NUTRIENTS AND FERTILITY STATUS OF SOIL UNDER RUBBER AND ARECANUT PLANTATIONS IN KOLASIB DISTRICT, MIZORAM

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DEPARTMENT OF ENVIRONMENTAL SCIENCE

MIZORAM UNIVERSITY, AIZAWL

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BY

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Submitted in partial fulfilment of the requirement of the degree of

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CERTIFICATE FROM SUPERVISOR

This is to certify that the thesis entitled, "Nutrient and Fertility Status of soil under Rubber and Arecanuts Plantations in Kolasib District, Mizoram," is a bonafied work assigned to Manzamawii, Reg No. MZU/Ph.D/716 of 19.05.2015, Department of Environmental Science for partial fulfillment of the requirement for the degree of Doctor of Philosophy under Mizoram University.

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DECLARATION

I, Manzamawii, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anyone else, and that the thesis has not been submitted by me for any research degree in other University/Instituted.

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LIST OF ABBREVIATIONS USED

°C	Degree Celsius
A.D.	After Death
ABFS	Arecanut Based Farming Systems
ANOVA	Analysis Of Variance
ANRPC	Association Of Natural Rubber Producing Countries
Apr.	April
ATP	Adenosine Triphosphate
Aug.	August
B.C.	Before Christ
BD	Bulk Density
C	Carbon
Ca	Calcium
cm	Centimeter
CPCRI	Central Plantation Crops Research Institute
Cu	Copper
Dec.	December
DoLR	Department Of Land Resources
DTPA	Diethylenetriamine Pentaacetic Acid
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic Acid
etc.	Et Cetera
FAO	Food And Agriculture Organization
Fe	Iron
Feb.	February
FYM	Farm Yard Manure
g	Gram
HCL	Hydrochloric Acid
hrs	Hours
i.e.	"Id Est", Means "That Is" Or "In Other Words".
ICAR	Indian Council Of Agricultural Research
Jan.	January
K	Potassium
kg/ha	Kilogram Per Hectare
km	Kilometre
l	Liter
m	Metre
m a.s.l.	Metres Above Sea Level
Mar.	March
Mg	Magnesium
mg/kg	Milligram/Kilogram
Mha	Million Hectares

min	Minutes
ml	Milliliter
mm	Millimeters
MMT	Million Metric Tons
Mn	Manganese
MP-AES	Microwave Plasma-Atomic Emission Spectrometer
MT	Million Ton
N	Nitrogen
Na	Sodium
NABARD	National Bank For Agriculture And Rural Development
NE	North Eastern
NEC	North Eastern Council
NEDFi	North-Eastern Development Finance Corporation
NI	Nutrient Index
NLUP	New Land Use Policy
nm	Nanometers
Nov.	November
NTFPs	Non-Timber Forest Products
Oct.	October
P	Phosphorus
PAR	Photosynthetically Active Radiation
ppm	Parts Per Million
RKVK	Rashtriya Krishi Vikas Yojana
S	Sulphur
sec	Seconds
Sept.	September
SFI	Soil Fertility Index
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPSS	Statistical Package For The Social Sciences
sq	Square
TEA	Triethanolamine
TN	Total Nitrogen
tons	Tonnes
viz.	Videlicet Which Means Namely
Zn	Zinc

Chapter 1

INTRODUCTION

Plantation tree crops are high-value crops of great economic importance and have gained widespread acceptance in tropical countries such as Thailand, Malaysia, Indonesia, India, China, Nigeria, and many other parts of the world. The major plantation crops are coconut, palmyra, coffee, cocoa, tea, rubber, cardamom, cashew, oil palm, and cinchona (Anon., 2011). It has great potential for utilization of wastelands in varied agro-ecosystems like rainfed, dryland, hilly, arid, and coastal, providing higher employment opportunities, nutritional security, eco-friendly, high potential for foreign exchanges earnings and above all providing livelihood security to people (Pradeepkumar *et al.*, 2008).

Plantation crops are among the oldest organized industries in India and continue to be the mainstay of agrarian economies in many states of the country (Pradeepkumar *et al.,* 2008). Since independence, these crops expand rapidly replacing secondary forests and land under shifting cultivation (Fox *et al.,* 2012). Shifting or *jhum* cultivation has been the way of life and integral part of the cultural ethos of the people in the north-eastern (NE) hilly region of India since time immemorial. However, with changing requirements of high population pressure on land, *jhum* cultivation becomes very devastating in nature causing a drastic decline in crop yield, loss of forest wealth, soil fertility, biodiversity, and environmental degradation (Saha and Mishra, 2007). Due to the shortening of the *jhum* cycle and continuous cropping, quite often, the secondary forests also do not get adequate time to regenerate (Lalnunmawia and Lalzarliana, 2013). Over the past decades, traditional forms of land use in many of these areas have evolved into more intensive agricultural systems. The NE region of India is emerging as one of the most suitable potential areas for the cultivation of arecanut and rubber due to its sub-tropical climatic condition.

The arecanut, *Areca catechu* L. also commonly known as 'betel nut' or 'supari', is the seed of *A. catechu* palm tree (Kumar *et al.,* 2015). It is one of the most popular plantation crops because of its extensive use by masses for mastication as well as value-added products (Pradeepkumar *et al.*, 2008). It belongs to Arecaceae family and thrives well in regions of 28° North (N) and 28°South (S) of the equator of the tropical Pacific, Asia, and parts of east Africa (Dransfield *et al.*, 2008; Balasimha, 2011; Heatubun *et al.*, 2012; Naagarajan and Meenakshi, 2016). It grows well within the temperature range of 14ºC (Degree Celsius) and 36ºC and is adversely affected by temperatures below 10ºC and above 40ºC. Its distribution mainly confined to China, Myanmar, Thailand, Philippines, Bangladesh, Indonesia, Malaysia, Sri Lanka, Maldives, Nepal, Kenya, and some of the Pacific Islands. Commercial cultivation of arecanut is done only in India, Bangladesh, and Sri Lanka.

The rubber tree, *Hevea brasiliensis* (Willd ex. A. Juss.) Mull. Arg. is a native tree species in the Amazon basin of South America, located within 5º Latitude of the equator and dominated with the wet equatorial type of climate (Strahler, 1969). It belongs to the Euphorbiaceae family and considered the most economically important member of the genus *Hevea*. It remains the only cultivated species as a commercial source of natural rubber (latex) and has many uses due to being highly waterproof, resilient, tough, stretchy, low heat buildup property, and convenience in harvesting (Mors and Rizzini, 1966; Opeke, 1982).

Changes in the land use cause significant modifications in soil properties in which agriculture has a major contribution (Pal *et al.*, 2013) and especially on the amount and distribution of nutrients (Reganold *et al.*, 1987; Singh and Singh, 2005), which may rapidly diminish in soil quality (Ayoubi *et al.*, 2011). Tropical soils around the world are widely known to be declining in fertility. Soil fertility is a dynamic natural property and it can change under the influence of natural (topography, soil types, and climatic factors) and human-induced (deforestation, desertification, mining, overgrazing, etc.) factors. Successful agriculture requires the sustainable use of soil resources because the soil is the most vital source of infinite life and not renewable over a short period (Sharma *et al.*, 2012). Hence, evaluation of the fertility status of soils is needed in relation to these land uses to ensure longer-term sustainability, crop production, or maintain soil quality under the study area.

1.1. Soil

The word "Soil" originates from two Latin words "*Solium*" meaning seat and "*Solum*" meaning ground. Soil is also named as "*Pedolith*" that means ground stone. The study of soil origin, composition and its properties are known as "*Pedolog*y". At one time, people thought that soils were static. It is only in the late 1800s since von Liebig in 1840 discovered the role of nutrients in crop production and Dokouchaiev in 1880 linked soil properties and bioclimatic zones that the soil is considered a dynamic body with variable properties and potential depending on variations in climate, vegetation and parent material (Verheye, 2007).

Therefore, depending on the discipline several definitions of soil are given below:

a) Traditional Definition

“Soil is a natural body consisting of layers (soil horizons) that are composed of weathered mineral materials, organic material, air and water that nourishes and supports growing” (Anon, 2018).

b) Biological Definition

“Soil is the weathered superficial layer of the earth’s crust in which the living organisms grow and also release the products of their activities, death, and decay” (Sharma, 2010).

c) Component Definition

“Mixture of mineral matter, organic matter, water, and air” (Anon., 2006).

d) Taxonomy Definition

“Collection of natural bodies of the earth’s surface, in places modified or even made by man or earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors” (Anon., 2006).

e) Pedological Definition

“Soil is a natural body, which evolved from surface weathering of the earth's crust and organic residues. Its structure and composition are the results of climate and live organisms living in the soil and on the soil” (Anon., 2008).

f) Geologic Definition

“Soil is an accumulation of loose material from mechanical and chemical weathering of rocks (also relocated) and containing a large admixture of various organic substances on the earth's surface” (Anon., 2008).

1.2. Soil Forming Factors

The properties of soil are the result of the interaction between the five soil-forming factors. These factors were first identified by Dokuchaev in the late 1800s and were popularized by the book “*The Factors of Soil Formation”* in which Jenny (1941) sought mathematical expressions of soil formation based on the variables (Amundson and Jenny, 1991). These factors are given below:

a) Climate

Temperature, precipitation, and frost action have a profound influence on the soil-forming processes that occur within a region. It governs the rate of chemical and physical weathering of the soils.

b) Biotic Factors

Microorganisms (like fungi, bacteria, etc.) promote acid conditions, decompose organic materials, and change the chemistry of the soil which in turn influences the type of soil-forming processes that take place. Burrowing animals (like rodents, ants, and earthworms, etc.) dig the soil and mix the materials in horizons (Anon., 2009). Plant roots penetrate the rocks and minerals and leave channels for the movement of air and water. They also excrete many substances particularly carbon dioxide which forms carbonic acid with water (Rai, 1995).

c) Topography or Relief

The shape of the land surface, its slope, and position on the landscape, greatly influence the kinds of soils formed. Soils that developed on higher elevations and sloping areas are generally excessively drained or well-drained. Therefore, the soil remains immature or underdeveloped. In smooth flat countries, soil profile development occurs in a complete manner resulting in good development and mature soil (Anon., 2009).

d) Parent Material

Parent material is the unconsolidated mineral and organic deposits in which soils are developing. It determines the mineralogical composition and contributes largely to the physical and chemical characteristics of the soil (Anon., 2009; Jenny, 1941).

e) Time

The formation of soils is a continuing process and generally takes several thousand years for significant changes to take place (Mankandan and Prabhu, 2017).

1.3. Physico-Chemical Properties of Soil

1.3.1. Physical properties

Physical properties of soil define movement of air and water/dissolved chemicals through the soil, as well as conditions affecting germination, root growth, and erosion processes.

a) Soil Temperature

Soil temperature refers to the relative hotness or coolness of the soil. Ideal soil temperatures for planting mostly ranges from 18°C to 24ºC. It also influences soil moisture content, aeration, nitrification rate, and availability of plant nutrients. (Manikandan and Prabhu, 2017).

b) Soil Moisture Content (SMC)

Generally, SMC is the water that is held in the spaces between soil particles. It plays a key role in crop production as it acts as a nutrient and serves as a solvent for other nutrients such as sodium, potassium, carbon, and nitrogen. It makes a significant impact on plant growth, percolation, and evaporation, microbiological decomposition of the soil organic matter, and also on heat exchange.

c) Soil Texture

Texture refers to the relative proportion of different soil components such as sand, silt, and clay in the soil. Sand particles have diameters between 0.05 millimeters (mm) and 2.0 mm and are gritty to the touch. The individual grains or particles can be seen with the naked eye. Silt particles are between 0.002 mm and 0.05 mm in size. They are smooth and slippery to the touch when wet. Clay is less than 0.002 mm in size and is sticky and plastic-like to handle when wet. These individual particles are extremely small and can only be seen with the aid of an electron microscope.

d) Bulk Density (BD)

The BD is defined as the ratio of the mass of dry solids to the bulk volume of the substrate (Blake and Hartge, 1986). High BD is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, poor movement of air, and water through the soil (Arshad *et al.*, 1996).

e) Soil Porosity

The porosity of soil refers to the percentage (%) of soil volume occupied by pore spaces. The pore space of a soil is defined as the portion of the soil volume occupied by air and water. Pore-spaces directly control the amount of water and air in the soil and indirectly influence the plant growth and crop production.

f) Water Holding Capacity (WHC)

WHC of soil usually refers to the amount of maximum water that can be held by the saturated soil. It is controlled primarily by the soil texture and the soil organic matter content. In the case of silt and clay, the larger the surface area the easier it is for the soil to hold onto water so it has a higher WHC.

1.3.2. Chemical Properties of Soil

The chemical properties of soils refer to the nature of the chemical changes taking place among soil particles and in the soil solution- the water retained by the soil. These chemical changes depend upon their chemical compositions and nature of the inorganic and organic materials contained in them, which have originated from gradual decomposition of the sial and organic materials, mainly of plant origin (Kolay, 2000).

a) Soil pH

pH measures the activity of the hydrogen ion (H^+) and hydroxyl ion (OH^-), which indicates whether the soil is acidic, neutral, or alkaline in reaction (Hazelton and Murphy, 2007). Factors influencing soil pH include organic matter decomposition, nitrogen fertilizer source, climate, land management practices, parent material, and minerals (McCauley *et al.*, 2017).

b) Electrical conductivity (EC)

EC is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to carry an electric current. The EC of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity.

c) Soil Organic Carbon (SOC)

SOC is the carbon that remains in the soil after partial decomposition of any material produced by living organisms. It constitutes a key element of the global carbon cycle through the atmosphere, vegetation, soil, rivers, and the ocean. It is the main component of soil organic matter and as such constitutes the fuel of any soil.

d) Soil Organic Matter (SOM)

The term SOM is used to describe the organic constituents in the soil in various stages of decomposition such as tissues from dead plants and animals, materials less than 2 mm in size, and soil organisms (Lefevre *et al.,* 2017). It is mainly composed of carbon, hydrogen, and oxygen but also has small amounts of nutrients such as nitrogen, phosphorus, sulphur, potassium, calcium, and magnesium contained within organic residues.

e) Total Nitrogen (TN)

The form has taken up by plant: NH^{4+}, NO^{3-}

Nitrogen (N) is the most important nutrient for all crop plants (Zhang *et al.*, 2010). The availability of N is closely associated with plant productivity (Giese *et al.*, 2010; Yuan and Li, 2007). It is used by plants in two forms, ammonium (NH_4-N) and nitrate (NO_3-N) (van Raij *et al.*, 1986). Nitrate is the dominant form of mineral nitrogen available for plant use (Wander *et al.*, 1995; Helali *et al.*, 2010). The sum of the two forms constitutes the pool of plant-available N (Ryan *et al.* 1996).

v) Phosphorus (P)

The form has taken up by plant: H_2PO^{4-}, HPO_4^{2-}

The concentration of the available form of P in soil is very low (Ryan *et al.*, 1996). It is a constituent of the cell nucleus, essential for the cell division and development of meristematic tissues at the growing points. It makes 0.1% to 0.5% of the dry weight of the plant.

g) Potassium (K)

The form has taken up by plant: K^+

K is an essential macronutrient for plant growth and development as well as for many plant functions (Maser *et al.*, 2002; Zhang *et al.*, 2010). K has four soil forms: solution, exchangeable, non-exchangeable, and mineral. The water-soluble and exchangeable forms represent the available fraction of K. Whereas, non-exchangeable and mineral K forms are known to be slowly available (Setia *et al.*, 2009).

h) Calcium (Ca)

The form has taken up by plant: Ca^{2+}

Ca is essential for the formation of cell-walls, as calcium pectate forms part of the middle layer of the cell-wall. The middle lamella regulates the entry of only those nutrients which are not toxic to the plant. In root-tips Ca is very essential for the meristematic activity or formation of new tissues. It also helps to keep up the sustained activity of the nodule bacteria in legumes.

i) Magnesium (Mg)

The form has taken up by plant: Mg^{2+}

It is needed by all green plants as a constituent of chlorophyll "the only mineral constituent of chlorophyll molecule". It maintains the dark-green color of leaves and regulates the uptake of other materials, particularly N and P. It appears to play an important role in the transport of P, particularly into the seeds. It is also said to promote the formation of oils and fats, possibly by increasing photosynthetic activity in the leaves.

j) Sulphur (S)

The form has taken up by plant: SO_4^{2-}

Being a constituent of S containing amino-acids like cysteine and methionine. It is involved in the synthesis of protein and enzymes and therefore, functionally important in plant growth. Due to the S deficiency rate of plant growth is reduced, rigid and brittle and the stem remains thin.

k) Sodium (Na)

The form has taken up by plant: Na^{+}

Na is not an essential element for plants but can be used in small quantities, similar to micronutrients, to aid in the metabolism and synthesis of chlorophyll. In some plants, it can be used as a partial replacement for K and aids in the opening and closing of stomata.

l) Iron (Fe)

The form has taken up by plant: Fe^{2+}, Fe^{3+}, chelate

The major portion of the total Fe is in the chloroplasts and it is essential in the synthesis of chlorophyll but not a constituent of it. The concentration of Fe ions plays an important part in the oxidation process in leaf cells. Its deficiency manifests itself in chlorosis, yellowing or whitening of leaves.

m) Zinc (Zn)

The form has taken up by plant: Zn^{2+}, $Zn\ (OH)_2$, chelate

In a general way, Zn is associated with the development of chlorophyll in leaves, and a high content of Zn is correlated with a high amount of chlorophyll. In its absence growth is less, buds fall off and seed development is limited.

n) Manganese (Mn)

The form has taken up by plant: Mn^{2+}, chelate

It is a prominent component of chloroplast and particularly involved in the reaction of photosynthesis. Due to deficiency of Mn, the carbohydrate synthesis is disturbed, resulting in retarded growth, a decrease in the content of ash, and failure to reproduce.

o) Copper (Cu)

The form is taken up by plant: Cu^{2+}, chelate

In the chloroplasts of leaves, there is an enzyme that is concerned with the oxidation-reduction processes. The presence of Cu is essential for this enzyme to function. Thus, Cu plays an important role in the process of photosynthesis.

1.4. Major Soil Types of India

India is a country of vast dimensions with varied conditions of geology, relief, climate, and vegetation. Therefore, India has a large variety of soil groups, distinctly different from one another. In 1953, the Indian Council of Agricultural Research (ICAR) set up an All India Soil Survey Committee in which Indian soils were classified into eight major groups (Anon., 2016; Mohita, 2010; Rajan and Rao, 1978). A brief account of these eight soils is given below:

a) Alluvial Soils

The alluvial soils cover about 15 lakh square (sq) kilometer (km) which is about 45.6 % of the total land area of the country, these soils contribute the largest share of our agricultural wealth and support the bulk of India's population. They are derived from the sediments deposited by rivers as in the Indo-Gangetic plain although some alluvial soils in the coastal areas have been formed by the sea waves. Geologically, the alluvium of the Great plain of India is divided into newer or younger khadar and older or bhangar soils.

They occur all along the Great Indo-Gangetic Plain starting from Punjab in the west to West Bengal and Assam in the east and Gujarat in the northern parts. They also occur in deltas of the Mahanadi, the Godavari, the Krishna, and the Cauvery.

b) Black Soils

The black soils spread over 5.46 lakh sq km which is about 16.6% of the total geographical area of the country. They are derived from two types of the volcanic rocks, the Deccan and the Rajmahal trap, and ferruginous gneisses and schists occurring in Tamil Nadu. The black colour of these soils has been attributed to the presence of a small proportion of titaniferous magnetite or even to iron and black constituents of the parent rock. These soils are mainly found in Maharashtra, Madhya Pradesh, and parts of Karnataka, Telangana, Andhra Pradesh, Gujarat, and Tamil Nadu.

c) Red Soils

The red soils occupy a vast area of about 3.5 lakh sq km which is about 10.6% of the total geographical area of the country. The main parent rocks are acid granites and gneisses, quartzite, and feldspathic. The colour of these soils is due to the wide diffusion rather than the too high percentage of iron content. These soils are spread on almost the whole of Tamil Nadu, Karnataka, south-east of Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Odisha, Chota Nagpur in Jharkhand; parts of south Bihar, West Bengal, Uttar Pradesh; Aravalis and the eastern half of Rajasthan (Mewar or Marwar Plateau) and parts of NE states

d) Lateritic Soils

Laterite soils cover an area of 2.48 lakh sq km of the total area of the country. They are formed under conditions of high temperature and heavy rainfall with alternate wet and dry periods. The colour of these soils is due to little clay and more gravel of red sand-stones and rich in bauxite or ferric oxides. They are well developed in south Maharashtra, parts of Karnataka, Andhra Pradesh, Odisha, West Bengal, Kerala, Jharkhand, Assam, and Meghalaya.

e) Forest-Mountain Soils

Such soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh sq km which is about 8.67% of the total land area of India. These soils are heterogeneous in nature, very rich in humus, deficient in potash, phosphorus, and lime. These soils are found mainly in the Himalayan region Sikkim, Arunachal Pradesh, Assam, Western and Eastern Ghats as well as in some parts of the peninsular plateau.

f) Arid-Desert Soils:

The desert soils cover a total area of 1.42 lakh sq km which is about 4.32% of the total area of India and received less than 50 centimeters (cm) of annual rainfall. The desert soils consist of aeolian sand (90% to 95%) and clay (5% to 10%). They occur in arid and semi-arid regions of Rajasthan, Punjab, and Haryana. Sandy soils without clay factor are also common in coastal regions of Odisha, Tamil Nadu, and Kerala.

g) Saline-Alkaline Soils:

These soils occupy about 68,000 sq km of the land area of India. Many undecomposed rock and mineral fragments, on weathering, liberate Na, Mg and Ca salts, and sulphurous acid. The accumulation of these salts makes the soil infertile and renders it unfit for agriculture. These soils are found in Andhra Pradesh, Karnataka, Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan, and Maharashtra.

h) Peaty-Marshy Soils

Peaty soils originate in humid regions as a result of the accumulation of large amounts of OM in the soils. They are black, heavy, and highly acidic, deficient in potash and phosphate. Soils belonging to this group are found in the Kottayam and Alappuzha districts of Kerala. Marshy soils with a high proportion of vegetable matter also occur in the coastal areas of Orissa and Tamil Nadu, Sunderbans of West Bengal, Bihar, and Almora district of Uttaranchal.

1.5. North-Eastern Hill Regions of India

The NE region of India, comprising of the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, covering an area of 26.2 million hectares (Mha), and about 8 % of country's landmass. It stretched between 21º57′ to 29º 26′ N latitudes and 89º41′ to 97º25′ East (E) longitudes possessing 1.3% of the total population of the country (Bandypadhyay *et al.,* 2016). The region is characterized by wide varying physiography, climate, and rich bio-diversity. About 54.1% of the total geographical area is under forests, 16.6% under crops, and the rest either under non-agricultural uses or uncultivated land (Saha *et al.*, 2012).

a) Arunachal Pradesh

The soils of Arunachal Pradesh are developed on sedimentary and metamorphic rocks of varying geological age (Poddar *et al.,* 1999). The whole of Lohit district, two-thirds of the Siang and Tirap district, and half of Kameng district are covered by red loam soil. The rest of the areas in the Siang, Subansiri and Kamang districts are covered by brown hill soils. Laterite soils have been found in the Tirap district. Soils of all the districts contain a high amount of OC and available N. Soils of the Kameng district contain medium amounts of available phosphoric acid, and the soils of the remaining districts contain low amounts of available phosphoric acid. Soils of Siang district contain medium amounts of available potash (Kolay, 2000).

b) Assam

The soils of Assam can broadly be divided into four main groups, viz. alluvial soils, piedmont soils, hill soils, and lateritic soils. The alluvial soils are extensively distributed over the Brahmaputra and Barak plain and are very fertile. It contains moderate amounts of OM, N, and high amounts of P, potash, and Mg. The young alluvial soils mostly composed of sandy to silty loams and slightly acidic in nature. On the other hand, the old alluvial soils occur in some patches of Kokrajgar, Barpeta, Nalbari, Kamrup, Darrang, Sonitpur, Lakhimpur and Dhemaji district. Generally, the old alluvial soils are very deep with fine loams to coarse loams in texture and are slightly to moderately acidic. The piedmont soils are confined to the northern narrow zone along the piedmont zone of the Himalayan foothills. The soils are very deep and fine to coarse loamy in texture. The hill soils are generally deep, dark grayish brown in colour and fine to coarse loamy in texture.

The hill soils may be divided into red sandy soils and red loamy soils. The red sandy soils are distributed covering as narrow belt along the Assam-Meghalaya border, the Karbi plateau, the southern part of the Barail range of North Cachar Hills districts. On the other hand, the red loamy soils occur in the narrow southern foothills belt running along the Assam border with Arunachal and Nagaland and also in the Southern fringes of Karbi Plateau and the Barail Hills of North Cachar Hills district. The lateritic soils are extensively occurring in North Cachar Hills district and some parts of the southern Karbi Plateau. These soils are dark and finely textured with heavy loams and deficient in N, potash, phosphoric acid, and lime (Anon., 2016a).

c) Manipur

The soil cover can be divided into two broad types, viz. the red ferruginous soil in the hill area and the alluvium in the valley (Anon., 2013). The soil on the steep hill slopes is subjected to high erosion resulting in the formation of sheets and gullies and barren rock slopes (Anon., 2015). The pH value ranges from 5.4 to 6.8. The soils may be divided into sandy loam, clayey loam, and loamy soil. The sandy loam soil is generally poor in plant nutrients, low in WHC, and possesses excessive internal drainage. The clayey loam soil is rich in plant nutrients and WHC. The loamy soil occupies an intermediate position, in respect of plant nutrients, WHC, and drainage (Singh, 1963).

d) Meghalaya

The soils of Meghalaya are derived from gneissic complex parent materials. Laterite, red and yellow soils, and alluvial soils cover the Khasi Hills. Almost all the entire soils of the state contain low amounts of available phosphoric acid and a medium of potash (Kolay, 2000). The red loamy soils are predominant in the central upland of Khasi-Jaintia Hills, where the soil is mostly sandy because of the sandstone outcrops. They are also rich in OM which again tends to be more in higher altitudes because of low temperature. Though the humus content is high, it is devoid of base minerals like Ca, K, Na, etc., except being rich in iron oxides. The western part of the Garo Hills regions is covered with lateritic soils, varying in nature from loam to silty loam, highly leached, acidic in reaction, and poor in plant nutrition. Further west, along with the border areas, the soil is predominantly alluvial being both older and younger alluvium (Anon., 2017).

e) Nagaland

The soils of Nagaland are derived from tertiary rocks belonging to Barail and Disang series. The soils are very rich in OC but poor in available phosphate and potash content

(Anon., 2008a). Due to large variations in topography and climate, the soils are divided into five main groups, viz. alluvial soils, hill soils, laterite soils, brown forest soils, and podzolic soils. The young alluvium occurs mostly in the western and southwestern parts of the state whereas the old alluvium is chiefly found in the northwestern part of Nagaland bordering Sibsagar district of Assam. The hills soil with pH 4.4 - 4.6 occurs mostly in the valleys of the central and eastern parts of the state. Laterite soil is the most widespread and occurs in the mid-southern part and the eastern part of the state with a pH value of 4.2 - 4.5. Brown forest soil with a pH content of 5.3-5.8 is found mainly in the intermediate high hill ranges while Podzolic soil with pH 5.4-6.0 occurs at high altitude with a humid and temperate climate in the central, southern and eastern part of the state.

f) Sikkim

The state constitutes hilly terrain with closely spaced elevated hill ranges and narrow valleys (Anon., 2007). Soils of Sikkim vary from loamy sand to clay loam with a considerable amount of coarse fragments. They are generally dark brown in colour on the surface and reddish in the subsurface. The soils of eastern and western districts are more acidic than those of the southern district. Despite high OM and K content, there is a widespread deficiency of N and more than 50% of the soils are low in available phosphates (Srivastav, 1981).

g) Tripura

The soil types of Tripura can be classified under four major groups, viz. reddish yellow-brown sandy soils, red loam and sandy loam soils, alluvial soils, and lateritic soils. Reddish yellow-brown sandy soils cover nearly 33.06% of the total geographical area of the state, poor in nutrient and mostly distributed along the north-south axis. Red loam and sandy loam soil occupy 43.07% of the total area. About 10% of the state is covered by older alluvial soil. Normally located in river terraces and high plains, the soil is rich in organic nutrients and suitable for arable farming. About 9% of the state is covered by younger alluvial soil, confined to the flood plains of the river (e.g. Khowai, Haora, Gumti and Muhari, etc.). This composed of clay loam and loam and is extremely rich and fertile due to the impact of annual flooding. Approximately 5% of the total land can be classified under "lateritic soil". Coarse in texture and very poor in nutrients, this soil type can support scrubland and wild bushes (Anon., 2002).

h) Mizoram

The soils of Mizoram are dominated by sedimentary formation belonging to the Barail, Surma, and Tipam series of Miocene to the Pleistocene period (Jha, 1997). These are generally young, immature, mostly developed from parent materials such as ferruginous sandstones and shale. The soils in the foothills are colloquium deposit and in plain areas alluvial deposits are predominant. The soils, however, be classified broadly in two groups, viz. alluvium and residual soils. Residual soils that may further be classified as lateritic, brown earth and podzolic occur in most of the state on steep slopes. Alluvial soils usually occur in the foothills of the north and west and the intermontane plains and valleys (Jha, 1997). The surface soils of the hilly terrains are dark, highly leached, and poor in bases and available P content, rich in OC and available potash content, and have pH values ranging from 4.5 to 5.5 (highly acidic). The surface soil textures are loam to clay loam with clay content increasing with depth (Anon., 1991). Soils of the valley flatlands are brown to dark brown, poor in bases, moderately acidic with pH ranging from 5.5 to 6.0, medium to high in OC content, low available phosphate, and medium to high available potash. The texture of the soil is mostly sandy loam to sandy clay loam. These are deep to very deep but moderately to poorly drained (Pachuau, 2009).

