2	Fungi	10^{-4}	Martin's rose bengal agar
3	Actinomycets	10^{-5}	Kenknight and Munaier's medium

LONG TERM EFFECT OF FIELD MANAGEMENT ON SOIL QUALITY IN ULTISOL

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Soil quality is directly related to agricultural sustainability. Assessment of soil quality is essential for determining the sustainability of land management systems. It is generally accepted that intensive agricultural production leads to a decline in soil quality. For this reason, it is highly essential to monitor soil quality to avoid soil degradation and in doing so, preserve the production capabilities of the land and protect environment. The response of soils to management and input depends on soil quality. It is therefore important to identify the soil characteristics responsible for changes in soil quality, which may eventually be considered as soil quality indicators for assessing agricultural sustainability.

The present investigation has been undertaken to study the "Long term effect of field management on soil quality in Ultisol". It was conducted in the main campus of Kerala Agricultural University, Vellanikkara during December, 2012 to June, 2013. The objective of the study was to evaluate the soil quality under different long term field management conditions in an Ultisol (Vellanikkara series) based on physical, chemical and biological indicators. Here, an attempt has been made to evaluate the physical, chemical and biological properties of soil using available soil quality indicators. Five different fields were selected namely, natural forest, rubber plantation, cocoa garden, STCR experimental field and tapioca fields. Soil samples were collected from three depths namely 0-15 cm, 15-30 cm and 30-60 cm. The different sampling sites within each field were selected based on slope percentage. The samples were characterized for soil texture, aggregate size distribution, soil temperature, water holding capacity, single value constants, pH, EC CEC, AEC, SiO_2/R_2O_3, organic carbon , lime requirement, available macronutrients, secondary nutrients, micronutrients, counts of bacteria, fungi and actinomycetes and enzyme activity. The sampling areas were also surveyed and documented for the presence of earthworms and termites.

The physical characteristics like water holding capacity, soil aggregate stability and soil temperature showed a decreasing trend with depth in the different fields. Forest ecosystem showed the most conducive physical characteristics followed by cocoa and rubber. The contents of available nutrients, secondary nutrients and micronutrients were found to be the highest in surface samples. The forest ecosystem showed relatively high values for organic carbon, and available nutrients like nitrogen, sulphur, boron, iron, manganese, zinc and copper. Microbial activity was found to be the highest in surface soils in almost all fields. The highest counts of

bacteria and actinomycetes were reported in forest ecosystem and lowest in tapioca field. Fungal activity was found to be the highest in cocoa field followed by forest ecosystem. Enzyme activity was also found to be the highest in surface soils in the different fields.

Soil quality was evaluated using available soil quality indicators. Based on scoring with the soil quality parameters, the highest scoring was observed for natural forest followed by cocoa field. Correlations between various soil quality parameters of different fields were also worked out.