1.6. Scope of the Study

Traditional shifting or slash-and-burn agriculture has always been an integral part of rural livelihood and major land use in Mizoram. It is often cited as a reason for the loss of forest cover, soil erosion, and disturbance of ecological balance. The climatic condition of the state with well-distributed rainfall and location in tropics and temperate zone with various soil types had widely contributed to the occurrence of a wide spectrum of rich and varied flora and flora. Thus, these natural features and resources have offer opportunities for growing a variety of plantation tree crops (Lalnunmawia and Lalzarliana, 2013). Arecanut and Rubber plantations are an affordable alternative for shifting cultivation and have been cultivated as a cash crop in the district of Kolasib District of Mizoram for quite a long time. Adoptions of such economically high valued tree crop plantations to these areas where agriculture is the mainstay for about 60% of the population and characterized by high dependence on rainfall has come as an opportunity for the farmers to embrace the mainstream and settled agricultural system that contributes a significant proportion of earnings. But the concerns about the long-term viability of these plantations in such non-traditional areas often arise. Hence, evaluation of the fertility status of the soils of an area or a region is an important aspect in the context of sustainable agriculture (Singh and Mishra, 2012). Therefore, the information generated from this study will assist in developing sustainable land-use strategies for enhanced production and provide a base for further research. This will be probably central to our success in the continuous cultivation of plantation tree crops on the same land at the profitable level for many years.

1.7. Objectives of the Study

The objectives of the proposed study envisage the followings:

a) To study the soil nutrient status in two different land-use systems of the Kolasib District viz. Rubber (*Hevea brasilensis* Willd. ex. A. Juss) Mull. Arg. and Arecanut (*Areca catechu* L.) plantations.

b) To conduct a comparative study of soil fertility level in two different land-use systems of Kolasib.

b) Formulation of measures to enhance the soil fertility level.

Chapter 2

LITERATURE REVIEW

Arecanut (*Areca catechu* L.) and Rubber (*Hevea brasiliensis* Willd ex. A. Juss.) Mull. Arg. are the two major cash crops sustaining millions of people globally. They are perennial and their productivity is affected by many reasons, out of which soil nutrient imbalance is one of the important productivity constraints. The status of soil fertility determines the level of crop productivity (Shetty *et al.,* 2008; Jyothi *et al.,* 2009). However, the heavy rainfall, variation in altitude, temperature fluctuation, etc. plays a dominant role in determining soil fertility and productivity (Vigneshwara, 1990). The sustainability of soil health is most important in the plantation belt as these crops occupy the land for decades (Sujatha *et al.,* 2011). The decline in native soil fertility, macro-nutrients, and micro-nutrients are the main indicators of the unsustainability of land-use patterns. Therefore, a brief survey of the literature was conducted to derive basic and useful information on soils under arecanut and rubber plantations to formulate better management practices.

2.1. Arecanut Plantation

The generic name Areca is derived from a name used locally on the Malabar Coast of India which means "cluster of nuts". The cultivation of arecanut is said to date back to the Pre-Christian era. De Candolle in his work ‘The origin of cultivated plants’ mentions that its origin is probably the Sunda Islands (Raghavan and Baruah, 1958). Garcia de Orta mentions it as being cultivated in Malacca before 1593, a fact later corroborated by Ridley (1925). Bretschneider's works indicate that the palms were found in the Malayan Archipelago and India in the first century A.D. According to Beccari (1919), the Philippine Islands were the original home of the arecanut; from this region, he has described various forms of *A. catechu* occurring closely allied and presumes that it was in the Philippines that the edible variety finally assumed its present specific characters. However, the large number of varieties of arecanut (e.g. Pinang Wangi) described from Malaya seems to suggest that the species originated in Malaya. Concerning a Chinese work 'San-fu-Huang' under the name 'Pinlang', a form of the Malayan equivalent of the fruit 'Pinang' was described during 140- 80 B.C. (Anon., 1957). The arecanut was first described by Herodotus in 340 B.C. (Raghavan and Baruah, 1958). The habit of the present system of betel chewing is mentioned in the work of the fourth century. The ancient Arabic writers seem to have recognized the importance of arecanut and call it "Fobal" or "Fufal", referring to the habit of Indians masticating it with lime. Arecanut palms growing wild in Malabar (India) have also been noted (Blatter, 1926; Tackholm and Drar, 1950). It is now believed that arecanut is indigenous to Southern Asia, Indonesia, and possibly the Philippines. It is an aboriginal introduction into New Guinea, the Solomon Islands and western Micronesia, and a recent introduction into Fiji, Samoa, and other islands (Blatter, 1926; Ahuja and Ahuja, 2011; Jayaprakash *et al.*, 2012).

2.1.1. Global

According to the Food and Agriculture Organization Corporate Statistical Database (Anon., 2017a), global arecanut production amounted to 1,319,814 tonnes (tons) in 2016. Some important arecanut growing country is Myanmar producing about 1,42,450 tons (61,832 ha in area and 11% in global production), Indonesia producing 135,000 tons (138,000 ha in area and 10.23% in global production), Bangladesh with a production of 1,21,448 tons (203,519 ha in area and 9.2% in global production), China with the production of 99,992 tons (42,576 ha in area and 7.58% in global production), Sri Lanka producing 44,689 tons (18,175 ha in area and 3.39% in global production), Thailand accounting for 38,105 tons of production (22,430 ha in area and 2.89% in global production), Nepal 14,225 tons (3,905 ha in area and 1.08% in global production) and Bhutan 9,467 tons (8,998 ha in area and 0.72% in global production). It is also cultivated in Malaysia (303 tons of production), Kenya (114 tons of production), and Maldives (22 tons of production) on a smaller scale. Overall, the global arecanut output pursued a moderate growth from 2007 to 2015. The trend pattern was relatively stable, with only minor fluctuations throughout the analyzed period. The total output figures increased at an average annual rate of +0.2%. The growth pace was the most rapid in 2012 when the output figure increased by +22% from the previous year level. In that year, the global arecanut production attained its maximum volume of 1,341 thousand tons. From 2014 to 2015, the total arecanut output growth failed to regain its strength.

2.1.2. National

India is the largest producer and consumer of arecanut in the world (Anon., 2017a). It is grown in an area of about 4,74,000 hectares (ha) with a production of 714,000 tons contributing to about 54.1% in global production. According to Horticultural Statistics Division (Anon., 2017b), Karnataka leads the country producing about 4,36,290 tons with an area of 2,35,770 ha during 2014-15 and 2015-16. The production has gone up from 1,25,930 to 1,32,450 tons with an area of 96,690 ha to 99,126 ha in Kerala during the respective periods. Among these states, Karnataka and Kerala together account for 70% of both area and production in the country. The area went up from 66,740 ha to 77,620 ha, and the production from 73,870 tons to 74,780 tons in Assam constituting about 10.48% of total production in the country during the period. Furthermore, the area under arecanut cultivation increased during 2014-15 and 2015-16 in Meghalaya from 16,770 to 16,870 ha, West Bengal from 11,480 to 11,520 ha, Goa from 1,750 to 1,780 ha, Andhra Pradesh from 480 to 520 ha. Mizoram, Tripura, Andaman and Nicobar, Maharashtra, and Pondicherry cover the same magnitude of the area i.e. 10,740 ha, 4,700 ha, 4,230 ha, 2,350 ha, and 60 ha respectively during the same period. A decline in the area from 6,730 to 6,690 ha and 1,570 to 390 ha was observed in Tamil Nadu and Nagaland. At the same time, there was a decline in the production from 8,660 to 2,300 tons (0.32% in global production) in Nagaland. The total arecanut production has gone up from 25,790 to 26,200 tons (3.67% in global production), 22,250 to 22,660 tons (3.17% in global production), 340 to 1,800 tons (0.25% in global production), 8,840 to 9,790 tons (1.37% in global production), 2,900 to 2,960 tons in Meghalaya, West Bengal, Andhra Pradesh, Tamil Nadu and Goa. Meanwhile, the production remained stagnant at 7,270 tons (1.02% in global production), 9,920 tons (1.39% in global production), 3,480 tons (0.49% in global production), 5,880 tons and 80 tons in Mizoram, Tripura, Maharashtra, Andaman and Nicobar, and Pondicherry during the respective periods.

2.2. Rubber Plantation

In 1876, an Englishman- Henry Wickham marks the starting point in the distribution and spreading of rubber plantations all around the tropical world (Polhamus, 1962; Mors and Rizzini, 1966; Roy, 2005). He collected some 70,000 seeds from the Tapajoz valley (Amazone, Brazil) and brought them to Kew Gardens (London) and further to Ceylon (Sri Lanka) and later it was introduced to other European colonies in the Far East (East Asian countries) by the European imperial powers for their commercial gains (Hong, 1999; Priyadarshan *et al.*, 2005). Although rubber was first an estate crop, local individual farmers soon adopted the crop and so they were drawn into the world commercial economy (Courtenay, 1979). The establishment of rubber plantation in tropical and sub-tropical regions of Asia and Africa begins in the early 19th century (Khanna and Gupta, 2004; Xu, 2006). The increasing demand for natural rubber and the high price of latex provide considerable income for local residents (Qiu, 2009). These have been the main driving forces for the conversion of forested areas to rubber cultivation (Ziegler *et al.*, 2009; Fox *et al.*, 2012; Zhe and Fox, 2012).

2.2.1. Global

According to a recent release from the Association of Natural Rubber Producing Countries (ANRPC), natural rubber production rose 6.8% to 13.3 million metric tons (MMT), compared to the 12.4 million ton (MT) produced in 2016 (Anon., 2018a). ANRPC (i.e. Bangladesh, Cambodia, China, India, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam) account for about 92% of the global production of natural rubber during 2016 (Anon., 2017c). The global demand for natural rubber grew 7.6% from 3.123 MT from 2017 to 3.361 MT during 2018. During the same reference period, the global supply of natural rubber posted a 3.3% growth at 3.152 MT on a year-to-year basis (Bich, 2018).

Currently, Thailand, Indonesia, Vietnam, China, Malaysia, and India are some of the world's largest natural rubber producers, contributing 86.5% to the global total output (Anon., 2017d). Thailand ranked as the largest natural rubber producer in 2016 with a total output of 4.5 MT and a share of 36.3% in 2016 (Anon., 2017e; Nick, 2017). Moreover, the country was the 1^{st} exporter of natural rubber which accounted for 36.8% of the world in 2016 (Workman, 2017). Indonesia is the 2^{nd} largest natural rubber producer globally after Thailand. It was estimated to be 3.16 MT in 2016, increased by

1.6% from the previous year. The size of Indonesian rubber plantations rose from 3.62 Mha in 2015 to 3.64 Mha in 2016, while the rubber productivity of plantations rose from 1.04 tons per ha to 1.05 tons per ha over the same period (Nick, 2018). Vietnam is the world's 3rd largest natural rubber producer and the 4th largest exporter after Thailand, Indonesia, and Malaysia (Anon., 2018b). Vietnam expanded its plantation area to 800,000 ha in 2015 to 976,400 ha in 2016, while the productivity of rubber plantations increased from 1,012,750 tons per ha to 1,035,333 tons per ha of the respective years (Anon., 2017f).

The top ten rubber consuming countries are China, the USA, India, Japan, Thailand, Brazil, Indonesia, Malaysia, Germany, and Russia (Anon., 2016b). The world natural rubber consumption increased to 3% to 12.6 MMT, while there was only a marginal growth of 0.4% in synthetic rubber consumption to 14.9 MT in 2016 (Anon., 2018c). Meanwhile, China is the world's largest consumer and importer of natural rubber, and its rubber consumption in 2016 jumped by 4.6% year on year to 4.896 MT, of which 77.9% was consumed in the country's booming tire industry (Zhe and Fox, 2012; Nick, 2017). Rubber consumption in Asia-Pacific, excluding China, increased at a rate of 3.4% to 8.15 MT in 2016 (Anon., 2017g).

According to Verheye (2010), *Hevea* was introduced in Africa in the early 20th century: Uganda and Nigeria in 1903, Congo in 1904, and Liberia in 1924. Africa accounts for around 5% of global natural rubber production, the main producing countries being Nigeria (300,000 ha), Ghana (63,000 ha), Liberia (100,000 ha), and Cote d'Ivoire (70,000 ha). Another natural rubber plantation major is the Singapore-based Golden Millennium Group owning 18,000 ha of plantations in Cameroon. According to statistics of the Food and Agriculture Organization (FAO) of the United Nations, among the African countries, Côte d'Ivoire ranks the 9th in global rubber production with an annual output of 312,029 tons followed by Nigeria at 151,104 tons, Liberia at 75,371 tons, Cameroon at 55,769 tons, Gabon at 23,161 tons, Ghana at 22,427 tons, Ecuador at 18,901 tons, the Democratic Republic of the Congo at 11,714 tons, Papua New Guinea at 7,292 tons, the Republic of the Congo at 2,305 tons and the Central African Republic at 1,509 tons. Most of these countries have massive unexploited areas highly conducive to natural rubber (Mathews, 2017).

2.2.2. National

Among all rubber producing countries, India is currently the 6th largest rubber producer, with 5% of world production. It continues to be the 2nd largest consumer of natural rubber, with 8.2% of world consumption (Narasimhan, 2017). According to ANRPC, the mature rubber area in India expanded by 90,000 ha during 2011-2016. It is estimated that during 2017-2023, a mature area in India is anticipated to be replanted at the annual rate of 2.8% (Anon., 2016c). Natural rubber production in India rose 23% to 690,000 tons during 2016-17, as against the anticipated 654,000 tons set by the Rubber Board for 2016-17. In 2015-16, the production stood at 562,000 tons, down 12.5% as compared to 2014-15 (Anon., 2017h; Narasimhan, 2017). India's natural rubber consumption was 1,044,075 tons in 2016-17, compared to 994,415 tons, an increase of 5% (Narasimhan, 2017). However, consumption declined to 994,425 tons in 2015-16 from 1,020,910 tons in 2014-2015. India's per capita rubber consumption remains the lowest among major rubber consuming countries at 1.2 kg against the world average of 3.12 kg. During 2016-17 due to lower international prices, imports showed a decline of 7% at 426172 tons, according to leading English daily (Thakkar, 2017). The exports were a meager 865 tons in 2015-16 and now have touched a four-year high of 20,012 tons (Anon., 2017h).

By 1900, most of the techniques and agricultural practices required to establish large plantations had been developed giving rise to two types of rubber plantations viz., the estates, or plantations and the smallholdings. The rubber plant, a native of Brazil, was introduced in India as early as 1873 at the Botanical Gardens, Calcutta as an experimental effort to grow rubber on a commercial scale. But, commercial cultivation of natural rubber was ventured by the British planters in Kerala at Thattekadu in 1902. Later in 1904, J. J. Murphy from Ireland started rubber plantation in the eastern parts (Yendayar) of Kottayam District in Kerala which paved the way for widespread rubber plantation.

The growing demand for natural rubber, coupled with the limited scope of area expansion in traditional regions has necessitated an increase in production from the non-traditional region of the country (Antony *et. al.*, 2010). The state of Kerala, Kanyakumari and Tamil Nadu are the traditional natural rubber cultivating regions, whereas the non-traditional regions are hinterlands of coastal Karnataka, Goa, Konkan Region of Maharashtra, Andhra Pradesh and Orissa, Andaman and Nicobar Islands, *etc.*, as classified by Rubber Board of India (Anon., 2013a). And further expand in the NE states of Assam, Tripura, Meghalaya, Manipur, Mizoram, and Nagaland.

The traditional region accounts for as much as 80% of the total area and 93% of the production of rubber in the country. The rubber plantation sector in India is dominated by smallholdings (less than 2 ha) which accounts for 92% of the production and 89% of the area of rubber in the country. Large scale rubber plantations are found along the western coasts of India, Kerala being the largest producer of rubber in India with an area of 5,39,565 ha (77%) and constitute 90% of the production (Prasad, 2016). The leading producer of rubber in Kerala is the Kottayam district which accounts for 21% of the area under rubber in Kerala (Vinitha and Ramalingam, 2017). The state had produced 6.48 lakh tons of rubber in 2013-14 and drop down to 4.39 lakh tons in 2015-16. Karnataka had produced 35,230 tons in 2013-14 to only 29,400 tons in 2015-16, while the production in Tamil Nadu also dropped from 25,000 tons to 19,495 tons during the same period.

Commercial plantation of rubber in the northeast was introduced during the British colonial rule and is now gainfully cultivated. Since then, rubber plantation has been taken up in a few of the NE states but not as extensively as in the southern part of India. However, the yield potential of rubber is quite low (1000-1100 kg/ha) in comparison to the national average (1700-1780 kg/ha) (Krishnakumar and Meenatoor, 2000). It has been estimated that NE India can afford to plant rubber in 4,50,000 ha, of land (Anon., 2011a). The crop was first introduced to NE India during 1913 at Hailakandi district of Assam. In Tripura, rubber plantation was introduced in 1963 by the forest department to check degradation due to slash and burn agriculture practiced by the local people at Patichhari as part of afforestation programs (Chaudhari *et al.*, 2012).

According to the North-Eastern Development Finance Corporation (NEDFi) data on the extent of rubber plantation in NE India, the rubber plantation growth in Tripura is found to increase from 574 ha during 1976-77 to an area covering 70,295 ha in 2014-15 viz. nearly 7% of the state's land area (Anon., 2018d). Tripura is the 2^{nd} largest rubber producer in the country for shot up from 39,000 tons in 2013-14 to 44,245 tons in 2015-16 which is 7.9% of the total production (Thomas, 2017). Estimates available from NEDFi show that in Assam, the area of rubber plantation grew from 16.5 thousand ha in 2006–07 to 49.0 thousand ha in 2013–14 with a notable uptick in production during the period from 13,600 ton to 14,560 ton (Thomas, 2017). In Meghalaya the area under rubber grew from 4029 ha during 2000–01 to 5331 ha in 2006–07 and it grows over 9,000 ha in 2012. Manipur showed a marginal increase from 1588 ha to 1859 ha from 2000–01 to 2006–07. In 2012-13, a total of 2400 ha of land was used for cultivating rubber trees (Anon., 2018e). Nagaland showed a comparatively high increase from 585 ha during 2000–01 to 2486 ha during 2006–07. According to the annual administrative report by the Department of Land Resources (DoLR), about 11,000 ha of rubber plantations have been developed in the state with an annual production of about 3000 million tons in 2014-15 (Anon., 2015a). During 2016-17, a total of about 18,000 ha have been brought under rubber plantation (Anon., 2017i). The Rubber Board of Arunachal Pradesh has identified about 3640 ha of land for rubber cultivation (Anon., 2015b).

In Mizoram, rubber plantation had been initiated since the 1960s. Encouraged by the success obtained from a rubber plantation in the neighboring Assam and Tripura state, the Mizoram government also had started taking initiatives to carry out rubber plantation on a broader scale. Under the government flagship program New Land Use Policy (NLUP), 3000 beneficiaries were selected for rubber plantation. For the year 2012-2013, about 1,117 ha under NLU) Phase I & II, 1,000 ha under National Bank for Agriculture and Rural Development (NABARD), 1,300 ha under Rashtriya Krishi Vikas Yojana (RKVK) and 5,000 ha within 12th Plan under North Eastern Council (NEC) has been estimated to cover. Meanwhile, only 50 ha had been covered by the State Soil and Water Conservation department and individuals (Anon., 2013b). The State's Soil and Water Conservation department had begun to set up budwood nursery and seedling nursery at six different places since 2010 under NLUP to bring self-sufficiency in rubber seedlings (Lallianthanga *et al.*, 2014).

2.3. Soil Properties under Arecanut and Rubber plantations

2.3.1. **Arecanut Plantation**

Arecanut production in India has now almost reached a level of self-sufficiency. The arecanut palm is capable of growing under a variety of climatic and soil conditions. Adequate supplies of plant nutrients in the soil throughout the life of the crop is essential to get a high yield. According to Wang *et al.* (2001), climate and geological history are also important factors to affect the soil properties on a regional and continental scale, however, some of the soil-related processes such as erosion, oxidation, mineralization, and leaching, etc. play an important role in the maintenance of soil in balanced condition related to the macro and micronutrients (Celik, 2005). Soil fertility is one of the important factors controlling the crop yield; soil-related limitations affecting the crop productivity including nutritional disorders can be determined by evaluating the fertility status of soils. Soil testing provides information about the nutrient availability of the soil upon which the fertilizer recommendation for maximizing crop yield is made (Supriya, 2018).

In India, arecanut plantations are by and large located in fertile valleys in the coastal and ghat regions in Kerala and Karnataka and alluvial deltas in Assam and West Bengal. Shetty *et al.* (2008) evaluate the soil fertility status of traditional arecanut growing areas of Karnataka. The majority of soils were medium in available N and P while K status was high. Batabyal and Shetty (2012) studied the distribution of P fractions in the soils of traditional arecanut growing areas of Karnataka. The total P content of the soils varied from 200.30 milligram/kilogram (mg/kg) to 710.30 mg/kg and, on average, 46.2% and 53.8% of this amount was shared by organic and inorganic P pools. Jayaprakash *et al.* (2012) suggested that the balanced supply of nutrients is very much essential from the point of soil health and also to avoid disorders in the non-traditional belt of arecanut growing areas of Karnataka. The majority of profiles where medium to high in available N and low to medium for available P. The available K was medium to high in all the surface and sub-surface soil profiles. Similar findings were also observed by Madiratta *et al.* (1985) in Areca gardens of Orissa. The higher contents of OM at the surface are due to management factor-like application of Farm Yard Manure (FYM) and green manures at regular intervals by the growers. Jayaprakash *et al.* (2012a) conducted a study to characterize the macro-nutrient status of non-traditional areca growing areas in Karnataka, where the majority of the soil samples ranged from medium to high. These variations in macro-nutrients are due to regular management like OM application, application of fertilizers and inherent soil properties and season temperature variations, etc. The exchangeable bases, Ca and Mg were dominant cations followed by Na and K.

Dhumgond *et al*. (2017) conducted a study to know the soil fertility status of different cropping systems in hill zone acid soils of Karnataka. Soil characterization revealed that soils were slightly acidic to moderately acidic in range with low soluble salts. Surface soils under paddy cropping system recorded higher exchangeable aluminum ion (Al^{3+}) and exchangeable acidity compared to coffee and areca cropping systems. Soils are medium in available N and P status but high in available K, Ca, Mg, and S status in all cropping systems. Amount of DTPA (Diethylenetriamine Pentaacetic Acid) - extractable Fe, Mn, Zn, and Cu were higher in coffee and areca systems compared to paddy system. Kavitha and Sujatha (2015) conducted a study to evaluate soil fertility status in various agroecosystems of Thrissur District, Kerala. Among the eight agroecosystems studied, soil fertility for NPK was medium, high, and low. Status of Mg, S were medium and Zn, Fe, Cu, Mn were high while Boron (B) was low in arecanut plantation. Babu *et al*. (2018) also reported the characteristics of the soil of the terai region of West Bengal as sandy loam in texture having acidic pH with low P and micronutrient content. Bhat and Sujatha (2014) studied the constraints in production, the importance of soil testing, and precision agricultural practices for nutrient management in arecanut. They reported that arecanut is predominantly grown in gravelly laterite soil of red clay type in southern states of India having high rainfall and undulating topography and the region experienced leaching of bases along with fixation of P and Zn.

The deficiency of micronutrients has become a major constraint to productivity and stability in areca growing soils. However, exploitive nature of modern agriculture like introducing high yielding varieties and the concomitant usage of high analysis NPK fertilizers coupled with limited use of organic manures and less recycling of crop residues are important factors contributing towards accelerated exhaustion of micronutrients from soil (Nagaveni and Subbharayappa, 2018). The emergence of micronutrient deficiency has generally been considered as secondary and arecanut is having a well-established root system. Nagaveni *et al.* (2017) undertaken a survey to assess the status of available micronutrients and their relationship with other factors such as pH and OC. However, the available Fe, Mn, Zn, and Cu were found to be more than the critical limit in all the soil samples and higher values of Fe was recorded in Davangere, Mn, and Zn were recorded in Honnali, Cu was in Channagiri, respectively. But available B was deficient in all the soil samples. All available micronutrient content in arecanut plantations decreased with depth, except B. A similar trend was observed by Singh *et al.* (1988) and Kumar *et al.*, (2012). It was also observed that 2.86% of the areas sampled were deficient in available

Zn and 98.14% in available B. Available Cu and B showed a significant negative correlation with pH whereas a significantly positive correlation was noticed between pH and available Fe, Mn, and Zn. Similar results were obtained for the hills of Uttar Pradesh (Rawat and Mathpal, 1981). All the available micronutrients showed a significantly positive correlation with OC. However, a positive significant correlation was observed between OC and micronutrients in traditional areca growing soils of Karnataka (Shetty *et al.*, 2009) and the Kashmir valley basin soils (Jalali *et al.*, 2002). B deficiency in arecanut reduces the yield which results in that nut splitting, nut, and flower dropping (Nagaveni and Subbharayappa, 2018). Rajakumar and Patil (2016) reasoned unimproved soil nutrients and properties status for nut drop in arecanut. The soils in Western Ghats soils of Uttar Kannada district match with the laterite characters and suggested applying lime/dolomite. To improve EC level and available potash status of soil, there is a need to apply an extra dose of potash to soil than the recommended dose. To increase available P in acidic soils, there is a need to apply rock phosphate. Since the available N is medium to high, the recommended N may be continued. The recommended dose of Zn and B has to be applied before the onset of monsoon and if nut drop prevails these have to be applied immediately after receipt of rains. Ranaweera *et al.* (2010) also suggested that organic fertilizers are more environmentally friendly as compared to inorganic fertilizers.

Arecanut Based Farming Systems (ABFS), as a productive land-use system has received much attention in the recent past. The positive impact of the arecanut based cropping system on soil quality indicators is well documented (Muralidharan, 1980). However, the research efforts on these aspects are being made since the fifties. Sundaramurthy (1950), Bavappa (1951), and Brahma (1974) stated that the crops chosen as inter/mixed crops vary from region to region. Crops like cocoa, clove, banana, tapioca, black pepper, colocasia, yams, pineapple, jack, and coconut were grown as inter/mixed crops in arecanut gardens (Bavappa *et al.*, 1986; Sannamarappa, 1993). In general, preference is given for elephant foot yams and tapioca as intercrops in Kerala, for citrus in Assam, for betel vine in West Bengal and Assam, cardamom in Malanad of Karnataka and a general preference for the banana in all the arecanut growing regions. The microclimate under arecanut canopy is suitable for growing various intercrops and mixed crops (Balasimha, 2011). Bhat (1975) stressed the importance of intercropping as a source of additional income during off-season and also as a safeguard against the uncertainties of returns from monoculture gardens. The review on inter/mixed cropping in arecanut showed ample evidence for maximum resource use efficiency and generation of supplemental income from the plantations (Muralidharan, 1980). According to Sujatha *et al.*, (2011), inter/mixed cropping in arecanut gives ample scope to overcome the soil, weather, and crop constraints by improving resource use efficiency. Increased root proliferation in arecanut due to intercropping was noticed by Muralidharan (1980), which in turn would increase OM content in the soil. Bopaiah (1983) and Mohapatra and Bhatt (1982) observed that intercropping legumes in arecanut plantation increased the soil, content of available N, recycled nutrients in the soil profile, prevent soil erosion and improved soil fertility. Thus, the cropping system approach is important for soil acidity management of laterite soils in the arecanut belt. These findings are worthwhile and indicate that inter/mixed cropping influences nutrient cycling, soil fertility, and carbon cycling. Sujatha and Bhat (2010) and Sujatha *et al.* (2011) state that is necessary to grow value-added and export-oriented intercropping in this era of trade liberalization to increase the yield potential per unit area, as there is little scope for horizontal expansion of the area under huge population pressure in developing countries for agriculture and developmental activities (urbanization and industrialization).

Sujatha *et al.* (2000), Bhat and Sujatha (2006), Bhat *et al.* (2007) and Bhat and Sujatha (2009), suggest that drip fertigation is very ideal for arecanut as it resulted in substantial yield increase, soil fertility improvement and reduced cost of production. Sujatha and Bhat (2012; 2013) investigated the effects of vermicompost and chemical fertilizer application alone or in combination with biomass partitioning, nutrient uptake, and productivity of arecanut. The organic wastes from arecanut and cocoa, which otherwise has no use, can be efficiently converted to vermicompost (Chowdappa *et al.*, 1999). OM recycling in the arecanut based cropping system reduces the fertilizer requirement of each component crop to 2/3rd of the recommended dose (Bhat and Sujatha, 2007). Long term application of vermicompost sustained yield levels of arecanut at 2,700 kilograms per hectare (kg/ha) compared to 3,100 kg/ha with mineral fertilizers (Anon., 2011b) and 3,500 kg/ha with drip fertigation (Bhat *et al.*, 2007). Leachates derived from vermicompost are regarded as beneficial and can be used as liquid fertilizers due to high concentration of plant nutrients (Gutierrez-Miceli *et al.*, 2008; Tejada *et al.*, 2008). Sujatha and Bhat (2015) further studied the effects of drip fertigation of NPK and vermicompost extract on soil fertility status of arecanut-only and arecanut-cocoa systems in a 4-year field study at the division of Crop Production, Central Plantation Crops Research Institute (CPCRI), Regional Station, Vittal. The destruction of natural forest and pasture ecosystems and its conversation to cropland can reduce precipitation or increase temperature, reduce soil productivity because of increased erosion, cause a decline in fertility, change in soil flora or fauna, and reduce SOM, which plays a crucial role in sustaining soil quality, crop production, and environmental quality (Doran and

Parkin, 1994; Spaccini *et al.,* 2001; Kara and Bolat, 2007). Panwar *et al.* (2011) attempted to quantify the changes in the properties of soil under the home garden, arecanut plantation, and agricultural land uses by comparing them with the properties of soils under natural forest. Soil fertility index (SFI) varied from 13.13 in arecanut plantation to 18.49 in the forest and soil evaluation factor ranged from 6.43 in agriculture to 6.56 in the forest.

2.3.2. Rubber Plantation

Thomas *et al.* (2015) highlighted that the increasing demand for natural rubber is leading to the spread of monoculture plantations with the establishment of >2 Mha during the last decade, threatening important areas of Asian forests, including many protected areas. The study reported by Fox *et al.* (2014) states that in the mountainous region of Mainland Southeast Asia, shifting cultivation has been replaced by permanent cropping, and in particular by rubber plantations. And it appears that these transitions could improve carbon (C) sequestration, which may be difficult to measure and, in any case, are not likely to be substantial. However, this massive land-use change could lead to drier conditions at the local level plus surface erosion, loss of soil quality, sedimentation, and disruption of streams and risk of landslides. Chun-man *et al.* (2007) further showed that rubber forest (272.08 t/hm^2) has more potentials for C fixation in comparison with C sequestration in biomass of rain forest, 234.305 t/hm^2 (Li *et al.*, 1998) and secondary rain forest, 150.203 t/hm^2 (Wu *et al.*, 1998), which is beneficial for reducing global warming.

Li *et al.* (2012) observed that tropical forest in Xishuangbanna has been converted into rubber plantations, tea gardens, and abandoned cultivated land can result in higher BD as well as soil compaction and lower SOM concentration. The rubber plantation and tea garden, which are frequently fertilized, had significantly lower NO_3^-N and higher NH_4^+N concentrations at the topsoil (0-20 cm) compared to the tropical forest and abandoned cultivated land. Recently Chen *et al.* (2016) observed the rapid expansion of rubber plantations into higher elevations, steeper terrain, and into nature reserves in Xishuangbanna, China poses a serious threat to biodiversity and environmental services. According to the studies carried out by Hu *et al.* (2008) and Hauser *et al.* (2015), the expansion of rubber monoculture in shifting agriculture and forest areas results in a loss of ecosystem services and changes in ecological functions, socio-economic conditions, and human welfare. Yang *et al.* (2004) observed a significant decline in concentrations and stocks of SOC (33% and 23%) and TN (20.4% and 20.4%) in surface soils (0-20 cm) of shifting cultivation and rubber tree plantation compared with an acuminate banana and a male bamboo secondary forest whereas the decreases of SOC and TN stocks in sub-soil layers (0-60 cm) were much less.

Snoeck *et al.* (2013) concluded that mixed plantation of *Hevea* with other tree crops rather than monoculture plantation on better land use, the seasonal spread of labour and a wider range of productivity and reduced susceptibility to market crashes. The plantation site presents a combination of rubber plantation mixed with arecanut and banana plants. Research and development (Anon., 2013c) showed that coffee or cocoa is a more profitable combination, helping the smallholders improve their income source and thereby make better use of their land. Diversity of crops including spices, plantation crops, leguminous cover crops (Ziegler *et al.*, 2012), medicinal plants, and vegetables combined with rubber help in sustained soil fertility (Jessy *et al.*, 2016). Khasanath *et al*, (2008) suggested that inter-planting of *Acacia mangium* within rubber plot may be an attractive option for smallholder rubber farmers in the tropics to increase their productivity. This study compares a series of growth and physiological parameters measured on rubber trees grown either in monoculture or associated with *A. mangium* in relation to leaf water potential and light interception by the canopy. However, the girth and canopy size of rubber trees grown in mixed systems was slightly smaller. The leaf water potential of *H. brasiliensis* did not show any consistent difference between the systems. But the amount of photosynthetically active radiation (PAR) intercepted was slightly lower in the mixed plantation than that of in monoculture. Zhang *et al.* (2007) also suggest that tea-rubber intercropping tends to sequestrate higher atmospheric C in soils than rubber monoculture through increased organic pools in the tea-row soils and reduced OC turnover rates in the rubber-row soils.

Dharmakeerthi *et al.* (2005) determine the nutritional status and degree of nutrient variability in the non-traditional rubber soils of Sri Lanka (Moneragala district) found that OC levels ranged from 0.4 to 1.5% indicating low soil fertility conditions. Total N content (0.10 to 0.25%) in these soils is higher than in traditional rubber growing soils but urease activity is very low. Available P (16-39 ppm) showed a medium variation. Exchangeable K (23-273 ppm) and Mg (15-347 ppm) contents exhibited a very high variability.

Yasin *et al.* (2010) examine the effect of rubber tree ages (1, 5, 10, 15, 20 years) on land degradation status in Damasraya district of West Sumatra, Indonesia. The OC and TN content in soils increased when the forest was converted into rubber tree until 1 year (2.64%, 0.19%). It decreased gradually to 10 years (1.67%, 0.11%) and again increased when the rubber tree reached 20 years (2.23%, 0.13%) old. The study carried out by Chun-man *et al.* (2007) showed that with the increase of stand age of rubber plantation, soil fertility decreased all along, including SOC, TN, available P, and K.

Slamet *et al.* (2015) examined the impact of land cover changes from forest to jungle rubber, rubber plantations, and oil plantations in the tropical lowland rainforest transformation landscape to several soil properties. The content of the OC, Na, Ca, Mg, K were very low and P were very high in the rubber plantation based on the criteria of Indonesia Soil Research Centre (Anon., 1983). However, the results of mean difference test analysis showed no significant difference, or in other words that forest cover changes do not provide a significant influence on the soil properties. Cook *et al.* (2014) and Geissen *et al.* (2009) in their study also reported that forest conversion to various land cover showed no significant differences for the content of the SOC, available P, TN, and C/N ratio. These results are contrary to the study carried out by Handayani (2004) and Cheng *et al.* (2007) that the conversion of forests into rubber plantations has reduced in SOC by 27%, and SOM by 48.2%.

The study examined by Njar *et al* (2011) revealed that the contents of OM and TN in mature rubber soils increase with the ages of trees (7, 16, 39, and 41 years) probably as a result of the increase in tree size and vegetation cover. Contrastingly, Ekukinam *et al.* (2014) showed that the contents of available P and exchangeable Ca, Mg, and K in the rubber plantation soils declined substantially with the increasing age of rubber tree. Deekor *et al.* (2012) evaluate the effects of vegetation cover on soil properties by comparing the properties of soils of 16-year-old rubber plantation, roadside vegetation, and secondary forest. The result further revealed that the OC and TN contents were higher in the secondary forest soil than in other land cover soils. Oku *et al.* (2012) carried out a study to examine the status of Mn, Fe, Cu, and Zn in rubber plantations. The results showed that Fe contents were rated as high whereas the Cu contents were rated as medium. Except for the 7-year-old plantation, where Zn was rated as medium. Mn content was rated as high, medium, medium, and low in the 7, 16, 39, and 41-year-old plantations, respectively. The low values of soil pH across the rubber plantation plots did not significantly favour the increase in selected micronutrient levels in the soil.

Puyravaud *et al.* (2010) and Thomas *et al.* (2015) highlighted that the increasing demand for natural rubber is leading to the fast expansion of monoculture plantations with the establishment of >2 Mha during the last decade. Although the rubber industry is important for socio-economic development, there is growing concern about the negative environmental impacts of increasing rubber plantation areas in India. Roy *et al.* (2014) have expressed concerns on the ecological impacts of rubber plantation bringing out the adverse effects on soil productivity (Zhang *et al.*, 2007a), biodiversity (Warren-Thomas *et al.*, 2015), microclimate stability, C stocks (Li *et al*, 2008; DeBlecourt *et al.*, 2013), reduction in species richness of 19% (Li *et al*, 2009), energy balances and water fluxes (Hu *et al.*, 2008; Ziegler *et al.*, 2009; Guardiola-Claramonte *et al.*, 2010).

Chankarakala *et al.* (2019) concluded that more than 60% of the total geographical area is under rubber cultivation in Elamdesam block, Idukki district, Kerala. Emphasis was placed on land characteristics or land qualities (Naidu *et al.*, 2006) which determine the limitation. An area of 69158 ha (32.48%) comes under one suitability class, i.e. marginally suitable whereas 74,526 ha area (34.99%) comes under not suitable due to constraints like relief, topography, limitation of root restriction, soil physicochemical attributes such as base saturation, pH, texture, and soil moisture regime (Gahlod *et al.*, 2017). Chandrasekhar *et al.* (1990) and Vijayakumar *et al.* (1998) reported similar findings. Karunakaran (2014) examined the changes in soil fertility of important crops (paddy, coconut, arecanut, and rubber) in Kasaragod District of Kerala. It is found that P and K elements are low and the groundwater level decreased severely in rubber-based cropping systems. It was evident from different studies that rubber plantations exhibit lower NPK components in comparison to other vegetation (Shaji and Abraham, 1994; Chattopadhyay and Richard, 2006; Kayarkanni, 2006; Karunakaran, 2013).

Viswanathan (2008) offered a comparative assessment of the emerging rubber farm livelihood systems in NE India and Southern Thailand. The socioeconomic significance of the rubber integrated farming systems assumes greater prominence from a sustainable livelihoods perspective. It provides ample capability for resilience during crises and ensures a sustained flow of income to the smallholders. Rubber was a part of the rehabilitation program to restore the ecological equilibrium that got disturbed due to deforestation and shifting cultivation practiced for ages in Tripura (Datta and DasChaudhuri, 2012). Studies also have shown that rubber soils have higher available WHC, moisture desorption patterns and sequestrate high amount of C with time. Rubber has a long gestation period that provides ample scope for the cultivation of annuals, biennials, and perennials in the interspaces (Datta and DasChaudhuri, 2012). Chakraborty *et al.* (2018) in their study focusses on the expansion of monoculture rubber plantation (*H. brasiliensis*) in selected sub-watersheds in northeast India. The foundation for rubber expansion in this region has proven to benefit the tribal communities while meeting the growing domestic demand for natural rubber. Rubber plantation provides gainful self-employment and sustainable livelihood opportunities generating direct employment-approximately 1000 man-days/ha (Anon, 2008b).

On the other hand, Majumder *et al* (2014) reported that the conversion of natural forest into a deciduous monoculture of rubber might disrupt the pattern of special and temporal controls over nutrient cycling. The untreated or partly treated effluents of natural rubber production may cause a potential threat to environmental balances such as contamination of surface and groundwater, soil and air, shrinking of natural forests and loss of diversity, and impacts on local rainfall and temperature. Bhattacharyya *et al* (1998) made an effort to evaluate soil-site criteria for rubber in the non-traditional tracts of Tripura, India. The study indicates that most of the soils of the state are moderately suitable for rubber which is estimated to be about 91,000 ha forming 8.3% of the total area of the state. The OM content of Tripura soils ranges from 0.7-2.4% in the surface and 0.1-0.6% in the subsurface horizons. Debbarma and Debbarma (2018) discussed the adoption of rubber in Tripura as an alternative to check forest degradation due to shifting cultivation and to resettle the Jhumias has left with a reduced land area for carrying out cultivation of short rotation seasonal crops. The entire phase of cultivation accounts for loss to local biological resources namely; medical plants and other Non-Timber Forest Products (NTFPs) and is also marked by a decline in vegetal C stocks and contributes to rising in CO_2 levels and subjecting the newer pristine forest areas to exploitation. Ahrends *et al.* (2015) observed that new rubber plantations are frequently sites on lands that are important for biodiversity conservation and ecological functions.

However, Roy *et al.* (2014) marked that rubber plantation has shown its credibility to improve soil health, initially when it was confined to bare land or denuded forest land or the land degraded by shifting cultivation. The recent attempt of the transition of lands covered by different vegetation including horticultural orchards and unrestricted expansion of the monoculture pose a threat to the ecology of the state Tripura. However, the impact of rubber monoculture on microclimate (Jiang and Wang, 2003), rainfall and climate of the state (Bhattacharjee, 2002; Sailajadevi, 2010), till date it has not made a significant impact on rainfall and temperature and even if the plantation is expanded up to target level.

Chapter 3

STUDY AREA AND STUDY SITES

3.1. Study Area

Mizoram is situated in the extreme eastern corner of the country and lies between 21º56’ to 24º31’ N Latitudes and 92º16’ to 93º26’ E Longitudes. Sandwiched between Bangladesh and Myanmar, its location is of strategic significance geographically and politically, and shares a common international boundary of about 585 km with these two countries. The total geographic area of 21,087 sq. km that is 0.64 % of the total area of India (Pachuau, 2009). On the Indian side, Mizoram is bounded by the state of Assam, Manipur, and Tripura. Its geographical borders with these states extend over 123 km, 95 km, and 66 km, respectively (Bisht, 2011; Anon, 2012).

3.2. Description of the Study Sites

The present study was conducted in Kolasib District of Mizoram. Kolasib is an important and potential district of Mizoram for agriculture production. It is situated in the northernmost regions of the state surrounded by Aizawl district in the south and east and Mamit district in the west and Assam state in the north. The geographical area of the district is 1,38,251 ha which 6.56% of the state area is. It is situated in between 23°-5′ to 24°-35′ N Latitude and 92°-3′ to 93° E Longitude. It can be categorized under two agro-climatic zones namely, as humid mild tropical, humid-subtropical hill zones. The district consists of two rural development blocks and 31 villages (Bhalerao *et al.*, 2015). It has difficult terrain and hills are separated by rivers flowing north to south, thus creating innumerable hurdles in intra-district communication. The major rivers flowing in the district are Tlawng and Serlui which are fed by several tributaries. These rivers flaws from south to north and ultimately confluences to the Barak river of Assam (Anon, 2012a).

A reconnaissance survey was held in the selected sites for sampling which includes: 24 years old Arecanut Plantation, 22 years old Rubber Plantation, and 25 years old Secondary Forest. The plantation sites are a monoculture land, while the secondary forest is characterized by dense vegetation (bamboo/shrubs) with numerous undergrowth. The Arecanut Plantation site is owned by Mr. Lalbiakseia, located at 21̥̊ 19"08.3" N and 92̊ 42'47.7" E in Bilkhawthir village which is along National H54. The Rubber Plantation site is owned by Mr. Kaphranga, located at 24̊ 14'45.7" N and 92̊ 39'51. 3" E which is

10 km away from Arecanut Plantation site along the Bairabi Village and the Secondary Forest is located at 24˚11’54.6” N and 92˚35’58.3” E in Pangbalkawn village (**Map 3.1**).

3.2.1. Demography and Literacy

As per the latest reports of Statistical Abstract of Mizoram (Anon., 2017j), Kolasib district had a population of 83,955 of which males and females were 42,918 and 41,037 respectively. The average sex ratio stood at 956 as per 1000 male and district density was at 61 people per sq. km of 2011 census data (**Table 1**).

Table 1: Salient features of Population Census in Kolasib District (2011 Census)

Area (Sq. Km.)	Population			% Decadal Growth Rate of Population (2001-11)	Sex Ratio (Females per 1000 males)	Population Density (per Sq. Km.)
	Persons	Males	Females			
1,382	83,955	42,918	41,037	27.28	956	61

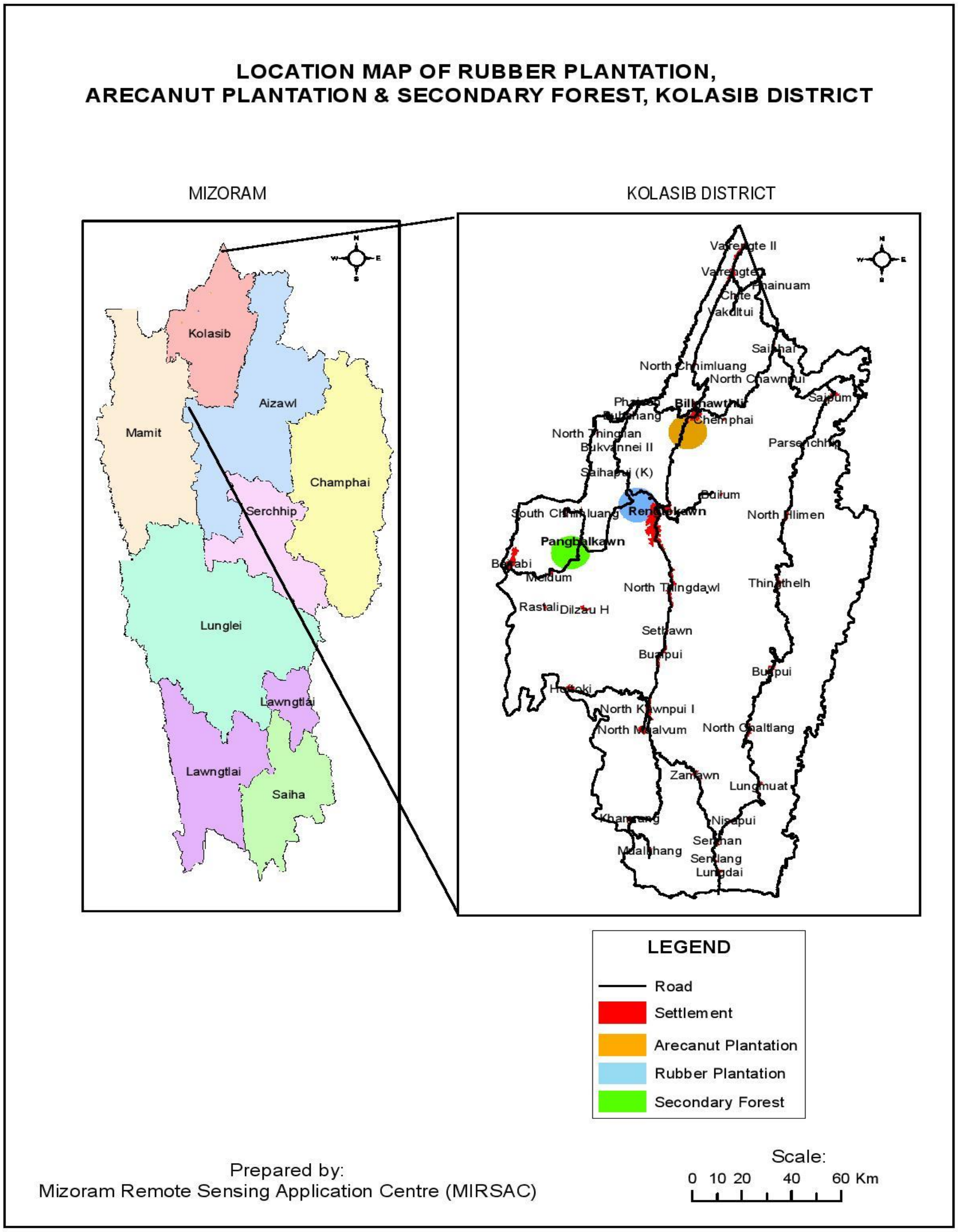
The average literacy rate of Kolasib in 2011 was 93.50%. At gender wise, male and female literacy were 94.57 and 92.38 respectively. Total literate in Kolasib district were 65,895 of which male and female were 34,147 and 31,748 respectively (**Table 2**).

Table 2: Literate Population and Literacy Rate in Kolasib District (Census 2011)

Number of Literate persons			Literacy rate (%)		
Males	Females	Total	Males	Females	Total
34,147	31,748	65,895	94.57	92.38	93.5

3.2.2. Topography

The topography, in general, is undulant with broken mountainous/hilly ranges, and between them lies the valley lands suitable for cultivation of field crops. The hills are suited for horticultural practices wherever the slopes are gentle/moderate. The soils in hills are rich in humus due to forest cover. However, in abandoned jhum lands the situation is reversed. The soil, in general, is acidic- pH ranging between 4.5-6, deficient in the base material, medium in OC, low in available P, and high in potash. The predominant soil taxonomy is Hapladults and Udontherrnts wherein moisture retention capacity is very low. Though the district mainly comprises of hilly terrain there are low lying valley lands in few pockets, where the altitude is rather low having warm and humid climate facilitating paddy cultivation. In fact, this district has many such rice pockets. The altitude ranges between 36-900 meters above sea level (m a.s.l.) (Anon, 2011c).



Map 3.1. Map Showing the Study Sites

Photo Plate 3.1. Photo Showing Arecanut Plantation Site

Photo Plate 3.2. Photo Showing Rubber Plantation Site

Photo Plate 3.3. Photo Showing Secondary Forest Site

3.2.3. Climate

Kolasib district is the northern part of Mizoram state which enjoys a moderate climate owing to its tropical location. It is neither very hot nor too cold throughout the year. It falls under the direct influence of the southwest monsoon which receives an adequate amount of rainfall during the monsoon season. The average rainfall of Kolasib district is 2703 mm per annum and the highest rainfall during a particular month was 852 mm recorded during August and July. The salient thermo-characteristics of the district are that temperatures do not fluctuate much throughout the year. The highest temperature observed during the past decade was 35ºC in July. The warmest months with a mean daily maximum at about 26ºC and a mean daily minimum at about 23ºC were observed during June and July. The temperature started to fall from November and it is minimized in December and January (Bhalerao *et al.,* 2015).

3.2.4. Forest Types

The forest type of Kolasib district is mainly tropical wet evergreen and tropical semi-evergreen forest associated with moist deciduous forests. Moist mixed deciduous forests are commonly found in small pockets on the hill slopes. The vegetation consists of a mixture of several species (Bhalerao *et al.,* 2015). Bamboo Forest covered the large land-use area. The dominant bamboo species found are *Dendrocalamus hamiltonii, D. longispathus,* and *Meloccana bambusoides*. Forest plantations are distributed throughout the district. Some of the prominent forest plantations are *Tectona grandis, Gmelina arborea, Hevea bengalensis.*

3.2.5. Meteorology

The meteorology data from 2013-2017 was procured from the Department of Meteorology, ICAR Complex, Kolasib.

The average ambient temperature at the Kolasib site ranged from 12.2˚C to 32.54˚C. The maximum and minimum monthly temperature values were 32.3˚ C (Apr) and 12.45˚C (Dec) during 2013; 32.54˚ C (Apr) and 13.24˚C (Dec) during 2014; 31.65˚C (Mar) and 13˚C (Jan) during 2015; 29.4˚C (Apr) and 12.2˚C (Jan) during 2016; 29.4˚ C (May) and 12.8˚C (Jan) during 2017.

The relative humidity ranged from 22% to 98%. The maximum and minimum monthly humidity values were 98% (Aug & Sept) and 31% (Mar) during 2013; 79% (Jan) and 22% (Oct & Nov) during 2014; 94% (July & Aug) and 26% (Jan) during 2015; 96% (Aug & Sep) and 51% (Feb) during 2016; 96% (Sept) and 42% (Feb) during 2017.

The average rainfall ranged from 0 mm to 954.9 mm. The maximum and minimum monthly rainfall values were 831.5 mm (May) and 0 mm (Jan, Nov & Dec) during 2013; 954.9 mm (July) and 0 mm (Jan & Dec) during 2014; 522.6 mm (Apr) and 7.8 mm (Mar) during 2015; 778.3 mm (Sept) and 2.4 mm (Jan) during 2016; 623.4 mm (June) and 0 mm (Jan & Nov) during 2017. During 2013-2017, Kolasib received a total annual rainfall of 15905.5 mm. July received the maximum percentage of annual rainfall (17.29%) with an average monthly rainfall of 550.04 mm and January received the minimum percentage of annual rainfall (0.12%) with an average monthly rainfall of 3.76 mm **(Fig 2).**

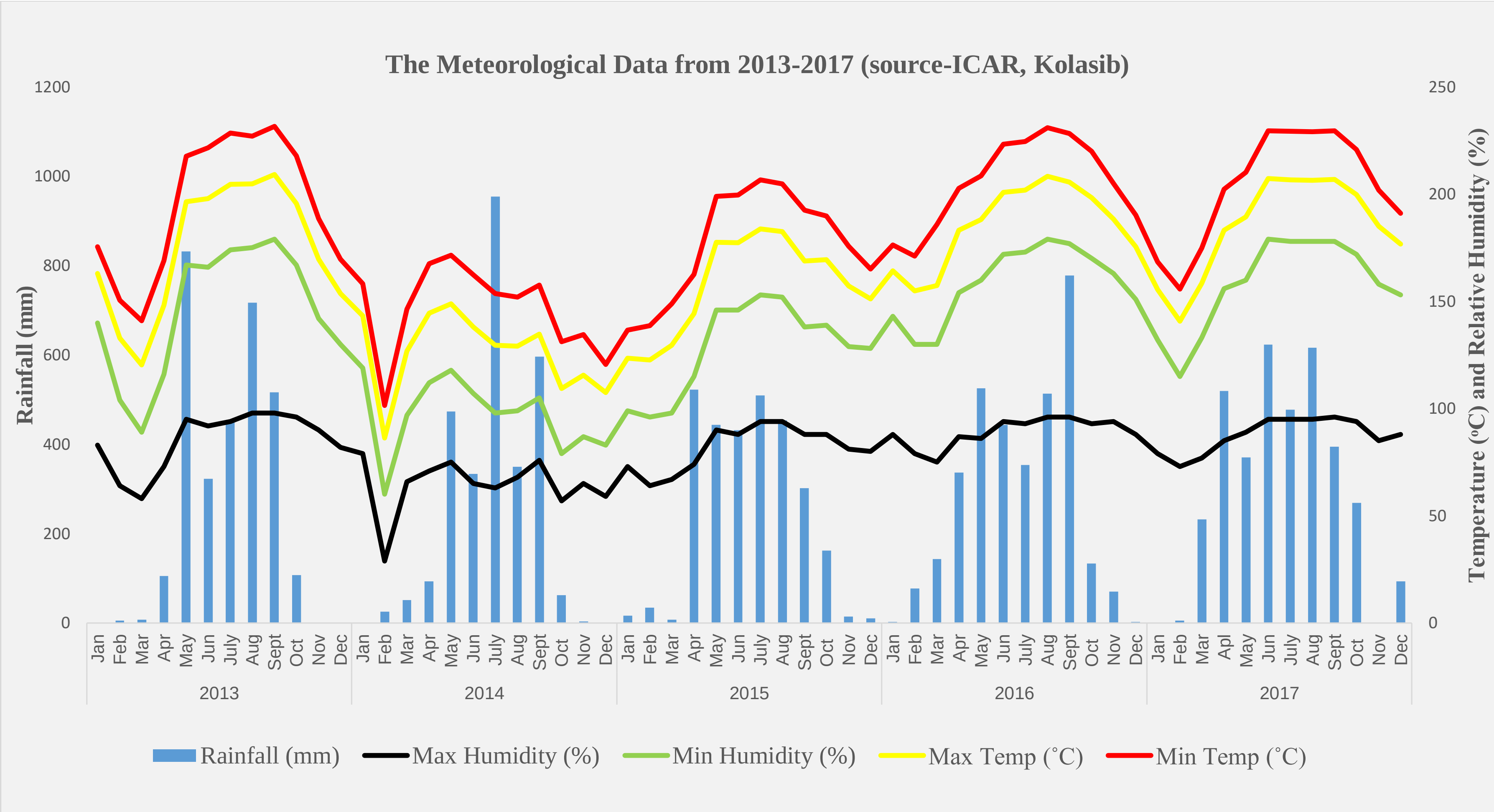


Fig 1. Climatograph showing means monthly rainfall (mm), maximum and minimum humidity (%), maximum and minimum temperature (˚C) during 2013-2017 of Kolasib District of Mizoram. (Source - ICAR, Kolasib)

Chapter 4

MATERIAL AND METHODS

4.1. Collection of soil samples

Two representative land use types namely, Rubber and Arecanut plantations were selected. Soil samples in four replicates from the three slope positions, gentle (0-15%), moderate (15-30%), and steep (< 30%) slope gradients were collected. From each slope position and land use types, a plot with a 20 x 20 meter (m) size was marked as a sample plot following a method applied by Chapman *et al.* (2009). The soil samples were then taken from five points in an 'X' design (from the middle and four corners of the plot) and from two subsequent depths (i.e. 0- 20 cm and 20-40 cm). Soil samplings were done for three seasons in a year viz. Pre-Monsoon (Feb-May), Monsoon (June-Sept), and Post-Monsoon (Oct-Jan) Season.

4.2. Preparation of soil samples

Soil samples collected were brought to the laboratory, thoroughly mixed, air-dried in shade, ground with a porcelain mortar and pestle and passed through 2 mm sieve. The sieved soil samples were stored in polythene bags with proper labeling for subsequent analysis. All the precautions outlined by Jackson (1973) were scrupulously followed to avoid contamination.

4.3. Methodology

The standard methods were followed for determination of physicochemical properties and available nutrients status in soils is given below:

4.3.1. Physical Properties

a) Soil Temperature

Soil temperature at the depths of the soil surface, 0-20 cm, and 20-40 cm was measured by using a long stem Digital Soil Thermometer.

b) Soil Texture

The particle size distribution of the soils was determined by Bouyoucos hydrometer method (Bouyoucos, 1962). 50 gram (g) of air-dried soil samples properly sieved through a 2 mm mesh was soaked overnight in a beaker containing 200 milliliter (ml) of distilled water and 5 ml of hydrogen peroxide (H_2O_2). Add 10 ml of sodium hexametaphosphate ($Na_6P_6O_{18}$) solution and keep it for 15 minutes (min). Disperse the sample in suspension by transferring it from the beaker to a 1 liter (l) cylinder and made up the volume to 1000 ml mark by adding distilled water and then stir for 10 min with an electric stirrer. Immerse hydrometer in the suspension carefully and take readings of the hydrometer at 40 seconds (sec) and 2 hours (hrs). Also, measure the temperature of the suspension using a thermometer. Before the hydrometer was used, a blank solution was performed. This consisted of hydrometer readings at 40 sec and

2 hrs in the same cylinder with dispersant samples and then water without the soil samples. If the reading is above 0 (zero) on the hydrometer scale (in other words, if the zero marks are below the surface), record the blank correction as a negative number.

Calculation was made using the formula below:

ii) Temperature correction factor, T_c (may be different for each reading):

$$T_c = (\text{Observed Temperature} - 20°C) \times 0.3$$

iii) Corrected 40-second reading:

$$40 \text{ sec(c)} = 40 \text{ sec} - \text{Blank Reading} + T_c$$

iv) Corrected 2-hour reading:

$$2 \text{ hr (c)} = 2 \text{ hr} - \text{Blank Reading} + T_c$$

v) $$\text{Sand \%} = \frac{\text{Air dry weight of soil (g)} - \text{Corrected 40 sec reading}}{\text{Air dry weight of soil (g)}} \times 100$$

vi) $$\text{Clay \%} = \frac{\text{Corrected 2 hrs reading}}{\text{The dry weight of soil (g)}} \times 100$$

vii) Silt % = 100% – (Sand % + Clay %)

c) Bulk Density (BD)

Bulk density was determined by the core method (Anderson and Ingram, 1993). In brief, the weight of the oven-dried soil samples drawn from the ground with soil corer of known volume (241.15 cm^3) were taken and calculated with the help of the following formula:

$$BD\ (g/cm^3) = \frac{\text{Weight of oven-dried soil (g)}}{\text{The volume of soil corer } (cm^3)}$$

d) Porosity of Soil

The porosity of soil can be measured with the help of bulk density and soil particle density (2.66 g/cm^3) using the following formula: -

$$\text{Soil Porosity (\%)} = \frac{100\ \% - \text{Bulk density of soil } (g/cm^3)}{\text{The particle density of soil } (g/cm^3)} \times 100$$

e) Soil Moisture Content (SMC)

Soil moisture content was determined by the Gravimetric Method. 10 g of freshly collected soil sample was kept in a hot air oven at 105˚C for 24 hrs. Re-weigh the oven-dried soil and the percentage of moisture content was calculated by using the equation: -

$$\text{SMC (\%)} = \frac{\text{Weight of fresh soil (g)} - \text{Weight of oven-dried soil (g)}}{\text{Weight of oven-dried soil}} \times 100$$

f) Water Holding Capacity (WHC)

Cut a filter paper to fit properly at the perforated bottom of the keen box and take the weight of the keen box along with the filter paper (W_1). Transfer the air-dried soil samples into the keen boxes and weigh again (W_2). Place the boxes in a Petri dish containing water and allow to saturate for 24 hrs. Take out the boxes from the water, whipped, and record their weight again (W_3). The water holding capacity was calculated with the following equation: -

$$\text{WHC (\%)} = \frac{(W_3 - W_2)}{(W_2 - W_1)} \times 100$$

Where, W_1 = Weight of keen-box and filter paper (g)

W_2 = Weight of keen-box, filter paper and soil sample (g)

W_3 = Weight of keen-box after overnight water absorbed (g)

$W_2 - W_1$ = Weight of the soil taken (g)

4.3.2. Chemical Properties

a) Soil pH

20 g of freshly collected soil samples were taken in a beaker containing 50 ml of distilled water. Stir the mixture with a glass rod for 30 min or with a magnetic stirrer for 5 min and keep it overnight. Soil pH was estimated by immersing the glass electrode of the electronic digital pH meter into the soil-water suspension (1: 2.5) in the beaker and take a reading (Jackson, 1973).

b) Electrical Conductivity (EC)

20 g of freshly collected soil samples were taken in a beaker containing 50 ml of distilled water. Stir the mixture with a glass rod for 30 min or with a magnetic stirrer for 5 min and keep it overnight. Soil EC was estimated from the supernatant solution of soil- water suspension (1:2.5) by using a conductivity meter (Jackson, 1973).

c) Soil Organic Carbon (SOC)

The modified method of Walkley and Black (1934) was used for determination of organic carbon. Weigh 1g of air-dried properly sieved (0.2 mm) soil samples in 500 ml conical flask. Add 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated sulphuric acid (H_2SO_4). Gently rotate the flask for 1 min to mix and let it stand for about 30 min. Add 200 ml of distilled water, 10 ml of ortho-phosphoric acid (H_3PO_4), and 1 ml of diphenylamine indicator [$(C_6H_5)_2NH$] to it. Titrate with 0.5 N ferrous ammonium sulfate [$FeSO_4\,(NH_4)_2\,SO_4.6H_2O$] solutions from the burette, until the colour changes from violet-blue to green and record burette readings. Simultaneously, a blank was run without soil in the same way. The organic carbon content of the soil is calculated by using the following formula:

$$\text{SOC (\%)} = N \times 0.003 \times \frac{(B-S)}{\text{Weight of soil taken (g)}} \times 100$$

Where, B = Volume of ferrous ammonium sulphate required for blank titration (ml)

S = Volume of ferrous ammonium sulphate required for soil sample (ml)

N = Normality of standard ferrous ammonium sulphate (0.5 N)

d) Soil Organic Matter (SOM)

Soil organic matter content is determined by multiplying the organic carbon obtained with Van Bemmelem factor of 1.724 because organic matter contains 58% organic carbon (Walkley and Black, 1934).

4.3.3. Available Primary Nutrients in Soils

a) Total Nitrogen (TN)

It was determined by wet-digestion, distillation, and titration procedures of the Kjeldahl method (Bremner and Mulvaney, 1990). Transfer 5 g soil samples to the digestion tube. Add 5 g digestion mixture and 20 ml of concentrated sulphuric acid (H_2SO_4). Heat the digestion tube for 1 hrs to 410º C till the sample color turns colorless or light green. After that, add 10 ml of distilled water and shake it well. Transfer the sample to 250 ml volumetric flask, add 40 ml of 40 % sodium hydroxide (NaOH), and 20 ml of boric acid (H_3BO_3) in Erlenmeyer flask and 4 drops of the indicator (Methyl Red and Bromocresol Green). Put the flask in the receiver end of the machine and start running the distillation process for 6 min. Take out the conical flask containing boric acid and titrate with 0.1 N hydrochloric acid (HCL) or H_2SO_4 till the solution turns pink. Record the burette reading and calculate the percentage of Nitrogen with the help of the following formula: -

$$\text{TN (\%)} = N \times 14 \times \frac{(S - B)}{\text{Weight of soil taken (g)} \times 1000} \times 100$$

Where, B = Volume of sulphuric acid required for blank titration (ml)

S = Volume of sulphuric acid required for soil sample (ml)

N = Normality of sulphuric acid solution (0.01 N)

b) Available Phosphorus (P)

It was determined by using the Bray and Kurtz (1945) method. In 2.5 g of soil samples, 25 ml of Bray and Kurtz No. 1 extractant (0.03 N NH_4F in 0.025 N HCL solution) was added in a conical flask. Add a pinch of activated charcoal, shake the suspension for 5 min, and filter the mixture through Whatman filter paper No. 42. Take 5 ml of an aliquot of the extract in a 25 ml volumetric flask. Again add 3 drops of p-nitrophenol indicator and 3-5 drops of 0.5 M sodium bicarbonate ($NaHCO_3$) to it. Acidify each sample with 2.5 M H_2SO_4 and dilute it with distilled water up to the mark. Run blank without soil. Read the absorbance of blanks, standards, and samples after 10 min on the spectrometer. Available phosphorous in the soil can be calculated by using the following formula: -

$$\text{P (kg/ha)} = R \times \frac{\text{The volume of extractant (ml)}}{\text{Volume of aliquot (ml)} \times \text{Weight of soil taken (g)}} \times 2.24$$

Where, R = ppm or µg mL^{-1} of P in the aliquot (obtained from the standard curve)

c) Available Potassium (K)

5 g of soil samples was treated with 25 ml of 1 N neutral normal ammonium acetate solution (CH_3COONH_4). Shake the flask for about 30 min on the mechanical shaker and filter through Whatman No. 42 to the obtained clear filtrate. The K was determined from the extract using Flame Photometer (Jackson, 1973) by the following formula: -

$$\text{K (kg/ha)} = \text{R} \times \frac{\text{Volume of extractant (ml)}}{\text{Weight of soil taken (g)}} \times 2.24$$

Where, R = ppm or µg ml^{-1} of K obtained from the standard curve

4.3.4. Available Secondary Nutrients in Soils

a) Available Calcium and Magnesium

It was determined by titration with 0.01 N Ethylenediaminetetraacetic Acid (EDTA) (Richards, 1954; Black, 1965). 5 g of soil samples was treated with 25 ml of 1 N of ammonium acetate (CH_3COONH_4) solution. Shake the flask for about 30 min on the mechanical shaker and filter through Whatman No. 42 to the obtained clear filtrate.

i) Estimation of Calcium (Ca)

Pipette a 5 ml aliquot of soil extract and dilute to a volume of 20 ml of distilled water. Add 5 drops of 4 N sodium hydroxide (NaOH) and calcon ($C_{20}H_{13}N_2NaO_5S$)

indicator. Titrant with 0.01 N EDTA till the color changes from orange-red to lavender or purple. Run blank without soil and record the burette reading.

ii) Estimation of Calcium (Ca) + Magnesium (Mg)

Pipette a 5 ml aliquot of soil extract and dilute to a volume of 20 ml of distilled water. Add 10 ml of ammonium chloride-ammonium hydroxide buffer (NH_4Cl- NH_4OH) solution and 3 drops of erichrome black T indicator. Titrant with 0.01 N EDTA till the colour changes from wine red to blue or green. Record the burette reading the following formula: -

$$\text{Ca + Mg (meq/L)} = \frac{(S-B) \times \text{Normality of EDTA}}{\text{The volume of aliquot taken (l)}} \times 1000$$

Ca + Mg (ppm or mg/kg) = Ca + Mg (meq/L) × equivalent weight (32)

Where, B = Volume of EDTA titrated for blank solution (ml)

S = Volume of EDTA titrated for the soil sample solution (ml)

b) Available Sulphur (S)

Transfer 5 g of soil into 150 ml Erlenmeyer flask and add 25 ml of 0.15 % calcium chloride ($CaCl_2$) solution to it. Shake for 30 min on a rotatory shake and filter the suspension through Whatman no. 42 filter paper and pipette a 5 ml of an aliquot of the extract in a 25 ml volumetric flask. Add 1 g of barium chloride ($BaCl_2.2H_2O$), 1 ml of 0.25 % gum acacia solution, and dilute it with distilled water up to the mark. Read the absorbance of blanks, standards, and samples on a spectrophotometer at 340 nanometers (nm) wavelength (Williams and Steinberg, 1969; Basak, 2010). Available Sulphur in the soil can be calculated by using the following formula: -

$$S\ (mg/kg) = \frac{R \times \text{Volume of extract(ml)}}{\text{Volume of aliquot (ml)} \times \text{weight of soil taken (g)}}$$

Where, R = ppm or mg/l of S in the aliquot obtained from the standard curve.

c) Available Sodium (Na)

5 g of soil samples was treated with 25 ml of 1 N neutral normal ammonium acetate (CH_3COONH_4). Shake the flask for about 30 min on the mechanical shaker and filter through Whatman No. 42 to the obtained clear filtrate. The available sodium ions were analyzed by a flame photometer (Richards, 1954) by the following formula: -

$$Na\ (mg/kg) = R \times \frac{\text{The volume of extract (ml)}}{\text{Weight of soil taken (g)}}$$

Where, R = ppm of K obtained from the standard curve

4.3.5 Available Micronutrients in Soils

Available micronutrients viz., Fe, Mn, Zn, and Cu were determined by DTPA (Diethylene Triamine Pentaacetic Acid) which consist of 1.97 g of 0.005 M DTPA extractant, 13.38 ml of 0.1 M TEA (triethanolamine) and add 1.47 g of 0.01 M calcium chloride, dehydrate ($CaCl_2.2H_2O$) to about 500 ml of distilled water taken in 1 L volumetric flask and add the DTPA- TEA mixture to it and make final volume to about 900 ml. Adjust the pH to 7.3 using 1N HCL, make the final volume to 1 L and mix thoroughly weigh 10 g of air-dry soil (0.2 mm) into a 125 ml of Erlenmeyer flask. Add 20 ml of DTPA-extracting solution. Shake for 2 hrs and filter the suspension through a Whatman No. 42 filter paper. Also, keep a blank with each set following all steps except the soil. Measure Fe, Mn, Zn, and Cu directly in the filtrate by Microwave Plasma-Atomic Emission Spectrometer (MP-AES) given by Lindsay and Norvell (1978) and measured by the following formula below:

$$\text{Fe, Mn, Zn, Cu} = (\text{R} - \text{Blank}) \times \frac{\text{The volume of the extract (ml)}}{\text{Weight of soil taken (g)}}$$

Where, R = ppm or $\mu g\ ml^{-1}$ of micronutrient obtained from the standard curve

4.4. Statistical analysis

An analysis of variance (ANOVA) was used to test the effects of land use and slope position on soil properties. Pearson's correlation was also used to determine the nature of the association between the selected soil properties. All tests were conducted using the software SPSS version 12.0.

Chapter 5

RESULTS

5.1. Soil Temperature

The soil temperatures (°C) in the three land use during the study period (2015-2017) have been presented in **Table 3**. The secondary forest (23.01°C) had lower soil temperatures followed by rubber (24.22°C) and arecanut (24.99°C) plantations.

The soil temperatures ranged from 23.1 to 25.05°C in the surface layer (0-20 cm) and 22.92 to 24.94°C in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher soil temperature was recorded from the surface soil layer, which decreased with increase in soil depth (**Fig 2**).

In the arecanut plantation, soil temperatures were recorded to be 24.83±0.09°C, 25.16±0.11°C, and 25.00±0.07°C, while in the rubber plantation soils temperatures were 26.58±0.19°C, 26.76±0.17°C, and 19.34±0.12°C during pre-monsoon, monsoon and post-monsoon seasons. In secondary forest soils, the soil temperatures were 24.08±0.41°C, 24.85±0.39°C, and 20.11±0.53°C during the same period respectively (**Table 5**). Henceforth, the soil temperatures were lowest in post-monsoon and highest in monsoon season (**Fig 3**).

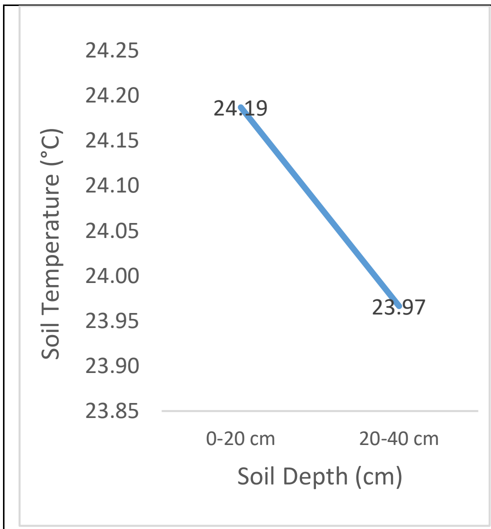
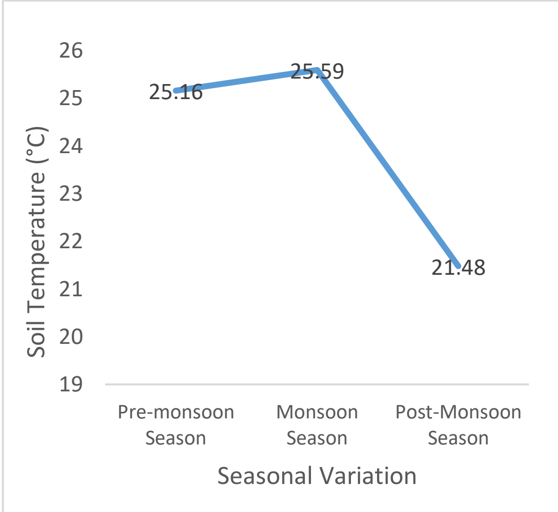
	

Fig 2. Soil temperature (°C) in response to soil depth (cm)	Fig 3. Soil temperature (°C) in response to different seasonal variation

5.2. Soil Texture

The particle size composition of soil in the three land use during the study period (2015-2017) has been presented in **Table 3**. The secondary forest (59.26±0.21%) had higher sand content followed by arecanut (58.53±0.13%) and rubber (56.86±0.13%) plantations. The higher silt content was recorded in arecanut (30.47±0.16%) and rubber plantations (27.37±0.25%) than in the secondary forest (17.35±0.12%). On the other hand, the lowest and highest clay content was recorded in arecanut plantations (11.00±0.16%) and the secondary forest (23.39±0.14%).

The sand content ranged from 57.22 to 59.99% in the surface layer (0-20 cm) and 56.50 to 58.54% in subsurface (20-40 cm) layer of soil. The silt content ranged from 17.16 to 30.43% in the surface layer (0-20 cm) and 17.54 to 30.51% in subsurface (20-40 cm) layer of soil. The clay content ranged from 10.71 to 15.36% in the surface layer (0-20 cm) and 11.29 to 23.92% in subsurface (20-40 cm) layer of soil (Table 4). Sand contents were lower in the subsurface layer while higher contents of silt and clay were recorded in this layer (**Fig 4**).

In arecanut plantation, the sand content was recorded to be 58.49±0.53%, 58.44±0.53%, and 58.66±0.53% during pre-monsoon, monsoon, and post-monsoon seasons. The silt content was recorded to be 30.45±0.28%, 30.54±0.27%, and 30.42±0.28%, while the clay content were 11.06±0.28%, 11.02±0.28%, and 10.93±0.28% respectively. In rubber soils, the sand content was found to be 56.92±0.21%, 56.57±0.22%, and 57.09±0.22%, silt content was 27.37±0.44%, 27.49±0.43%, and 27.24±0.45% and clay content were 15.72±0.52%, 15.94±0.54% and 15.67±0.52% in the corresponding seasons. On the other hand, the sand content in the secondary forest soils was found to be 59.28±0.38%, 59.01±0.36%, and 59.49±0.37%, silt content was 17.31±0.22%, 17.44±0.20%, and 17.30±0.22% and clay content were 23.40±0.24%, 23.55±0.25% and 23.21±0.22% during the same seasons (**Table 5**). Moreover, the sand content was the lowest in the monsoon and the highest in the post-monsoon season. Contrastingly, the lowest silt and clay content were recorded in post-monsoon and the highest was recorded in monsoon and pre-monsoon seasons (**Fig 5**).

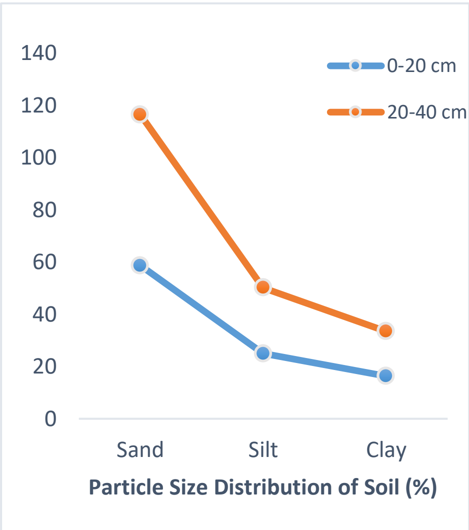
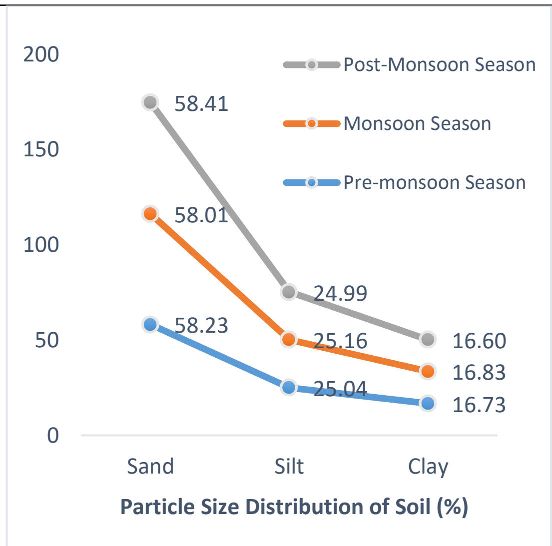
	

Fig 4. Soil particle size distribution (%) in response to soil depth (cm)	Fig 5. Soil particle size distribution (%) in response to different seasonal variation

5.3. Bulk Density (BD)

The BD of soils in the three land uses during the study period (2015-2017) has been presented in **Table 3**. Overall, arecanut (1.25±0.01 g/cm³) and rubber (1.24±0.01 g/cm³) plantations had higher soil BD than secondary forest (1.16±0.01 g/cm³).

The BD of soils ranged from 1.15 to 1.23 g/cm³ in the surface layer (0-20 cm) and 1.17 to 1.27 g/cm³ in subsurface (20-40 cm) layer of soil (**Table 4**). Higher soil BD was recorded in sub surface soil which increased with an increase in soil depth (**Fig 6**).

In the arecanut plantation soils, BD was recorded to be 1.26±0.02 g/cm³, 1.22±0.01 g/cm³ and 1.25±0.01 g/cm³, while in the rubber plantation soils, BD were 1.27±0.02 g/cm³, 1.21±0.02 g/cm³ and 1.23±0.01 g/cm³ during pre-monsoon, monsoon and post-monsoon seasons. In secondary forest soils, the BD was found to be 1.18±0.02 g/cm³, 1.15±0.03 g/cm³, and 1.16±0.0.02 g/cm³ during the same period respectively (**Table 5**). Furthermore, the highest BD was observed in the pre-monsoon season among the study sites (**Fig 7**).

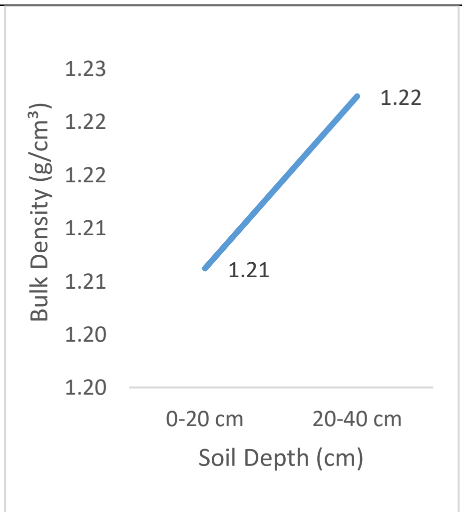


Fig 6. Soil BD (g/cm³) in response to soil depth (cm)

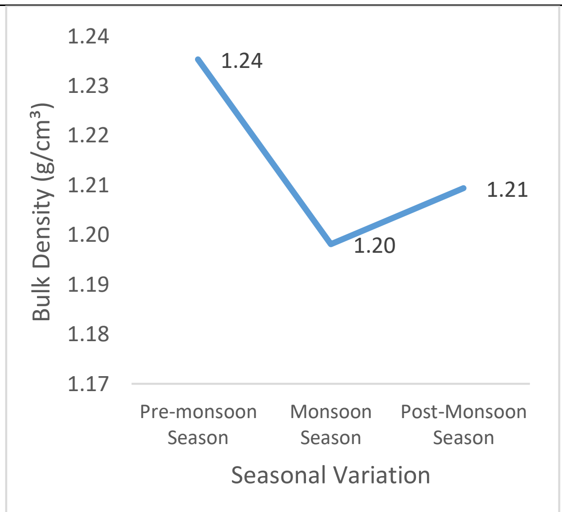


Fig 7. Soil BD (g/cm³) in response to the different seasonal variation

5.4. Porosity of Soil

The porosity of soils in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The soil porosity was higher in secondary forest

(56.23±0.48%) followed by rubber (53.34±0.35%) and arecanut (53.29±0.40%) plantations.

The soil porosity ranged from 52.38 to 56.66 % in the surface layer (0-20 cm) and 53.79 to 55.97 % in subsurface (20-40 cm) layer of soil (**Table 4**). Higher soil porosity was recorded in subsurface while lower porosity was obtained in the surface layer (**Fig 8**).

In the arecanut plantation, soil porosity was recorded to be 54.03±0.73%, 53.14±0.44%, and 52.71±0.55%, while in the rubber plantation, porosity were 54.38±0.70%, 53.60±0.67% and 52.37±0.48% during pre-monsoon, monsoon and post-monsoon seasons. In secondary forest soils, porosity was 56.47±0.67%, 56.76±1.01%, and 55.60±0.76% during the same period respectively (**Table 5**). Henceforth, the soil porosity was lowest in post-monsoon and highest in the pre-monsoon season (**Fig 9**).

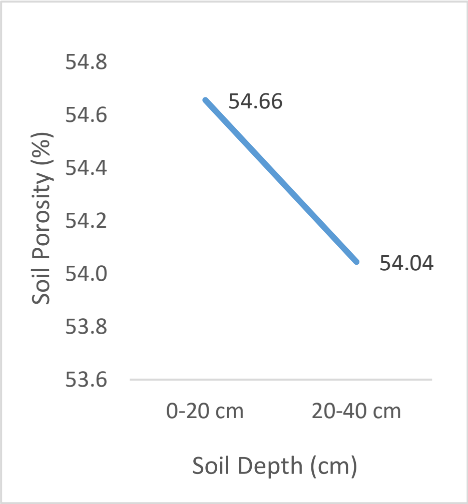


Fig 8. Soil porosity (%) in response to soil depth (cm)

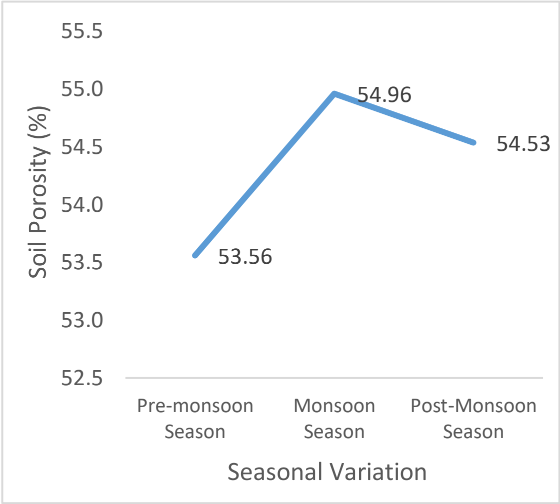


Fig 9. Soil porosity (%) in response to the different seasonal variation

5.5. Soil Moisture Content (SMC)

The SMC in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The secondary forest (25.30±0.41%) had higher SMC followed by rubber (18.93±0.34%) and arecanut plantations (18.46±0.22%).

The SMC ranged from 18.85 to 26.31% in the surface layer (0-20 cm) and 17.89 to 24.28% in subsurface (20-40 cm) layer of soil (**Table 4**). Higher SMC was recorded on the surface while lower SMC was obtained in the subsurface layer (**Fig 10**).

In the arecanut plantation, SMC was recorded to be 17.42±0.23%, 19.00±0.38%, and 18.96±0.48%, while in the rubber plantation, SMC were 18.80±0.68%, 19.50±0.70% and 18.50±0.34% during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, the SMC was 26.14±0.79%, 26.45±0.59%, and 23.3±0.66% during the same period (**Table 5**). However, the SMC was the highest monsoon season (**Fig 11**).

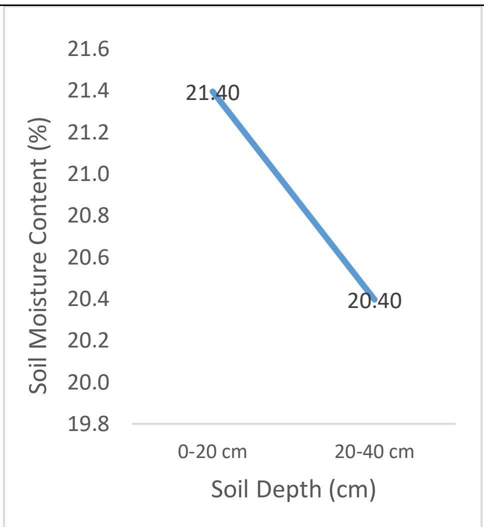


Fig 10. SMC (%) in response to soil depth (cm)

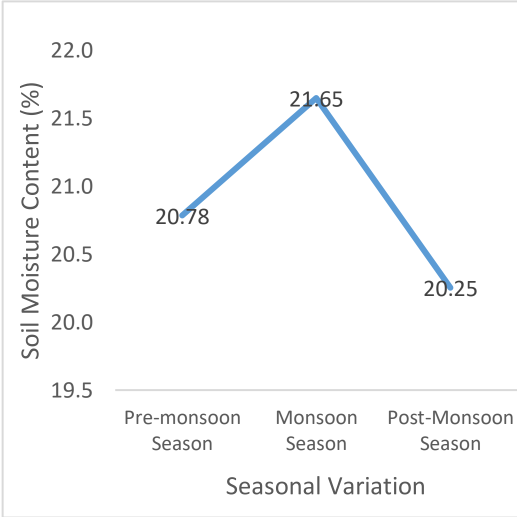


Fig 11. SMC (%) in response to the different seasonal variation

5.6. Water Holding Capacity (WHC)

The WHC of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The soil of the secondary forest (42.69±0.59%) contained higher WHC followed by rubber (35.34±0.53) and arecanut (32.88±0.55%) plantation soils.

The WHC ranged from 31.37 to 43.52 % in the surface layer (0-20 cm) and 34.39 to 41.86 % in the sub-surface (20-40 cm) layer of soil (**Table 4**). Slightly high WHC were observed in the sub-surface than in the surface layer of soil (**Fig 12**).

In the arecanut plantation, WHC was recorded to be 33.42±0.90%, 33.03±0.96%, and 32.20±1.01%, while in a rubber plantation, WHC were 37.48±0.87%, 34.73±0.83% and 33.80±1.00% during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, the WHC was recorded to be 42.38±1.06%, 45.43±1.01%, and 40.20±0.87% during the same period respectively (**Table 5**). However, the WHC was the lowest in the post-monsoon and the highest in monsoon season (**Fig 13**).

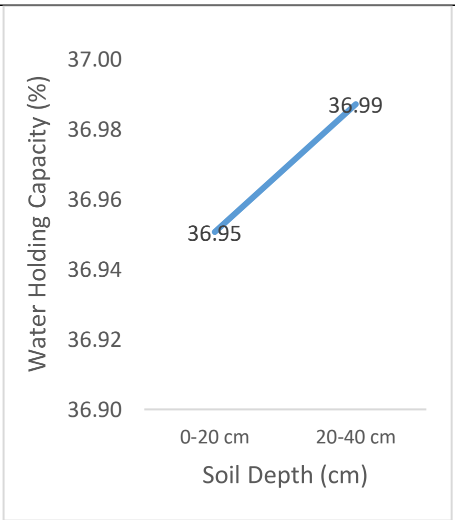


Fig 12. WHC of the soil (%) in response to soil depth (cm)

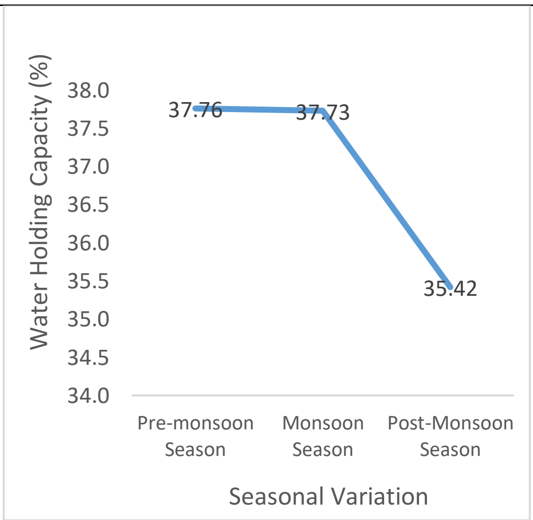


Fig 13. WHC of the soil (%) in response to the different seasonal variation

5.7. pH

The pH in the three land uses during the study period (2015-2017) has been presented in **Table 3.** The highest pH was observed from the arecanut (5.18±0.03) followed by the rubber plantation (5.10±0.03) and the lowest in secondary forest (4.92±0.03).

The pH ranged from 4.95 to 5.23 in the surface (0-20 cm) and 4.90 to 5.14 in the sub-surface (20-40 cm) layer (**Table 4**). The sub-surface layers contained more acidic reactions in comparison to the surface layers of the three land uses (**Fig 14**).

In the arecanut plantation, soil pH was recorded to be 5.03±0.04, 5.32±0.05 and 5.19±0.05, while in the rubber plantation, pH was 5.06±0.05, 5.12±0.04 and 5.11±0.06 during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, pH was 5.08±0.04, 4.94±0.05, and 4.75±0.05 during the same period respectively (**Table 5**). However, pH was most acidic in the post-monsoon season (**Fig.15**).

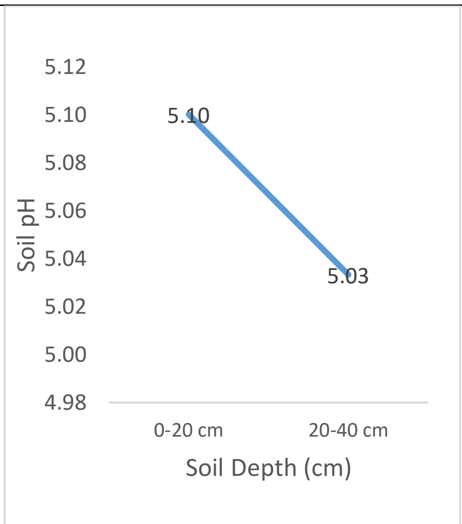


Fig 14. Soil pH in response to soil depth (cm)

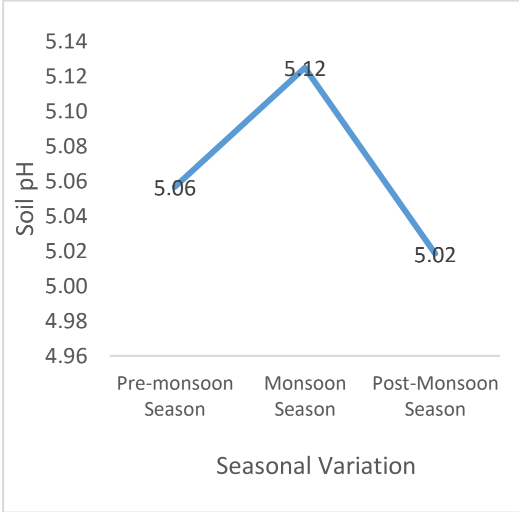


Fig 15. Soil pH in response to the different seasonal variation

5.8. Electrical Conductivity (EC)

The EC of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest EC (0.28±0.02 dS/m) was observed in the arecanut and the highest (0.34±0.02 dS/m) in the rubber plantation.

The EC ranged from 0.28 to 0.34 dS/m in surface layer (0-20 cm) and 0.27 to 0.35 dS/m in sub-surface (20-40 cm) layer (**Table 4**). The sub-surface layers had slightly higher EC in comparison to the surface layers of the three land uses (**Fig 16**).

In the arecanut plantation, EC was recorded to be 0.33±0.02 dS/m, 0.22±0.05 dS/m, and 0.29±0.02 dS/m during pre-monsoon, monsoon and post-monsoon seasons. In the rubber plantation, EC were 0.32±0.03 dS/m, 0.39±0.3 dS/m and 0.32±0.02

dS/m respectively. In the secondary forest, EC was 0.33±0.02 dS/m, 0.26±0.03 dS/m, and 0.3±0.03 dS/m during the same period respectively (**Table 5**). However, EC was higher in pre-monsoon and lowest in the monsoon season (**Fig 17**).

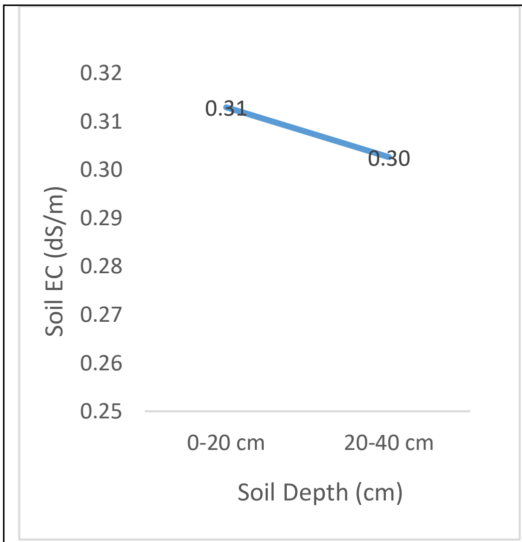


Fig 16. Soil EC (dS/m) in response to soil depth (cm)

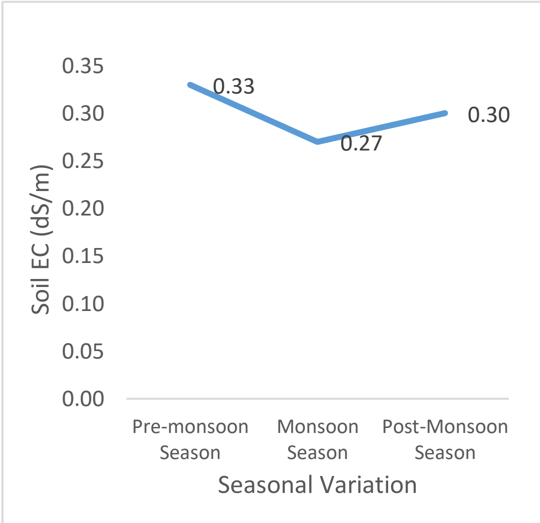


Fig 17. Soil EC (dS/m) in response to the different seasonal variation

5.9. Soil Organic Carbon (SOC)

The SOC in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The secondary forest (2.09±0.03%) had higher SOC followed by rubber (1.87±0.04%) and arecanut (1.71±0.05%) plantations.

The SOC ranged from 1.83 to 2.11% in the surface layer (0-20 cm) and 1.59 to 2.06% in sub-surface (20-40 cm) layer (**Table 4**). Higher SOC was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 18**).

In the arecanut plantation, SOC was recorded to be 1.89±0.06%, 1.32±0.05%, and 1.91±0.10%, while in the rubber plantation, SOC were 1.95±0.06%, 1.62±0.07% and 2.03±0.07% during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, SOC was 2.12±0.05%, 2.14±0.05%, and 2±0.06% during the same period respectively (**Table 5**). However, SOC was the lowest in monsoon season and almost similar in both pre-monsoon and post-monsoon seasons (**Fig 19**).

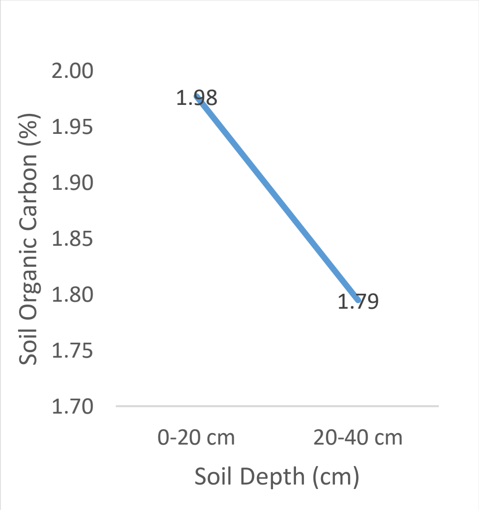


Fig 18. SOC (%) in response to soil depth (cm)

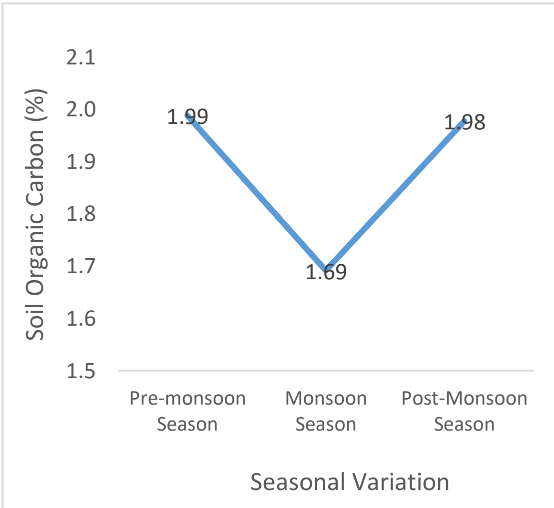


Fig 19. SOC (%) in response to the different seasonal variation

5.10. Soil Organic Matter (SOM)

The SOM in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The secondary forest site (3.60±0.06%) had higher SOM followed by rubber plantation (3.22±0.07%) and arecanut plantations (2.94±0.08%).

The SOM ranged from 3.15 to 3.64% in the surface layer (0-20 cm) and 2.74 to 3.55% in the subsurface (20-40 cm) layer (**Table 4**). Higher SOM was recorded in the surface layer than in the subsurface layer in all the land uses (**Fig 20**).

In the arecanut plantation, SOM was recorded to be 3.26±0.11%, 2.27±0.09%, and 3.29±0.17%, while in the rubber plantation, SOM were 3.36±0.10%, 2.80±0.12% and 3.50±0.13% during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, SOM was 3.66±0.08%, 3.68±0.09%, and 3.44±0.11% (**Table 5**) during the same period respectively. However, SOM was the lowest in monsoon and almost similar in both pre-monsoon and post-monsoon seasons (**Fig 21**).

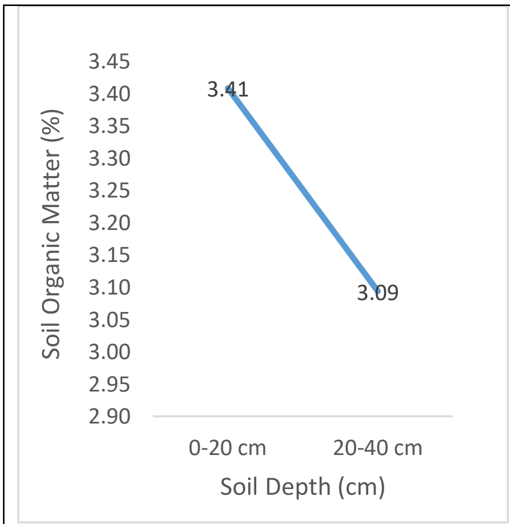


Fig 20. SOM (%) in response to soil depth (cm)

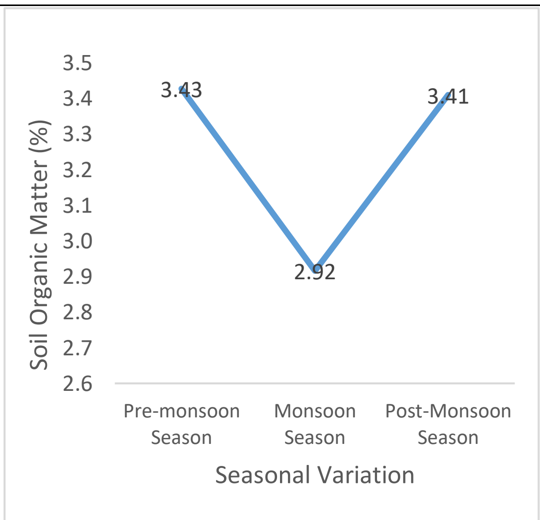


Fig 21. SOM (%) in response to the different seasonal variation

5.11. Total Nitrogen (TN)

The TN of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The secondary forest site (2.18±0.05%) had higher TN content followed by arecanut (1.34±0.09%) and rubber plantation (0.94±0.02%).

The TN content ranged from 0.95 to 2.13% in the surface layer (0-20 cm) and 0.93 to 2.23% in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher TN content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 22**).

TN content was recorded to be 0.89±0.06%, 0.90±0.17%, and 2.23±0.13% in arecanut plantation, while in the rubber plantation, TN content were 0.94±0.06%, 0.96±0.04% and 0.92±0.06% during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, TN content was 2.12±0.09%, 2.03±0.10%, and 2.38±0.13% during the same period respectively (**Table 5**). However, the TN content was the lowest in monsoon than in pre- and post-monsoon seasons (**Fig 23**).

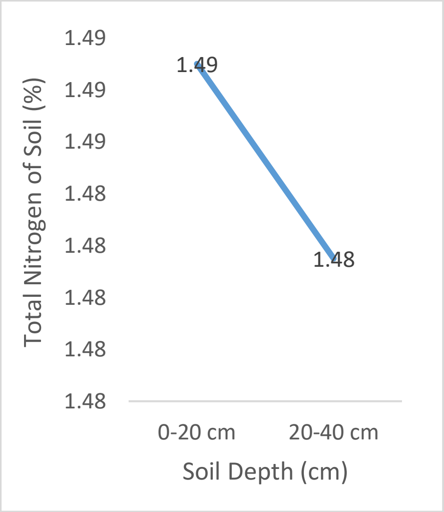


Fig 22. TN (%) in response to soil depth (cm)

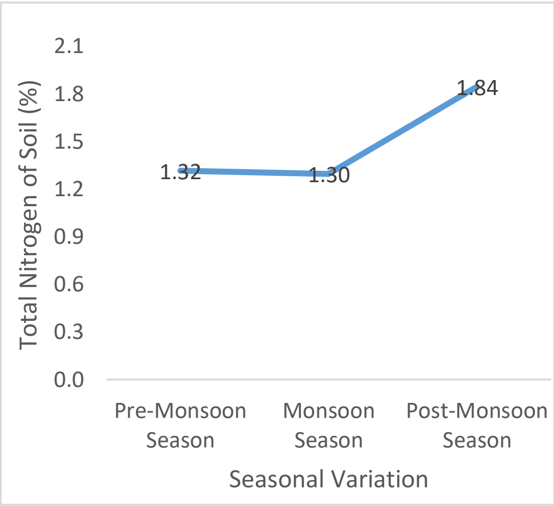


Fig 23. TN (%) in response to the different land uses

5.12. Available Phosphorus (P)

The available P of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest available P content (14.23±0.53 kg/ha) was observed from the arecanut and the highest (20.67±0.63 kg/ha) from the secondary forest.

The available P ranged from 15.15 to 20.35 kg/ha in the surface layer (0-20 cm) and 13.32 to 20.99 kg/ha in sub-surface (20-40 cm) (**Table 4**). Higher available P content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 24**).

In the arecanut plantation, P content was recorded to be 14.25±0.84 kg/ha, 12.06±1.00 kg/ha and 16.39±0.79 kg/ha, while in the rubber plantation, P was 18.20±0.96 kg/ha, 17.72±0.86 kg/ha and 19.88±0.93 kg/ha during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, P contents were 19.23±0.87 kg/ha, 18.85±0.98 kg/ha, and 23.93±1.25 kg/ha during the same period respectively (**Table 5**). The available P content was the highest in a post-monsoon while the lowest in the monsoon season (**Fig 25**).

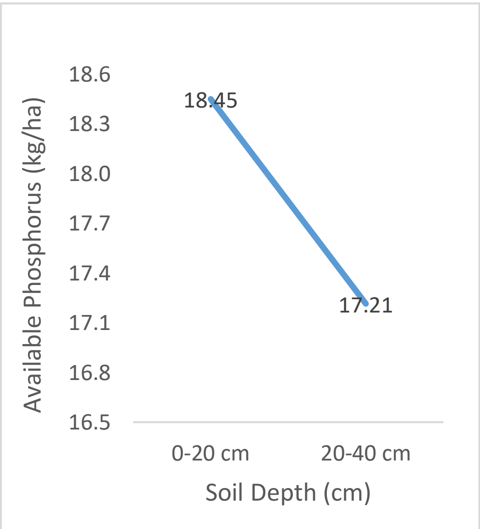


Fig 24. Available P (kg/ha) in response to soil depth (cm)

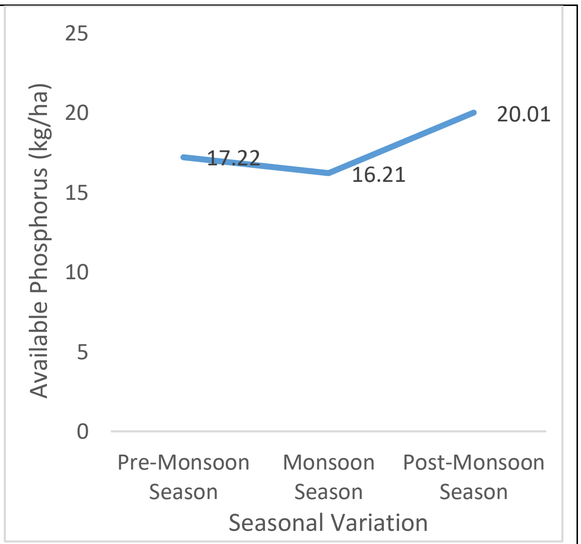


Fig 25. Available P (kg/ha) in response to the different seasonal variation

5.13. Available Potassium (K)

The available K in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest available K (146.73±4.34 kg/ha) was observed in the rubber plantation and the highest (208.49±3.62 kg/ha) in the secondary forest.

The available K content ranged from 151.29 to 208.02 in the surface layer (0-20 cm) and 142.17 to 208.96 in subsurface (20-40 cm) layer of soil (**Table 4**). Higher K content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 26**).

In the arecanut plantation, available K were recorded to be 170.06±4.92 kg/ha, 182.04±6.59 kg/ha and 157.66±6.39 kg/ha while in the rubber plantation, available K were 167.21±8.72 kg/ha, 115.83±3.66 kg/ha and 157.16±7.13 kg/ha during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, available K were 206.14±6.10 kg/ha, 205.27±6.49 kg/ha, and 214.06±6.26 kg/ha during the same period (**Table 5**). However, the available K was the lowest in the monsoon and the highest in the pre-monsoon season (**Fig 27**).

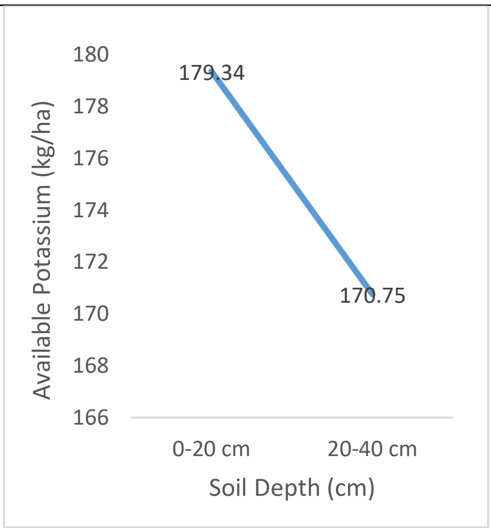


Fig 26. Available K (kg/ha) in response to soil depth (cm)

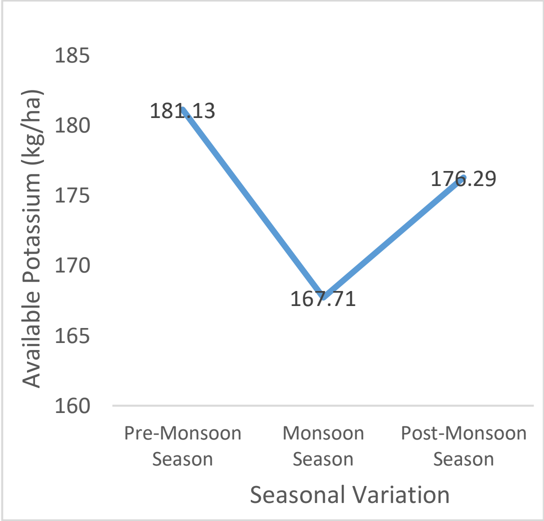


Fig 27. Available K (kg/ha) in response to the different seasonal variation

5.14. Available Calcium (Ca)

The Ca content of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Ca content (82.79±2.5 mg/kg) was observed in the arecanut plantation and the highest (182.37±9.32 mg/kg) in the rubber plantation.

The Ca content ranged from 94.32 to 202.67 in the surface layer (0-20 cm) and 71.24 to 162.06 in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher Ca content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 28**).

In the arecanut plantation, Ca content were recorded to be 89.78±3.10 mg/kg, 79.92±3.39 mg/kg and 78.67±3.18 mg/kg, while in the rubber plantation, Ca content were 245.04±21.73 mg/kg, 144.80±7.73 mg/kg and 157.27±11.55 mg/kg during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Ca content was 117.15±4.46 mg/kg, 96.14±3.94 mg/kg, and 89.16±5.6 mg/kg during the same period respectively (**Table 5**). However, Ca content was the highest in pre-monsoon and the lowest in monsoon seasons (**Fig 29**).

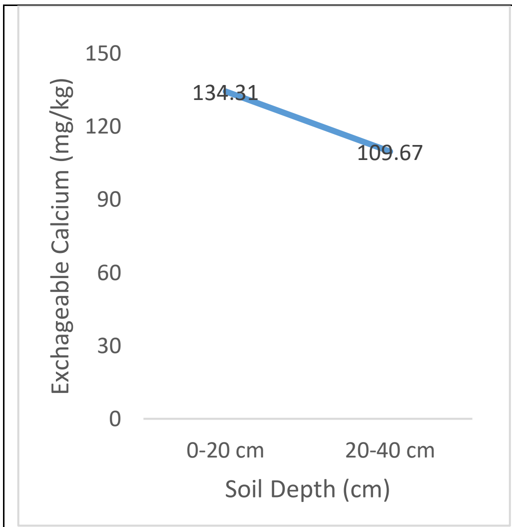


Fig 28. Available Ca (mg/kg) in response to soil depth (cm)

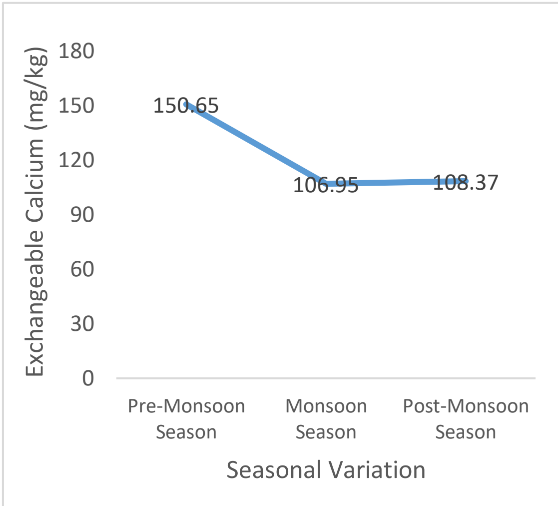


Fig 29. Available Ca (mg/kg) in response to the different seasonal variation

5.15. Available Magnesium (Mg)

The Mg content of the soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Mg content (96.66±3.5 mg/kg) was observed in the arecanut plantation and the highest (124.57±6.89 mg/kg) in the rubber plantation.

The Mg content ranged from 106.78 to 132.39 mg/kg in the surface layer (0-20 cm) and 86.55 to 116.75 mg/kg in sub-surface (20-40 cm) layer (**Table 4**). Higher Mg content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 30**).

In the arecanut plantation, Mg content was recorded to be 115.85±7.19 mg/kg, 100.41±5.68 mg/kg and 73.73±2.88 mg/kg, while in the rubber plantation, Mg content was 187.15±16.33 mg/kg, 105.65±5.42 mg/kg and 80.91±2.45 mg/kg during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Mg content was 110.46±5.95 mg/kg, 105.49±6.71 mg/kg, and 101.45±5.92 mg/kg during the same period respectively (**Table 5**). However, the Mg content was the lowest in the post-monsoon and highest in pre-monsoon seasons (**Fig 31**).

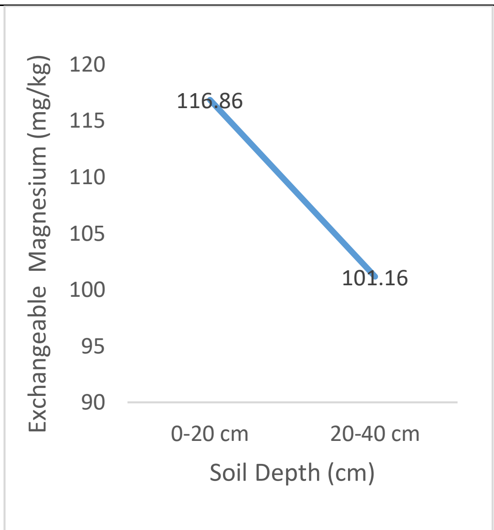
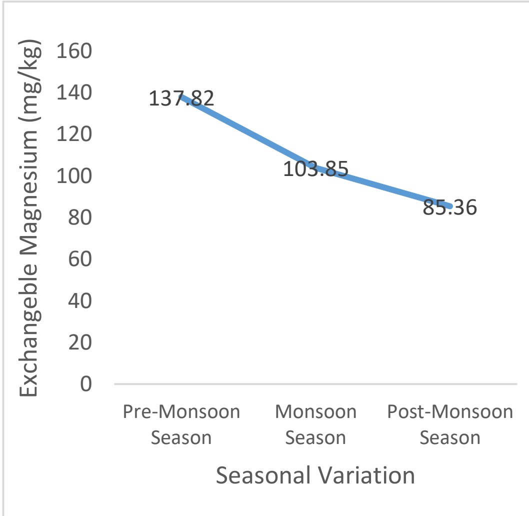
	

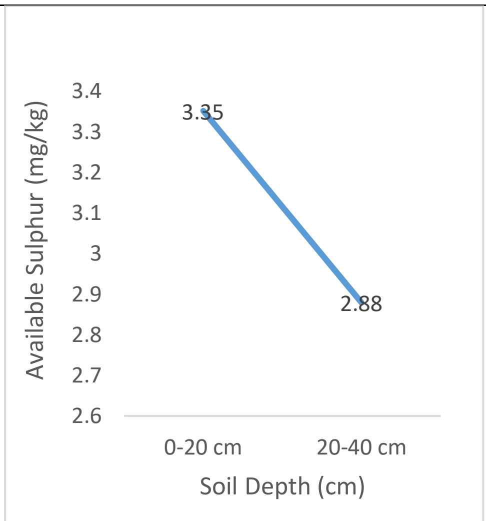
Fig 30. Available Mg (mg/kg) in response to soil depth (cm)	Fig 31. Available Mg (mg/kg) in response to the different seasonal variation

5.16. Available Sulphur (S)

The available S of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest available S content (2.37±0.05 mg/kg) was observed in the secondary forest and the highest (4.05±0.08 mg/kg) in the arecanut plantation.

The S content ranged from 2.44 to 4.46 in the surface layer (0-20 cm) and 2.30 to 3.63 in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher S were recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 32**).

In the arecanut plantation, available S content was recorded to be 4.16±0.15 mg/kg, 3.31±0.10 mg/kg and 4.67±0.10 mg/kg, while in the rubber plantation, available S were 2.70±0.10 mg/kg, 2.96±0.08 mg/kg and 3.12±0.05 mg/kg during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, available S were 2.47±0.09 mg/kg, 2.25±0.07 mg/kg, and 2.40±0.07 mg/kg during the same period respectively (**Table 5**). However, the available S content was the lowest in monsoon and highest in pre-monsoon seasons (**Fig 33**).



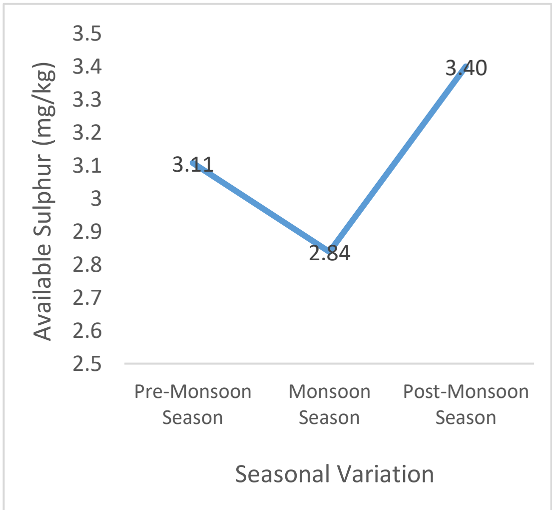


Fig 32. Available S (mg/kg) in response to soil depth (cm)	Fig 33. Available S (mg/kg) in response to the different seasonal variation

5.17. Available Sodium (Na)

The available Na of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest available Na content (1.50±0.03 mg/kg) was observed in the secondary forest and the highest (2.86±0.13 mg/kg) in the rubber plantation.

The Na content ranged from 1.65 to 2.88 in the surface layer (0-20 cm) and 1.35 to 2.84 in subsurface (20-40 cm) layer of soil (**Table 4**). Higher Na content was recorded in the surface layer than in the subsurface layer of soil in all the land uses (**Fig 34**).

In arecanut plantation, available Na content was recorded to be 2.22±0.06 mg/kg, 1.41±0.07 mg/kg and 4.07±0.11 mg/kg, while in rubber plantation, available Na content was 2.93±0.22 mg/kg, 2.18±0.14 mg/kg and 3.47±0.24 mg/kg during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, available Na content was 1.55±0.06 mg/kg, 1.34±0.04 mg/kg, and 1.60±0.05 mg/kg during the same period (**Table 5**). However, the available Na content was the lowest in post-monsoon and highest in monsoon seasons (**Fig 35**).

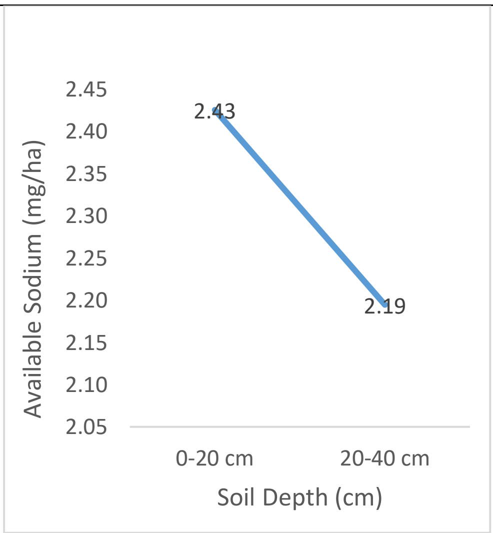


Fig 34. Available Na (mg/kg) in response to soil depth (cm)

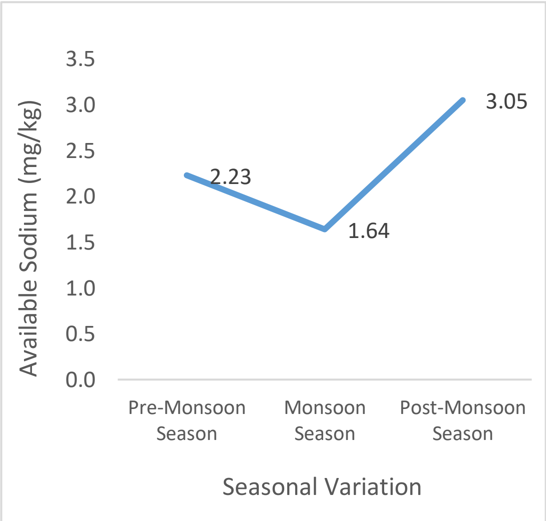


Fig 35. Available Na (mg/kg) in response to the different seasonal variation

5.18. Available Iron (Fe)

The available Fe of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Fe content (1.19±0.04 ppm) was observed in the secondary forest and the highest (4.04±0.05 ppm) in the rubber plantation.

The Fe content ranged from 1.20 to 4.90 ppm in the surface layer (0-20 cm) and 1.17 to 4.00 ppm in subsurface (20-40 cm) layer of soil (**Table 4**). Higher Fe was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 36**).

In the arecanut plantation, Fe content was recorded to be 3.37±0.09 ppm, 3.67±0.10 ppm, and 3.74±0.09 ppm, while in the rubber plantation, Fe content was 3.82±0.08 ppm, 4.4±0.10 ppm, and 3.91±0.08 ppm during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Fe content was 0.90±0.07 ppm, 1.19±0.05 ppm, and 1.48±0.05 ppm during the same period respectively (**Table 5**). However, Fe content was the lowest in the pre-monsoon and highest in monsoon seasons (**Fig 37**).

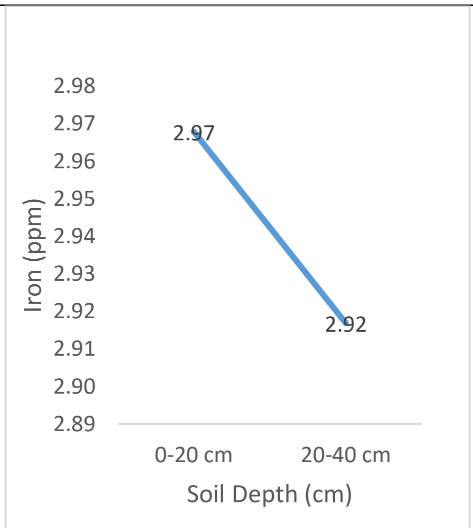
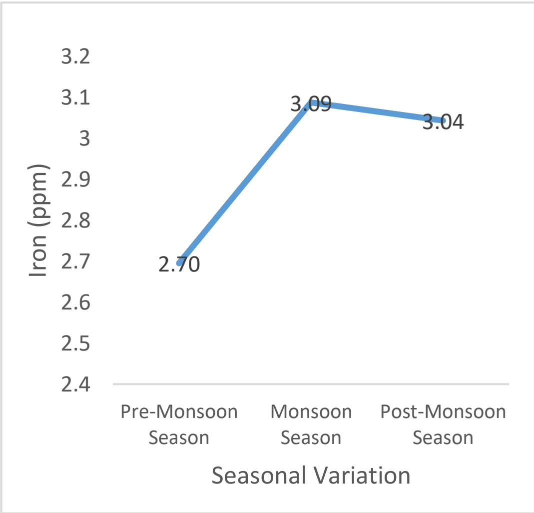
	

Fig 36. Available Fe (ppm) in response to soil depth (cm)	Fig 37. Available Fe (ppm) in response to the different seasonal variation

5.19. Available Manganese (Mn)

The available Mn of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Mn content (0.59±0.02 ppm) was observed in the arecanut plantation and the highest (0.92±0.05 ppm) in the rubber plantation.

The Mn content ranged from 0.60 to 0.88 ppm in the surface layer (0-20 cm) and 0.53 to 0.96 ppm in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher Mn content was recorded in the surface layer than in the sub-surface layer of soil in all the land uses (**Fig 38**).

In the arecanut plantation, Mn content was recorded to be 0.61±0.05 ppm, 1.03±0.06 ppm, and 1.12±0.11 ppm, while in the rubber plantation, Mn content was

0.56±0.04 ppm, 0.54±0.04 ppm, and 0.68±0.05 ppm during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Mn content was 0.53±0.06 ppm, 0.56±0.06 ppm, and 0.73±0.08 ppm during the same period respectively (**Table 5**). However, Mn content was the lowest in the pre-monsoon and highest in post-monsoon seasons (**Fig 39**).

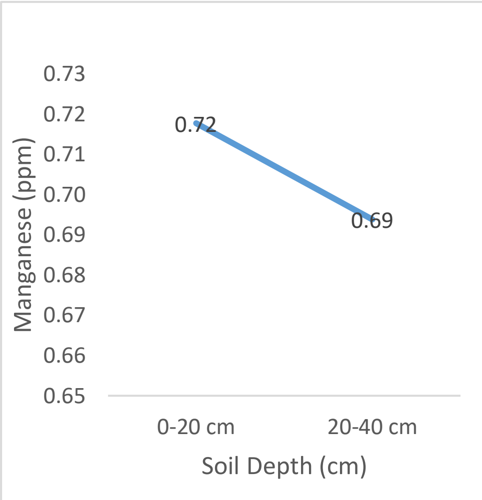


Fig 38. Available Mn (ppm) in response to soil depth (cm)

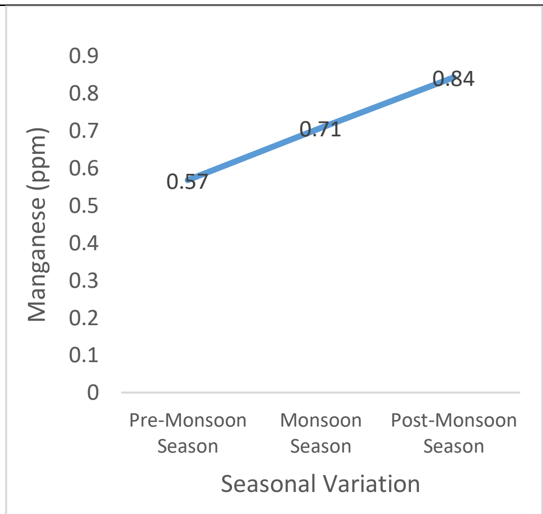


Fig 39. Available Mn (ppm) in response to the different seasonal variation

5.20. Available Zinc (Zn)

The available Zn of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Zn content (0.20±0.01 ppm) was observed in the secondary forest and the highest (0.34±0.02 ppm) in the rubber plantation.

The Zn content ranged from 0.20 to 0.35 ppm in the surface layer (0-20 cm) and 0.21 to 0.33 ppm in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher Zn content was recorded in the sub-surface layer than in the surface layer of soil in all the land uses (**Fig 40**).

In the arecanut plantation, Zn content was recorded to be 0.24±0.02 ppm, 0.30±0.02 ppm, and 0.27±0.02 ppm, while in the rubber plantation, Zn content was 0.33±0.02 ppm, 0.33±0.03 ppm, and 0.36±0.03 ppm during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Zn content was 0.17±0.02 ppm, 0.24±0.01 ppm, and 0.20±0.02 ppm during the same period respectively (**Table 5**). However, Zn content was the lowest in the pre-monsoon and highest in post-monsoon seasons (**Fig 41**).

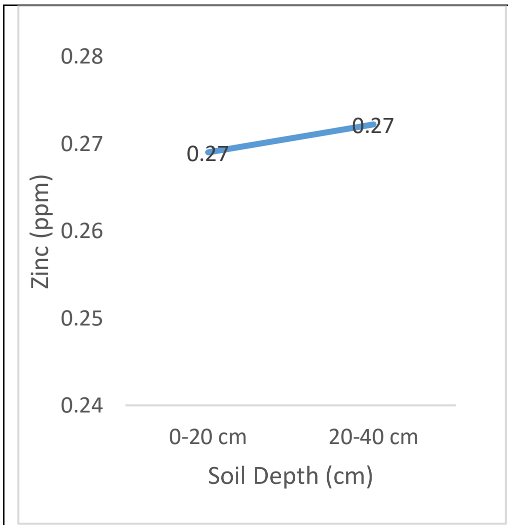


Fig 40. Available Zn (ppm) in response to soil depth (cm)

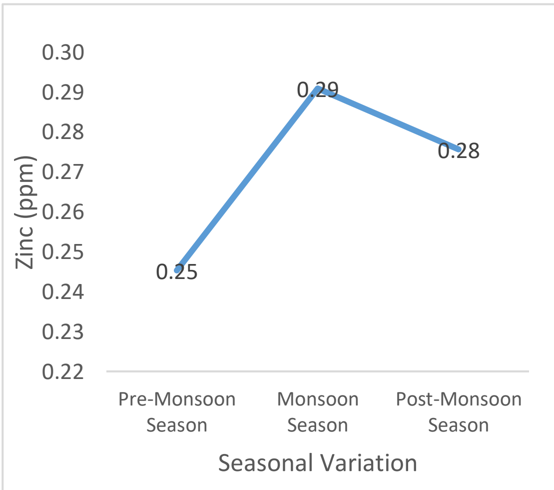


Fig 41. Available Zn (ppm) in response to the different seasonal variation

5.21. Available Copper (Cu)

The available Cu of soil in the three land uses during the study period (2015-2017) has been presented in **Table 3**. The lowest Cu content (0.16±0.01 ppm) was observed in the arecanut plantation and the highest (0.23±0.02 ppm) in the secondary forest.

The Cu content ranged from 0.17 to 0.25 ppm in the surface layer (0-20 cm) and 0.16 to 0.23 ppm in the sub-surface (20-40 cm) layer of soil (**Table 4**). Higher Cu content was recorded in the sub-surface layer than in the surface layer of soil in all the land uses (**Fig 42**).

In the arecanut plantation, Cu content was recorded to be 0.16±0.01 ppm, 0.18±0.01 ppm, and 0.16±0.01 ppm, while in the rubber plantation, Cu content was 0.19±0.01 ppm, 0.20±0.01 ppm, and 0.25±0.01 ppm during pre-monsoon, monsoon and post-monsoon seasons. In the secondary forest, Cu content was 0.19±0.04 ppm, 0.32±0.04 ppm, and 0.17±0.02 ppm during the same period respectively (**Table 5**). However, Cu content was the lowest in the pre-monsoon and highest in monsoon seasons (**Fig 43**).

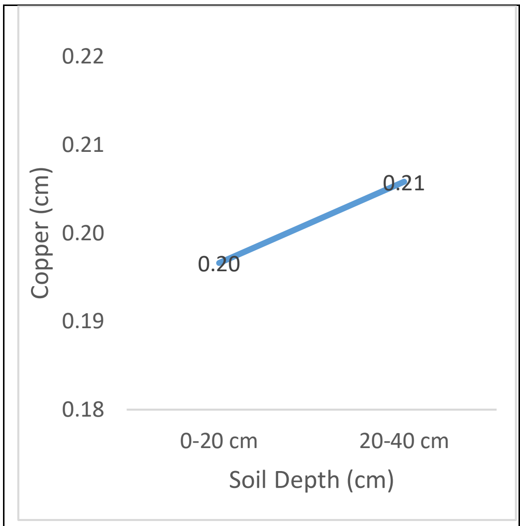


Fig 42. Available Cu (ppm) in response to soil depth (cm)

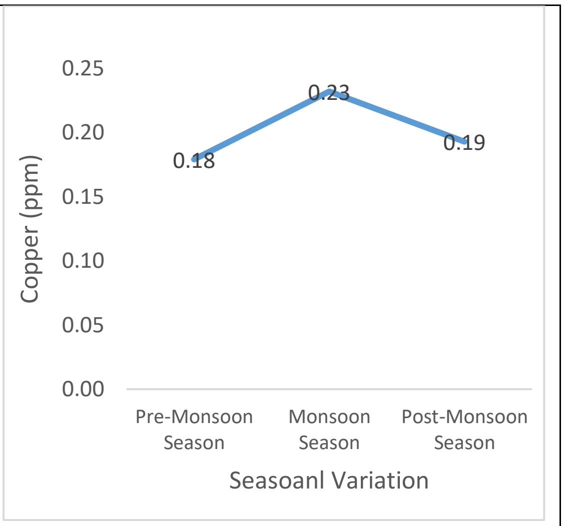


Fig 43. Available Cu (ppm) in response to the different seasonal variation

Chapter 6

DISCUSSION

6.1. Physical Properties of Soils

The variation in the soil temperature of the three study sites was significant ($P < 0.05$) among the land uses (**Table 3**) and between seasons (**Table 5**) except for soil depths (**Table 4**). Soil temperatures in the arecanut and rubber plantation sites were higher than the secondary forest. This could be due to low vegetation and sparse cover that caused heating up of the soil surface by solar radiation. On the contrary, the lower soil temperatures at secondary forest sites might be due to the presence of abundant vegetal cover and a thick layer of litter on the forest floor which protects direct heating of the soil surface due to insolation leading to lowering of the soil temperature at the site.

According to the United States Department of Agriculture (Anon., 1987), the particle size composition of soil in the arecanut and rubber plantations were categorized under sandy loam while the secondary forest was dominated by sandy clay loam texture. Variations in soil textural composition influence soil fertility status and hence plantation productivity. Soils of the three land use had higher sand content than that of silt and clay contents. This is so as the studied soils in the area developed from sandstone parent materials (Brammer, 1971). Since the secondary forest has the ability to protect the soil surface from the rainfall and keeps clay particles in a high percentage (Yasin *et al.* 2010). Higher clay content in the soil enhances soil water-retaining, OM, and nutrient-holding capacities that strongly affect tree regeneration. Hence, plantations established on such sites would be more productive and sustainable in the long run (Aweto, 1981). However, a soil with a large amount of clay may cause difficulties and turn out to be impermeable to air, water, and plant roots (Rai, 1995). Therefore, the highest sand content and clay content were recorded from the secondary forest. While the lowest sand content was recorded from the rubber plantation. The highest silt contents and the lowest clay fractions were recorded on the arecanut plantation. This may be due to the change in land use from forest to plantation system reducing cover which accelerates erosion and transportation of the clay particle despite sand (Kiflu and Beyene, 2013). This result was in agreement with Zhang *et al.* (1997) which found that the erosion rate was affected by land use changed and aggregate stability.

Therefore, ANOVA revealed that the particle size composition of soils in different land use was significant ($P < 0.05$) (**Table 3**). This clearly showed that sand, silt, and clay fractions differed across the studied land-use type. Although the texture is an inherent property, this might be attributed to accelerated weathering as a result of disturbance during continuous cultivation (Kiflu and Beyene, 2013). The particle size composition of soils was texturally similar throughout the seasons. Therefore, no significant variation was found between texture and the seasons in the three studied land uses (P > 0.05) (**Table 5**).

The bulk density and soil porosity of the study sites varied significantly (P < 0.05) (**Tables 3**) while insignificant seasonal variation (P > 0.05) was observed among the studied land uses (Tables 5). The higher BD in the arecanut and rubber plantations was an indication of higher soil compaction possibly due to the change in land use from forest to plantation system, continuous cultivation and human activities such as tillage, trampling and weeding which reduces the formation of large pores (Guggenberger *et al.*, 1994; Ojima *et al.*, 1994; Motavalli and McConnell, 1998; Wang *et al.*, 2008; Li *et al.*, 2012). Another reason for increased BD could be due to a lower amount of OC in comparison to the secondary forest site (Srivastava and Singh, 1989; Celik, 2005; Steffens *et al.*, 2008; Gupta *et al.*, 2010). The BD typically increases with soil depth since sub surface layers have reduced OM, aggregation and root penetration compared to surface layer and therefore, contain less pore space. Furthermore, the BD of the studied soils was found to be less than 1.61 g/cm^3 which is acceptable and indicates that the studied soils are not compacted (Amusan *et al.*, 2001; Aytenew, 2015).

The soil porosity was higher in the secondary forest followed by rubber and arecanut plantations soils. The total porosity of the soil is inversely related to the BD of the studied soil (Chaudhari *et al.*, 2013). Reduction in porosity at the surface causes a reduction in infiltration and percolation that propagates surface runoff, soil erosion, and ultimately serious land degradation (Giertz *et al.*, 2005). According to the Food and Agriculture Organization (Anon., 2006a) rating of total porosity, the percent total porosity values in all slope gradients were very high (greater than 40%). This indicates that the studied soils are physically fertile.

Soil moisture content and water holding content varied significantly ($P < 0.05$) among the three study sites (**Table 3**). The higher SMC in the secondary forest revealed that the presence of a thick litter layer (higher OM) on the forest floor throughout the year might have reduced the rapid evaporation of soil water thus increasing the WHC of the soil in this site. However, the absence of the thick litter layer could be the reason for the rapid evaporation of soil water leading to declining in the moisture content of the soil in the plantation systems. However, maximum moisture content was recorded during the monsoon season followed by pre-monsoon and post-monsoon seasons. This fluctuation was related to the amount of rainfall, air, and soil temperatures of these sites.

6.2. Chemical Properties of Soils

Soil pH of the study sites is strongly acidic (pH 4.92-5.18) in reactions and these might be a result of the acidic nature of parent rock coupled intensive leaching of bases (Akhtaruzzaman *et al.*, 2014). The minimum pH values recorded in the secondary forest may be due to high content of OM and subsequent decomposition of this OM releases acids and makes soil more acidic. In addition, the soils under the canopy of rubber trees were rated as strongly acidic (pH 5.10). This range of values was however consistent with the works of Kumar and Potty (1989), Karthikakuttyamma *et al.* (2000), Dharmakeerthi *et al.* (2005) and Orimoloye *et al.* (2010) who reported that rubber can be grown in a wide range of soil pH (4.5 to 6.0). The higher pH values at the surface layer across the study sites corresponded to adequate amounts of OM in the surface soil layer since all the sites are covered with trees. The release of exchangeable bases from OM through litter decomposition was responsible for higher pH in surface soils (Gafur et al., 2004; Akhtaruzzaman et al., 2014). Statistically significant difference ($P<0.05$) on soil pH and EC were found in the three land use (**Table 3**). Furthermore, low EC of soils indicates that the conditions prevailed were not favourable for the accumulation of salts. The low EC of soil might be due to high leaching of soluble salts that take place from surface to sub-subsurface depending on texture as well as high permeability of the soil. Similar findings were reported by

Shirgire (2012) and Chavda *et at*., (2018) in Jamnagar and Gandhinagar districts of Gujarat. Similar results were also obtained for soils of Indo Gangetic alluvial plain in the Amritsar district of Punjab (Sharma, 2008).

Soil organic carbon is the basis of soil fertility and the main source of energy for soil microorganisms. Likewise, organic matter is an important source of nutrients for plants. The variation of OC and OM content among the three study sites were significant ($P < 0.05$) (**Table 3**). The OC and OM content in rubber and arecanut plantations were significantly influenced by the seasonal variation (**Table 5**) at the surface and sub-surface soil layers of the study sites ($P < 0.05$) (**Table 4**). While insignificant seasonal variation (**Table 5**) were observed in secondary forest at both depth ($P > 0.05$) (**Table 4**). The proportion of OC was found to be greater in secondary forest soil than in rubber and arecanut plantation soils which declined with an increase in depth of soil. Likewise, the content of OM was even greater in the secondary forest than in rubber and arecanut plantation soils. This finding was in agreement with the work of Oku *et al.,* (2012), Li *et al.,* (2012) and Iwara *et al.*, (2013). Yasin (2001) reported that the forest is the most stable and sustainable ecosystem which able to supply nutrients by themselves. The abundance and diversity of litter which was accumulated for over a long period provide adequate cover to surface floor thereby decompose to form nutrient and encourages high soil OM content in the secondary forest while low content of OM in rubber and arecanut plantations soils may be due to changes in soil moisture and temperature regimes, and continuous cultivation resulting in the loss of biomass, anthropogenic influence, on and by the effect of slope gradient which encourages runoff resulting in the loss of plant nutrients. Soils OM under the studied land uses was rated medium (2.59–5.17%) (Tekalign, 1991).

6.2.1. Available Nutrients in Soils

Total Nitrogen is the sum of nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), and organically bonded nitrogen. The N content marked a significant variation among the land uses ($P < 0.05$) (**Table 3**). While insignificant variation was observed at both depth in the studied land uses ($P > 0.05$) (**Table 4**). On the other hand, TN in arecanut plantation and secondary forest vary with the changes in seasons ($P < 0.05$) except in rubber plantation ($P > 0.05$) (**Table 5**). The lower N content of soils in all the sites during the monsoon season could be due to a faster decomposition rate of OM as a result of higher temperature and rapid surface runoff leading to declining in the nutrient concentration of the cultivated soils. The mean concentration of TN was very much higher in secondary forest soil than arecanut plantation. The status of N was very low and insufficient for rubber. As OM content is an indicator of N status of soils, greater input of N in the secondary forest may occur through higher decomposition rate of litterfall (Akpokodje and Aweto, 2007; Iwara *et* *al.*, 2013). In support of which studies show that rates of N mineralization and nitrification are higher in intact tropical forests than in agricultural lands (Piccolo *et al.*, 1994; Neill *et al.*, 1997; Templer *et al.*, 2005; Tripathi and Singh, 2009).

Rubber requires a larger amount of N because it was grown for a much longer period and usually requires external sources of N, which may be leguminous cover crops or mineral fertilizers (Timkhum *et al.*, 2013). Orimoloye *et al.* (2010) also stated that N deficiency is a common problem for rubber-growing soils. This range of values was however in consistent with the works of Dakota and Donald (2002), Dharmakeerti *et al.* (2005), and Kungpisadan (2009). The tropical plantations with monoculture structure lack understory vegetation cover and have less litter (Deng *et al.*, 2003) causing a lower rate of net N mineralization and nitrification (Sha *et al.*, 2000; Meng *et al.*, 2001; Li and Sha, 2005). Another reason for the rapid loss of the total N from the plantation sites may be due to heavy rainfall occurred in the sites causing nutrient runoff from the hill slopes.

Phosphorus plays an important role in energy transformations and metabolic processes in plants (Rai *et al.*, 2012). Karthikakuttyamma *et al.*, (2000) stated that P deficiency will lead to defoliation and whorling up of leaves in the middle to upper whorl. Soil P contents were found to be higher in the secondary forest than rubber and arecanut plantations. Higher content of P in the secondary forest may be due to the rapid recycling of nutrients by decomposition and mineralization of litters. A substantial declined in the level of available P in soils of rubber and arecanut plantations with increasing age of cultivation was recorded. The low levels of P across arecanut plantation soils are attributed to high precipitation in the area resulting in the leaching of cations (Yasin *et al.*, 2010). Optimum soil moisture level makes P available to plants but an excess of moisture reduces O_2 thus limiting root growth and lowering P uptake (Anon., 2003). However, the secretion of citric acid in rubber roots may enhance the P uptake (Timkhum *et at.*, 2013). Therefore, rubber can grow better than many crops when P is immobilized in the soils (Onthong and Osaki, 2006). Available P contents under the soils of studied land uses were rated medium (10-25 kg/ha) (Anon., 2011d). The surface layers contained a higher total P than the sub-surface layer in all sites. No significant difference was found in arecanut plantation and secondary forest between the depths of the soil ($P > 0.05$) except in rubber plantation (**Table 4**). Contrarily, available P in arecanut plantation and secondary forest vary with the changes in seasons ($P < 0.05$) but did not vary in rubber plantation ($P > 0.05$) (**Table 5**).

Potassium is a major mineral that exists within the soil and plays a major role in plant growth (Tandy *et al.*, 2012). K participates in glycolysis, respiration, laticiferous vessel formation, and osmotic rebalancing after tapping (Jacob *et al.*, 1989).

Sivanadyan *et al.*, (1975) reported that lack of K limits the active leaf area and reduces the photosynthetic activity of foliage resulting in slow growth and a prolonged immature growth phase. The content of available K happened to be fairly higher in the secondary forest than in arecanut and rubber plantation soil. The availability of K in these soils was regulated by the content of OM decomposition as humus and soil pH (Yasin *et al.,* 2010 and Kavitha *et al.,* 2015). Continuous cultivation, less use of farmyard manure, no addition of chemical fertilizers, and higher leaching loss from the surface and poor recycling of nutrients from litter residues may also have resulted in low K content in the soils of rubber plantation (Chase and Singh, 2014; Chauhan *et al.,* 2014). Available K contents under the soils of studied land uses were rated medium (108−280 kg/ha) (Anon., 2011d).

6.2.2. Available Secondary Nutrients in Soils

Calcium, magnesium, and sulphur are essential plant nutrient called "secondary" macronutrients because they are moderately required by plants but are just as important as N, P, and K. Ca is involved in cell division, growth, root lengthening and activation of enzymes (Watson, 1989; Kumar and Potty, 1992). Mg occupies the central position of chlorophyll and so, it is needed for photosynthesis and is an important cofactor for the production of adenosine triphosphate (ATP) (Watson, 1989; Karthikakuttyamma *et al.,* 2000). The amount available of exchangeable Ca and Mg is importantly related to mineral weathering and degree of leaching (Foth, 1978). Na is not an essential element for the plant but can be used in small quantities, similar to micronutrients, to aid in the metabolism and synthesis of chlorophyll. The high Ca and Mg content in rubber plantation may be attributed to the development of dense overhead canopy which protects the soil from the direct impact of rain (Ekukinam *et al.*, 2014). However, high levels of Ca and Mg may result in latex instability, and the latter, in extreme deficiency, there can be defoliation and reduction in tree growth (Watson, 1989; Kumar and Potty, 1992; Karthikakuttyamma *et al.*, 2000). The low Ca and Mg content observed in arecanut plantation may be due to scanty overgrowth and canopy gaps that did not afford the soil adequate cover resulting in the leaching of base cations (Yasin *et al.*, 2010). Among different soils studied, the lowest and highest content of S was found in secondary forest and arecanut plantation. The highest content of Na was found in a rubber plantation and the lowest in the secondary forest. The secondary nutrients showed significant variations with seasons in arecanut and rubber plantations ($p<0.05$) (**Table 5**). In arecanut plantation, significant variations were observed in the contents of Ca, Mg, and S with the soil depth ($p < 0.05$), while the content of Na did not vary ($p > 0.05$) (**Table 4**). In rubber plantation, the contents of Mg and Na did not vary with the soil depth ($p < 0.05$) (**Table 4**). While the content of Ca, Mg, and S in the secondary forest showed no variations with the soil depth ($p < 0.05$) (**Table 4**). Such results are in agreement with the observations of Akbar *et al.*, (2010) and Akhtaruzzaman *et al.*, (2014), who found that a higher concentration of exchangeable bases at the surface layer was probably due to the contribution of OM accumulated from plants.

6.2.3. Available Micronutrients in Soils

Micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) are necessary for plant growth in only extremely small quantities and an excessive amount of micronutrients concentrations in soil can be harmful to plants (Askin *et al.*, 2016). The micronutrients varied significantly among the studied land uses ($p < 0.05$) (**Table 3**). But they do not vary between the soil layer and changes in seasons ($P>0.05$) **Table** (**4 & 5**). The highest concentration of micronutrients was recorded in the soils of rubber plantation followed by an arecanut plantation. Despite the significant variation, the concentration of Fe, Mn, Zn, and Cu were in very low in all land-use systems based on the rating established by the Northwest Agricultural Consultants (2003).

Micronutrients are natural components of the earth's crust; geologic substrate and subsequent geochemical and pedogenic regimes determine the total amounts of micro-nutrients in soils. (Yurembam *et al.*, 2015). However, the total amount is rarely indicative of the availability by plant, because availability depends on soil pH, OM, clay content, phosphorous, and other physical, chemical, and biological conditions in the rhizosphere (Fisseha, 1992; Yurembam *et al.*, 2015). In addition, White and Zasoski (1999), Adelekan and Alawode (2011) and Aref (2012) had acknowledged that micronutrient levels in the soil are influence SMC, pH, and clay content.

In arecanut plantation, the Pearson's correlation matrix (**Appendix I**) indicate that Fe had positive and significant relation with clay (r = 0.411**) and pH (r = 0.246**) contents. Mn and Zn showed negative but significant relation with OM (r = – 0.339*; r = – 0.435**). Cu showed a significant and positive relation with the clay content (r = 0.227**) but negative relation with moisture content (r = – 0.201*) and OM (r = – 0.225**). In rubber plantation (**Appendix II**), Fe had positively correlated with pH (r = 0.171*) and negatively with OM (r = – 0.315**). The clay content negatively correlated with Zn (r = – 0.522*) and Cu (r = – 0.339**). Mn showed a significant and positive relation with pH (r = 0.241**) while Zn showed negative correlation with pH (r = – 0.341**). In secondary forest soil (**Appendix III**), the clay content had negative correlation with Fe (r = – 0.167*) but positive relation with Cu (r = 0.268*). Mn and Zn shared positive correlation with SMC (r = 0.317**; r = 0.307**) and negative correlation with SOM (r = – 0.234**; r = – 0.208**).

6.3. Soil Quality in Response to Slope

6.3.1. Arecanut Plantation

The variation in soil temperature was significant in the arecanut plantation ($P<0.05$) (**Table 6**). The soil temperatures ranged from 25.17°C, 25.05°C, and 24.76°C along the slope gradient. Significant differences between the slope gradient in respect of soil particle composition were observed ($P<0.05$) (**Table 6**). Sand is the dominant inorganic fragment in all three segments of the slope with the higher value occurring in the steep slope soils. While silt and clay contents showed an increasing trend down the slopes with the gentle slope having the highest fraction. Pearson's correlation matrix (**Appendix I**) showed that sand content had a high, negative, and significant relationship with silt and clay (r = - 0.951**). This implies that an increase in sand content significantly decreases the amount of silt and clay in the soils of the arecanut plantation. Soil BD was lower (1.20 g/cm^3) in a gentle slope, while its porosity was higher (54.74%) on a gentle slope (**Table 6).** SMC was higher (19.64%) on a moderate slope than in any other segment of the slope. Soil pH tends ranged from 5.02, 5.24, and 5.28 for steep, moderate, and gentle slopes. The increase in soil pH may be due to the increase in exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+). There were no significant differences between the slope gradient in respect of WHC, SOC, SOM, and Mg ($P > 0.05$) (**Table 6**). Soil WHC, SOC, and SOM were higher in moderate slope followed by gentle and steep slopes. In addition, OM had a positive and significant relationship with TN (r = 0.315**) (**Appendix I**). This is obvious as the contents of TN in the soil are the function of the amount of OM and vice versa. Available P tends was higher (16.30 kg/ha) in moderate slope followed by steep (14.59 kg/ha) and gentle slope soils (11.81 kg/ha). The availability of P content was favoured by pH (r = 0.180*) and moisture content (r = 0.474**) (**Appendix I**). The available K, S, and Na contents were significantly higher in the gentle slope, reflecting the higher clay fraction of that slope segment. Therefore, the clay content had significant and positive with K (r = 0.260**) and S (r = 0.196*), while silt content had positive and significant relation with Na (r = 0.192*). Mg content was highest in moderate slope (103.57 mg/kg) and lowest (86.60 mg/kg) in steep slope soils. The concentration of micronutrients Fe, Mn and Cu were significantly higher in the gentle slopes, the levels of the Mn and Zn did not vary significantly between the slope gradient ($P > 0.05$) (**Table 6**).

6.3.2. Rubber Plantation

The variation in soil temperature was insignificant in rubber plantation ($P > 0.05$) (**Table 6**). The soil temperatures were found to be higher in steep (24.51°C) and moderate (24.39°C) slopes than in gentle slope (23.77°C) in the studied land uses. ANOVA revealed that the effect of soil gradient on particle size distribution, BD, and total porosity was significant ($P < 0.05$) (**Table 6**). Accordingly, the lowest sand content (55.18%) was recorded in a gentle slope, while the highest was recorded in steep slope (58.25%). Contrastingly, the lowest clay content (13.16%) was recorded in a steep slope, while the highest clay content was recorded in gentle slope (17.78%). The lowest silt content (26.48%) was recorded on a moderate slope, while the highest silt content (28.59%) was recorded on a steep slope. This is supported by the significant and negative correlation with clay and sand ($r = -0.551^{**}$) and negative and significant correlation with clay and silt ($r = -0.909^{**}$) (**Appendix II**). The soil BD and soil porosity of rubber plantation varied significantly ($P < 0.05$) along the slope gradient (**Table 6**). Soil BD was highest in both steep (1.26 g/cm^3) and gentle (1.26 g/cm^3) slopes and the lowest (1.20 g/cm^3) in moderate slope, its soil porosity was found to be highest (54.80%) in moderate slope and the lowest (52.73%) in a steep slope. The higher SMC and WHC (20.05%, 37.76%) were recorded on a moderate slope and lowest (17.73%, 31.29%) were recorded on a gentle slope. Soil pH data showed a significant ($p < 0.05$) effect of the slope gradient on soil reaction (**Table 6**). The lowest pH value (4.96) was recorded on soils of a gentle slope, whereas the highest pH (5.28) was obtained on a steep slope. There was a statistically significant effect ($p < 0.05$) of the slope gradient on SOC and SOM (**Table 6**). The SOC and SOM were lowest (1.68%, 2.90%) in moderate slope and higher (2.17%, 3.74%) in gentle slopes, presumably due to the higher clay content of the soil in this slope segment. The Pearson correlation coefficient revealed that soil OM was positively correlated with clay content (r = 0.246**) (**Appendix II**). This is because of the reason that clay is poor in aeration and slows in drainage properties resulting in a slow oxidation process in the soil system (Aytenew, 2015). Whereas OM correlated negatively with sand (r = - 0.185*) since sand particles allow further decomposition of OM (**Appendix II**). The result in agreement with the investigation of Teshome *et al.*, (2013).

There were no significant differences between the three slope segments in respect of total nitrogen (P > 0.05) (**Table 6**), although TN was lowest (0.91%) in steep slope and highest (0.97%) on a moderate slope. As most of the soil N is found in organic form, TN and SMC had a positive relationship (r = 0.239**). However, TN showed negative relationship with Ca (r = - 0.252**) and Mg (r = - 0.188*) (**Appendix II**). Available P content was lowest (17.01 kg/ha) in steep slope and highest (21.01 kg/ha) in a gentle slope. The Pearson correlation coefficient revealed that available P negatively correlated with sand (r = - 0.262**) and pH (r = - 0.183*) (**Appendix II**).

Available K and S were lowest (135.32 kg/ha, 2.67 mg/kg) in steep slope and highest (168.09 kg/ha, 3.22 mg/kg) in gentle slope (**Table 6**). Available K showed positive and significant relation with pH (r = 0.284**) and OM (r = 0.521**)

(**Appendix II**). The Ca and Mg content were lowest (153.40 mg/kg, 105.68 mg/kg) in moderate and highest (210.12 mg/kg, 150.01 mg/kg) in steep slopes. This available Ca and Mg showed negative and significant relation with SMC (r = - 0.312**; r = - 0.253**) and TN (r = - 0.252**; r = - 0.188*), positive and significant relation with pH (r= 0.283**; r= 0.169*) and OM (r = 0.360**; r = 0.204*) (**Appendix II**). The Fe content was higher (4.20 ppm) in moderate slopes and lowest (3.76 ppm) in a gentle slope. Mn contents was higher (0.64 ppm) in steep slopes and lowest (0.56 ppm) in a gentle slope. The Zn content was lowest (0.31ppm) in moderate slope and higher (0.35 ppm) in both gentle and steep slope. The Cu contents were higher (0.22 ppm) in steep slopes and lowest (0.21 ppm) in a moderate and gentle slope (**Table 6**). Soil pH and the exchangeable bases (K^+, Ca^{2+}, Mg^{2+}, and Na^+) has a major influence on the availability of micronutrients in the soil.

6.3.3. Secondary Forest

The variation in soil temperature was significant in secondary forest (P < 0.05) (**Table 6**). The soil temperatures were found to be higher in steep (24.22°C) and moderate slopes (24.06°C) than in a gentle slope (20.76°C). ANOVA revealed that the effect of soil gradient on particle size distribution was significant (P < 0.05) (**Table 6**). Accordingly, the lowest sand content (57.48%) was recorded in a moderate slope, while the highest was recorded in steep slope (62.49%). The lowest silt content

(15.72%) was recorded on a steep slope, while the highest silt content (18.79%) was recorded on a gentle slope. The lowest clay content (21.79%) was recorded on a steep slope, while the highest clay content was recorded at a moderate slope (24.98%). This is supported by the significant and negative correlation with sand and silt (r = - 0.804**) and clay (r= - 0.842**) (**Appendix III**). However, the variation of soil BD and total porosity were insignificant at the secondary forest (P > 0.05) (***Table 6***). The lowest BD contents (1.16 g/cm³) were recorded for soils from both moderate and gentle slope segments. The highest BD contents (1.17 g/cm³) were recorded on a steep slope. Whereas its porosity was higher in moderate (56.53%) and gentle slopes (56.22%) than in steep slope (56.19%). The SMC was higher (26.92%) in steep slope and lowest (24.00%) in moderate slopes. This is supported by the positive and significant relationship of SMC with sand (r = 0.240**) and a negative and significant relation with clay (r = - 0.230**) fractions. WHC was lowest (38.61%) on a gentle slope and highest (45.31%) on a steep slope. This may be attributed to the high clay fraction, total porosity, and OM content. Soil pH data showed an insignificant (p > 0.05) effect of the slope gradient on soil reaction (**Table 6**). The lowest pH value (4.86) was recorded on soils of a gentle slope, whereas the highest pH (4.96) was obtained on a steep slope

There was a statistically significant effect ($p < 0.05$) of the slope gradient on SOC, SOM, and TN (**Table 6**). The SOC and SOM were lowest (1.95%, 3.36%) in steep slope and higher (2.21%, 3.81%) in gentle slopes. On the other hand, TN was lowest (1.97%) in moderate slope and highest (2.51%) on a gentle slope. This is most probably due to transportation and deposition of the finer soil materials (OM) on the lower slope gradient by rainfall, erosion, and leaching (Ojanuga, 2006). Similar results have been reported by Mohammed *et al.,* (2005), Brady and Weil (2007) and Ayetenew (2015). Available P was lowest (17.48 kg/ha) in steep slope and highest (24.72 kg/ha) in a gentle slope. Available K was lowest (196.26 kg/ha) in steep slope and highest (219.08 kg/ha) in a gentle slope (**Table 6**). As seen in **Appendix III**, available P correlated positively with OM ($r = 0.205^*$) and TN ($r = 0.192^*$) and available K correlated positively with available P ($r = 0.236^{**}$). The Pearson correlation coefficient revealed that soil Mg ($r = 0.210^{**}$) and Na ($r = 0.287^{**}$) was positively correlated with sand content.

The concentration of Fe and Cu between the slope gradient were significant ($p < 0.05$) while Mn and Zn did not vary ($p > 0.05$) (**Table 6**). Fe showed positive and significant correlation with sand ($r = 0.202^*$) and TN ($r = 0.210^*$), negative and significant correlation with clay ($r = - 0.167$) (**Appendix III**). Soil moisture is an important factor affecting Mn and Zn status of soil, reflecting their positive correlation (r = 0.317**; r = 0.307**). Meanwhile, Mn and Zn showed negative and significant correlation with OM (r = - 0.234**; r = - 0.208*), Ca (r = - 0.266**; r = - 0.361**) and Mg (r = - 0.315**; r = - 0.403**). The level of Cu showed negative and significant correlation with sand (r = - 0.288**), positive and significant correlation with clay (r = 0.268**) (**Appendix III**). Accordingly, the highest values of Fe, Mn and Zn were recorded in steep, while Cu was highest moderate slopes. This might be due to loss through runoff and erosion from higher slope area and accumulation in lower slope areas.

6.4. Nutrient Index of Soils in the Study Area

The nutrient index (NI) values of selected soil nutrients viz N, P, and K were calculated using the following equation (Ramamoorthy and Bajaj, 1969).

$$\text{Nutrient Index (NI)} = \frac{\mathrm{NL}\times 1 + \mathrm{NM}\times 2 + \mathrm{NH}\times 3}{\mathrm{NT}}$$

Where, NL, NM, and NH are several samples falling in low, medium, and high classes of nutrient status respectively and NT is the total number of samples analyzed for a given area. These nutrient index values were then characterized as Nutrient Index category I, II, and III. Based on **Table 7**, the fertility index along with the corresponding nutrient index categories for the soil under the study area is given in **Table 8**. The nutrient availability status of N, P, and K ranged from medium to medium in secondary forest. Similarly, arecanut and rubber plantations both showed medium to medium fertility status respectively. In line with this finding, Motsara (2002) reported high N fertility status in Mizoram (NI= 2.72). Therefore, it can be argued that there has been much depletion of soil fertility over the years. The P and K values from this study indicate that there was a sufficient amount of available P and K in the soils of the three land uses. On the other hand, the nutrient availability of Ca, Mg, and S in secondary forest show medium- high-low status. While arecanut and rubber plantations both showed low-high-low fertility status respectively. The DTPA -Fe, Mn, Zn, and Cu were found to be in a low range in all three land uses.

Soil fertility index for different land uses was calculated to find out the overall effect of land-use systems on soil quality. It is clearly evident that the secondary forest soils maintains greater availability of soil nutrients and fertility status, compared to arecanut and rubber plantations. It could be due to an abundance of leaf litter that covers the ground floor and hold plant nutrients for a long period in the standing biomass leading to an extended period of nutrient cycling. Soil nutrients availability thus depends on soil OM content, soil pH, adsorptive surface, soil texture, and nutrient interactions in the soil (Chase and Singh, 2014; Yurembam *et al.*, 2015). Comparatively lower fertility status in arecanut and rubber plantations may be due to extraction of latex, and removal of biomass which leads to leaching loss, causing higher soil acidity conditions, change of C sequestration (Chun-man *et al.*, 2007), continuous cultivation and no addition of organic mineral fertilizers.

Table 3. Soil Properties in Response to Land Uses

Land Uses					
Soil Properties	Arecanut Plantation	Rubber Plantation	Secondary Forest	F-value	p-value
Temp	24.99±0.05	24.22±0.30	23.01±0.31	15.69	0.00
Sand	58.53± 0.31	56.86± 0.13	59.26± 0.21	29.62	0.00
Silt	30.47± 0.16	27.37± 0.25	17.35± 0.12	1356.00	0.00
Clay	11.00± 0.16	15.78± 0.30	23.39± 0.14	879.58	0.00
BD	1.25±0.01	1.24±0.01	1.16±0.01	18.29	0.00
Porosity	53.29±0.4	53.34±0.35	56.23±0.48	18.28	0.00
SMC	18.46±0.22	18.93±0.34	25.30±0.41	129.16	0.00
WHC	32.88±0.55	35.34±0.53	42.69±0.59	83.42	0.00
pH	5.18±0.03	5.10±0.03	4.92±0.03	21.78	0.00
EC	0.28±0.02	0.34±0.02	0.30±0.02	3.58	0.03
OC	1.71±0.05	1.87±0.04	2.09±0.03	21.46	0.00
OM	2.94±0.08	3.22±0.07	3.60±0.06	21.43	0.00
TN	1.34±0.09	0.94±0.02	2.18±0.05	101.99	0.00
P	14.23±0.53	18.60±0.53	20.67±0.63	33.79	0.00
K	169.92±3.55	146.73±4.34	208.49±3.62	65.61	0.00
Ca	82.79±2.5	182.37±9.32	100.82±2.88	85.03	0.00
Mg	96.66±3.5	124.57±6.89	105.80±3.57	8.38	0.00
S	4.05±0.08	2.92±0.05	2.37±0.05	195.22	0.00
Na	2.57±0.11	2.86±0.13	1.50±0.03	54.03	0.00
Fe	3.59±0.05	4.04±0.05	1.19±0.04	961.15	0.00
Mn	0.92±0.05	0.59±0.02	0.61±0.04	22.90	0.00
Zn	0.27±0.01	0.34±0.02	0.20±0.01	28.49	0.00
Cu	0.16±0.01	0.21±0.01	0.23±0.02	5.63	0.00

Mean values ± standard errors; Difference between means is significant at 0.05 levels.

Table 4. Soil Properties in Response to Soil Depth under the Studied Land Uses

Soil Depths	Arecanut Plantation				Rubber Plantation				Secondary Forest			
	0-20 cm	20-40 cm	F	p	0-20 cm	20-40 cm	F	p	0-20 cm	20-40 cm	F	p
Temp	25.05±0.08	24.94±0.07	0.94	0.33	24.41±0.43	24.03±0.43	0.38	0.54	23.10±0.45	22.92±0.43	0.09	0.77
Sand	58.87±0.42	58.19±0.44	1.22	0.27	57.22±0.18	56.50±0.17	8.65	0	59.99±0.30	58.54±0.27	12.62	0
Silt	30.43±0.22	30.51±0.24	0.07	0.79	27.42±0.35	27.32±0.36	0.04	0.84	17.16±0.16	17.54±0.18	2.45	0.12
Clay	10.71±0.22	11.29±0.23	3.38	0.07	15.36±0.42	16.19±0.43	1.93	0.17	22.85±0.21	23.92±0.15	17.46	0
BD	1.22±0.01	1.27±0.01	7.66	0.01	1.23±0.02	1.25±0.01	0.89	0.35	1.15±0.02	1.17±0.02	0.52	0.47
Porosity	54.21±0.43	52.38±0.50	7.66	0.01	53.79±0.60	53.10±0.41	0.89	0.35	56.66±0.72	55.97±0.63	0.52	0.47
SMC	19.03±0.33	17.89±0.30	6.66	0.01	18.85±0.44	19.01±0.54	0.06	0.81	26.31±0.63	24.28±0.51	6.28	0.01
WHC	31.37±0.76	34.39±0.76	7.87	0.01	36.96±0.70	34.71±0.80	1.38	0.24	43.52±0.75	41.86±0.91	1.99	0.16
pH	5.23±0.03	5.14±0.04	2.72	0.1	5.13±0.04	5.07±0.04	1.15	0.29	4.95±0.04	4.90±0.04	0.71	0.4
EC	0.28±0.03	0.29±0.03	0.11	0.74	0.34±0.03	0.35±0.02	0.04	0.84	0.32±0.02	0.27±0.02	2.87	0.09
OC	1.83±0.07	1.59±0.07	6.37	0.01	1.99±0.06	1.74±0.05	9.88	0	2.11±0.04	2.06±0.05	0.75	0.39
OM	3.15±0.11	2.74±0.12	6.41	0.01	3.43±0.11	3.00±0.09	9.9	0	3.64±0.08	3.55±0.08	0.73	0.39
TN	1.39±0.13	1.29±0.13	0.28	0.6	0.95±0.02	0.93±0.03	0.61	0.44	2.13±0.09	2.23±0.09	0.85	0.36
P	15.15±0.78	13.32±0.69	3.06	0.08	19.86±0.78	17.34±0.70	5.78	0.02	20.35±0.77	20.99±1.01	0.32	0.61
K	178.73±5.08	161.12±4.75	6.4	0.01	151.29±5.73	142.17±6.52	1.1	0.3	208.02±4.93	208.96±5.34	0.02	0.9
Ca	94.35±2.45	71.24±2.69	40.32	0	202.67±12.93	162.06±13.07	4.88	0.03	105.93±3.96	95.70±4.14	6.46	0.08
Mg	106.78±4.53	86.55±5.08	8.83	0	132.39±9.20	116.75±10.25	1.29	0.26	111.4±4.13	100.2±5.3	2.45	0.12
S	4.46±0.10	3.63±0.11	30.36	0	3.15±0.06	2.70±0.06	27.07	0	2.44±0.07	2.30±0.06	2.21	0.14
Na	2.75±0.16	2.39±0.14	2.78	0.1	2.88±0.18	2.84±0.19	0.03	0.87	1.65±0.04	1.35±0.04	31.36	0
Fe	3.61±0.09	3.58±0.07	0.08	0.78	4.09±0.08	4.00±0.07	0.73	0.4	1.20±0.05	1.17±0.06	0.16	0.69
Mn	0.88±0.06	0.96±0.07	0.74	0.39	0.60±0.03	0.59±0.04	0.01	0.93	0.68±0.06	0.53±0.04	3.82	0.05
Zn	0.26±0.02	0.28±0.01	0.71	0.4	0.35±0.03	0.33±0.02	0.4	0.53	0.20±0.01	0.21±0.01	0.43	0.51
Cu	0.17±0.01	0.16±0.01	0.35	0.55	0.25±0.01	0.23±0.01	0.94	0.05	0.22±0.03	0.23±0.04	0.03	0.86

Mean values ± standard errors; Difference between means is significant at 0.05 levels.

Table 5. Soil Properties in Response to Seasonal Variation under the Studied Land Uses

Seasons	Arecanut Plantation					Rubber Plantation					Secondary Forest				
	Pre-monsoon	Monsoon	Post-Monsoon	F	p	Pre-monsoon	Monsoon	Post-Monsoon	F	p	Pre-Monsoon	Monsoon	Post-Monsoon	F	p
Temp	24.83±0.09	25.16±0.11	25.00±0.07	3.49	0.03	26.58±0.19	26.76±0.17	19.34±0.12	664.88	0	24.08±0.41	24.85±0.39	20.11±0.53	32.55	0
Sand	58.49±0.53	58.44±0.53	58.66±0.53	0.05	0.96	56.92±0.21	56.57±0.22	57.09±0.22	1.5	0.23	59.28±0.38	59.01±0.36	59.49±0.37	0.42	0.66
Silt	30.45±0.28	30.54±0.27	30.42±0.28	0.06	0.95	27.37±0.44	27.49±0.43	27.24±0.45	0.08	0.92	17.31±0.22	17.44±0.20	17.30±0.22	0.13	0.87
Clay	11.06±0.28	11.02±0.28	10.93±0.28	0.06	0.94	15.72±0.52	15.94±0.52	15.67±0.52	0.08	0.93	23.40±0.24	23.55±0.25	23.21±0.22	0.52	0.6
BD	1.26±0.01	1.22±0.02	1.25±0.01	1.31	0.27	1.27±0.01	1.21±0.02	1.23±0.02	2.64	0.08	1.18±0.02	1.15±0.03	1.16±0.02	0.61	0.54
Porosity	52.71±0.55	54.03±0.73	53.14±0.44	1.31	0.27	52.37±0.48	54.38±0.70	53.60±0.67	2.64	0.08	55.60±0.76	56.76±1.01	56.47±0.67	0.61	0.54
SMC	17.42±0.23	19.00±0.38	18.96±0.48	5.71	0	18.80±0.68	19.50±0.70	18.50±0.34	0.74	0.48	26.14±0.79	26.45±0.59	23.30±0.66	6.37	0
WHC	33.42±0.90	33.03±0.96	32.20±1.01	0.42	0.66	37.48±0.87	34.73±0.83	33.80±1	4.52	0.01	42.38±1.06	45.43±1.01	40.25±0.87	7.02	0
pH	5.03±0.04	5.32±0.05	5.19±0.05	10.73	0	5.06±0.05	5.12±0.04	5.11±0.06	0.4	0.67	5.08±0.04	4.94±0.05	4.75±0.05	11.88	0
EC	0.33±0.05	0.22±0.02	0.29±0.02	2.88	0.06	0.32±0.03	0.39±0.03	0.32±0.03	2.07	0.13	0.33±0.03	0.26±0.02	0.30±0.03	2.33	0.1
OC	1.89±0.06	1.32±0.05	1.91±0.10	21.36	0	1.95±0.06	1.62±0.07	2.03±0.07	10.02	0	2.12±0.05	2.14±0.05	2.00±0.06	1.98	0.14
OM	3.26±0.11	2.27±0.09	3.29±0.17	21.34	0	3.36±0.10	2.80±0.12	3.50±0.13	10.01	0	3.66±0.08	3.68±0.09	3.44±0.11	1.97	0.14
TN	0.89±0.06	0.90±0.17	2.23±0.13	34.77	0	0.94±0.03	0.96±0.03	0.92±0.03	0.27	0.77	2.12±0.09	2.03±0.09	2.38±0.10	3.93	0.02
P	14.25±0.84	12.06±1.00	16.39±0.79	6.05	0	18.20±0.96	17.72±0.86	19.88±0.93	1.51	0.22	19.23±0.87	18.85±0.98	23.93±1.25	7.32	0.02
K	170.06±4.92	182.04±6.59	157.66±6.39	4.11	0.02	167.21±8.72	115.83±3.66	157.16±7.13	15.86	0	206.14±6.10	205.27±6.49	214.06±6.26	0.59	0.55
Ca	89.78±3.10	79.92±3.39	78.67±3.98	3.01	0.05	245.04±21.73	144.80±7.73	157.27±11.55	13.46	0	117.15±4.46	96.14±3.94	89.16±5.6	9.52	0
Mg	115.85±7.19	100.41±5.68	73.73±2.88	14.78	0	187.15±16.33	105.65±5.42	80.91±2.45	30.68	0	110.46±5.95	105.49±6.71	101.45±5.92	0.53	0.59
S	4.16±0.15	3.31±0.10	4.67±0.10	33.5	0	2.70±0.10	2.96±0.08	3.12±0.05	7.48	0	2.47±0.09	2.25±0.07	2.40±0.07	2.04	0.13
Na	2.22±0.09	1.41±0.07	4.07±0.11	214.39	0	2.93±0.22	2.18±0.14	3.47±0.24	9.76	0	1.55±0.06	1.34±0.04	1.60±0.05	8.05	0
Fe	3.37±0.09	3.67±0.10	3.74±0.09	4.52	0.01	3.82±0.08	4.40±0.10	3.91±0.08	13.06	0	0.90±0.07	1.19±0.05	1.48±0.05	25.26	0
Mn	0.61±0.05	1.03±0.06	1.12±0.11	12.26	0	0.56±0.04	0.54±0.04	0.68±0.05	3.55	0.03	0.53±0.06	0.56±0.06	0.73±0.08	2.46	0.09
Zn	0.24±0.02	0.30±0.02	0.27±0.02	2.36	0.1	0.33±0.02	0.33±0.03	0.36±0.03	0.27	0.77	0.17±0.02	0.24±0.01	0.20±0.02	5.65	0
Cu	0.16±0.01	0.18±0.01	0.16±0.01	0.8	0.45	0.19±0.01	0.20±0.01	0.25±0.01	7.96	0	0.19±0.04	0.32±0.04	0.17±0.02	4.49	0.01

Mean values ± standard errors; Difference between means is significant at 0.05 levels.

Table 6. Soil Properties in Response to Slope Gradient under the Studied Land Uses

Slopes	Arecanut Plantation					Rubber Plantation					Secondary Forest				
	Steep	Moderate	Gentle	F	p	Steep	Moderate	Gentle	F	p	Steep	Moderate	Gentle	F	p
Temp	25.17±0.09	25.05±0.09	24.76±0.09	5.71	0	24.51±0.51	24.39±0.52	23.77±0.55	0.56	0.57	24.22±0.45	24.06±0.48	20.76±0.53	16.14	0
Sand	63.18±0.09	57.94±0.06	54.47±0.12	2138	0	58.25±0.15	57.15±0.09	55.18±0.10	172.33	0	62.49±0.17	57.48±0.18±	57.82±0.14	295.51	0
Silt	28.35±0.06	30.28±0.11	32.78±0.09	656.74	0	28.59±0.11	26.48±0.15	27.04±0.70	6.85	0	15.72±0.10	17.54±0.12	18.79±0.11	196.52	0
Clay	8.47±0.06	11.78±0.12	12.75±0.06	735.16	0	13.16±0.12	16.39±0.18	17.78±0.73	29.33	0	21.79±0.15	24.98±0.15	23.39±0.13	128.97	0
BD	1.26±0.01	1.26±0.02	1.20±0.02	4.8	0.01	1.26±0.02	1.20±0.02	1.26±0.01	3.58	0.03	1.17±0.02	1.16±0.02	1.16±0.03	0.05	0.95
Porosity	52.60±0.51	52.54±0.58	54.74±0.63	4.8	0.01	52.73±0.57	54.80±0.82	52.81±0.39	3.58	0.03	56.19±0.67	56.53±0.69	56.22±1.07	0.05	0.95
SMC	17.90±0.36	19.64±0.36	17.84±0.40	7.44	0	19.02±0.67	20.05±0.73	17.73±0.23	3.92	0.02	26.92±0.82	24.00±0.64	24.96±0.61	4.59	0.01
WHC	32.56±0.89	33.35±0.92	32.73±1.06	0.19	0.83	36.97±0.69	37.76±1.04	31.29±0.71	18.21	0	45.31±1.02	44.14±0.73	38.61±1.04	14.49	0
pH	5.02±0.04	5.24±0.05	5.28±0.04	10.06	0	5.28±0.04	5.06±0.04	4.96±0.06	12.43	0	4.96±0.05	4.94±0.05	4.86±0.05	0.93	0.4
EC	0.20±0.02	0.31±0.03	0.34±0.04	5.31	0.01	0.35±0.03	0.35±0.03	0.33±0.03	0.18	0.84	0.33±0.03	0.31±0.02	0.25±0.02	2.36	0.1
OC	1.65±0.06	1.76±0.08	1.71±0.10	0.39	0.68	1.74±0.07	1.68±0.06	2.17±0.07	16.49	0	1.95±0.06	2.10±0.05	2.21±0.06	5.8	0
OM	2.85±0.11	3.03±0.15	2.94±0.17	0.39	0.68	3.01±0.12	2.90±0.10	3.74±0.12	16.47	0	3.36±0.10	3.61±0.08	3.81±0.10	5.84	0
TN	1.21±0.16	1.08±0.14	1.72±0.17	4.85	0.01	0.91±0.03	0.97±0.02	0.95±0.03	1.08	0.34	2.05±0.09	1.97±0.09	2.51±0.09	10.45	0
P	14.59±0.86	16.30±0.83	11.81±0.95	6.65	0	17.01±0.86	17.78±0.89	21.01±0.93	5.62	0	17.48±0.86	19.80±0.87	24.72±1.24	13.48	0
K	153.63±5.87	173.54±5.54	182.60±6.35	6.25	0	135.32±4.73	136.79±5.65	168.09±10.15	6.54	0	196.26±6.16	210.13±5.62	219.08±6.67	3.48	0.03
Ca	78.17±3.50	92.08±3.47	78.12±3.39	5.43	0.01	210.12±17.85	153.40±10.75	83.58±17.99	3.19	0.04	107.73±5.33	108.04±5.72	93.68±3.57	2.01	0.14
Mg	86.60±3.83	103.57±7.24	99.83±6.40	2.21	0.11	150.01±16.50	105.68±6.52	118.02±9.83	3.82	0.02	119.73±6.44	109±4.95	88.66±6.3	7.07	0
S	3.62±0.14	4.25±0.15	4.27±0.12	7.2	0	2.67±0.08	2.89±0.08	3.22±0.05	13.44	0	2.27±0.07	2.59±0.09	2.25±0.07	6.15	0
Na	2.33±0.17	2.44±0.19	2.93±0.18	3.1	0.05	3.03±0.21	3.55±0.22	2.00±0.17	15.52	0	1.56±0.05	1.32±0.05	1.62±0.05	11.2	0
Fe	3.15±0.06	3.77±0.10	3.87±0.08	22.49	0	4.18±0.09	4.20±0.10	3.76±0.08	7.64	0	1.36±0.07	1.09±0.06	1.12±0.06	5.23	0.01
Mn	0.88±0.07	0.84±0.06	1.04±0.11	1.47	0.23	0.64±0.04	0.57±0.04	0.56±0.04	1.32	0.27	0.65±0.08	0.62±0.07	0.54±0.05	0.76	0.47
Zn	0.28±0.02	0.27±0.02	0.26±0.02	0.25	0.78	0.35±0.03	0.31±0.02	0.35±0.03	0.5	0.61	0.21±0.02	0.19±0.01	0.21±0.01	0.63	0.54
Cu	0.14±0.01	0.14±0.01	0.21±0.01	12.21	0	0.22±0.01	0.21±0.01	0.21±0.02	0.45	0.64	0.14±0.02	0.28±0.05	0.26±0.04	3.83	0.02

Mean values ± standard errors; Difference between means is significant at 0.05 levels.

Table 7. Soil Nutrient Index with Range and Remarks

Nutrient Index (NI)	Range of Soil Nutrients	Fertility Level
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Table 8. Soil Fertility Status of the Studied Land Uses with Respect to Soil Nutrient Index

Nutrients	Arecanut Plantation Soil			Rubber Plantation Soil			Secondary Forest Soil		
	NI values	NI	Fertility Status	NI values	NI	Fertility Status	NI values	NI	Fertility Status
N	1.94	II	Medium	1.77	II	Medium	2.1	II	Medium
P	1.69	II	Medium	2.13	II	Medium	2.18	II	Medium
K	1.96	II	Medium	1.83	II	Medium	2.2	II	Medium
Ca	1.01	I	Low	1.57	I	Low	1.91	II	Medium
Mg	2.58	III	High	2.68	III	High	2.67	III	High
S	1.22	I	Low	1	I	Low	1	I	Low
Fe	1	I	Low	1.09	I	Low	1	I	Low
Mn	1.45	I	Low	1.1	I	Low	1.2	I	Low
Zn	1	I	Low	1.02	I	Low	1	I	Low
Cu	1.35	I	Low	1.58	I	High	1.45	I	Low

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

The land-use change had resulted in changes in the availability of soil nutrients compared to soils in its natural state and show a statistically significant decrease in the number of nutrients responsible for soil fertility. This problem is persistent mostly with the increasing population pressure resulting in the rapid shortening of the *jhum* cycle. Plantation agriculture is thus seen as an alternative land-use system to enhance crop production. For instance, arecanut (*Areca catechu* Linn.) and rubber (*Hevea brasilensis*) plantations have consequently become an important feature in the agricultural economy of Mizoram.

From the study, it was possible to conclude that soil physicochemical properties significantly vary among the studied land-use systems. The particle size composition of soil in the arecanut and rubber plantations were categorized under sandy loam textural class while the secondary forest was dominated by sandy clay loam texture. The strongly acidic nature of the studied soils could result from the high rainfall which is adequate to remove basic cations out of the surface horizons of the soils. In addition, the higher values of soil porosity, moisture content, soil organic carbon, and organic matter contents, total nitrogen, available phosphorus, and available potassium were obtained under the soil of secondary forest as compared to arecanut and rubber plantations soil at both depths. However, the higher availability of soil nutrients and fertility status in secondary forest soils could be due to an abundance of leaf litter that covers the ground floor and hold plant nutrients for a long period in the standing biomass leading to an extended period of nutrient cycling. Comparatively, the lower availability of soil nutrients in arecanut and rubber plantations may be due to changes in soil moisture and temperature regimes, and continuous cultivation resulting in the loss of biomass, and anthropogenic influence that eventually increase bulk density. Therefore, the shift in land use systems from secondary forest to other plantation systems show a detrimental effect on soil physical and chemical properties.

Topography and slope gradients are one of the important factors that have influenced the process of drainage, runoff, and soil erosion, thereby affecting soil properties through the redistribution of soil and soil organic matter. These distributions of individual soil series have considerable influence on the land use pattern of the study area. The soil temperature, sand content, silt content, clay content, moisture content, available phosphorus, available potassium, available sulphur, available sodium, and available iron contents vary significantly between the steep, moderate and gentle slopes among the studied land uses. Soil fertility problems in the area under study relate to poor cultivation practices and landslides which are common features during the rainy seasons. Slope steepness is the dominant factor where the soil eroding agents remove the finer soil particles including soil organic matter and plant nutrients. They face greater degradation consequences compared to soils in ground areas as they generally have limited nutrient and water storage capacities which affect the soil properties and crop productivity. Moreover, the sand content, moisture content, pH and magnesium content declined downslope, implying decreased availability of plant nutrients in the gentle slope segment. The moderate slope had higher available iron on account of the higher moisture. On the other hand, soil organic matter content is highest in the gentle slope, presumably due to the higher clay content of soils in this slope segment. Furthermore, total nitrogen content, available phosphorus, available potassium, available sulphur, and available copper contents reflect the higher status in the gentle slope. However, the detrimental effects of the slope gradient were higher in steep slope areas as compared to gentle slope areas. The results of this study showed that topographical variation associated with leaching, soil erosion, and deposition affects the physical and chemical properties of the studied soils. Therefore, there is a need to restore and sustain the nutrient balance along the different slope gradients.

On the other hand, the soil micronutrients (Fe, Mn, Zn, and Cu) varied significantly among the studied land use. The highest concentration of micronutrients was recorded in the soils of rubber plantation followed by an arecanut plantation. A relatively low level of micronutrients was observed in all land-use systems that indicate no contamination as it always had retained its natural concentration of chemicals in the environment.

According to the fertility test based on the calculated nutrient indices, nitrogen, phosphorus, and potassium attained medium value in all three land uses. Status of calcium attained medium value in secondary forest and low in arecanut and rubber plantations. Status of magnesium attained high and sulphur attained low values in all land uses. This indicated that there was a sufficient amount of nutrients in the soils of the three land uses. The status of any nutrient in soils indicates its nutrient supplying capability to the crops growing on it. It is therefore essential that nutrient supplying capacity of soil be continuously monitored to ensure and improve the sustainability of agriculture.

However, in areas where agriculture relied mostly on upon inherent nutrients of soil and rainfall, the continuous cultivation of arecanut and rubber has had its challenges. Despite the odds, the northeastern state is fortunate enough with a pleasant agro-climatic condition which is suitable for arecanut and rubber to flourish. Plantations may affect or modify the chemical properties of the soil through nutrient depletion but this opportunity can help improve the socio-economic development of the state. Thus, the proper soil fertility management that focuses on enhancing the organic matter and nitrogen levels, and reducing the effects of high slope gradient in the study area are required for improving crop production on a sustainable basis. It can be concluded that proper management of arecanut and rubber plantations could maintain soil under good conditions.

From the findings of the present study, the following recommendations were made to improve soil physicochemical properties:

i) Introduction of suitable intercrops which helps minimize the effects of erosion in relation to the addition of nutrients in the soil.

ii) Proper land management practices with the application of Green Manures and Farm Yard Manure (FYM) at regular intervals.

iii) Use of vegetative barriers to create natural terraces against runoff.

iv) Mulching should be adopted to protect the soil surface against raindrops.

v) Weeding and thinning should be done regularly to provide adequate space for the remaining plants to grow efficiently.

vi) Soil conservation and agricultural production no longer should be regarded as separate activities. It must be an integral part of agriculture development and should start with an improved farming system.

vii) Community nurseries should be promoted by providing training and technical support to farmers to improve the quality of planting material

viii) Due to the steepness of hill slopes, most of the rainwater losses as runoff and very less amount of rainwater remained for utilization during the dry seasons. The application of proper water storage and harvesting techniques, which contribute to agricultural development and resource conservation are required.

ix) To create awareness regarding the utility of the arecanut sheaths for commercial purposes such as plates and bowls this will enhance the income of the growers. Many crafts products can be made from each part of the arecanut plant which is biodegradable and eco-friendly.

Chapter 8

SUMMARY

Plantation crops are among the oldest organized industries in India and continue to be the mainstay of agrarian economies in many states of the country. Since independence, these crops expand rapidly replacing secondary forests and land under shifting cultivation. Due to the shortening of the *jhum* cycle and continuous cropping, quite often, the secondary forests also do not get adequate time to regenerate. Arecanut and Rubber plantations are an affordable alternative for shifting cultivation and have been cultivated as a cash crop in the district of Kolasib District of Mizoram for quite a long time. Adoptions of such economically high valued tree crop plantations to these areas where agriculture is the mainstay for about 60% of the population and characterized by high dependence on rainfall has come as an opportunity for the farmers to embrace the mainstream and settled agricultural system that contributes a significant proportion of earnings. But the concerns about the long-term viability of these plantations in such non-traditional areas often arise. Hence, evaluation of nutrient and fertility status of soils is needed in relation to these land uses to ensure longer-term sustainability, crop production or maintain soil quality under the study area'

A detailed investigation in relation to soil properties can be summarized as follows:

8.1. Soil Properties in Response to Land Uses

i) The secondary forest (23.01°C) had the lowest value of temperatures followed by rubber (24.22°C) and arecanut (24.99°C) plantations.

ii) The rubber plantation (56.86±0.13%) had the lowest value of sand content followed by arecanut (58.53±0.13%) plantation and secondary (59.26±0.21%) forest.

iii) The secondary forest (17.35±0.12%) had the lowest value of silt content followed by rubber (27.37±0.25%) and arecanut (30.47±0.16%) plantations.

iv) The secondary forest (23.39±0.14%) had the lowest value of clay content followed by rubber (15.78±0.30%) and arecanut (11.00±0.16%) plantations.

v) The secondary forest (1.16±0.01 g/cm^3) had the lowest value of bulk density (BD) content followed by rubber (1.24±0.01 g/cm^3) and arecanut (1.25±0.01 g/cm^3) plantations.

vi) The arecanut plantation (53.29±0.40%) had the lowest value of porosity content followed by rubber (53.34±0.35%) plantation and secondary (56.23±0.48%) forest.

vii) The arecanut plantations (18.46±0.22%) had the lowest value of soil moisture content (SMC) followed by rubber (18.93±0.34%) plantation and secondary (25.30±0.41%) forest.

viii) The arecanut plantation (32.88±0.55%) had the lowest value of water holding capacity (WHC) followed by rubber (35.34±0.53%) plantation and secondary (42.69±0.59%) forest.

ix) The secondary forest (4.92±0.03) had the lowest value of pH followed by the rubber (5.10±0.03) and arecanut (5.18±0.03) plantations.

x) The arecanut plantation (0.28±0.02 dS/m) had lowest value of electrical conductivity (EC) followed by secondary forest (0.30±0.02 dS/m) and rubber (0.34±0.02 dS/m) plantation.

xi) The arecanut plantation (1.71±0.05%) had the lowest value of soil organic carbon (SOC) followed by rubber (1.87±0.04%) plantation and secondary (2.09±0.03%) forest.

xii) The arecanut plantation (2.94±0.08%) had the lowest value of soil organic matter (SOM) followed by rubber (3.22±0.07%) plantation and secondary (3.60±0.06%) forest.

xiii) The rubber plantation (0.94±0.02%) had the lowest value of total nitrogen (TN) content followed by arecanut plantation (1.34±0.09%) and secondary (2.18±0.05%) forest.

xiv) The arecanut plantation (14.23±0.53 kg/ha) had the lowest value of available phosphorus (P) content followed by rubber (18.60±0.53 kg/ha) plantation and secondary forest (20.67±0.63 kg/ha).

xv) The rubber plantation (146.73±4.34 kg/ha) had the lowest value of available potassium (K) followed by arecanut plantation (169.92±3.55 kg/ha) and the secondary forest (208.49±3.62 kg/ha).

xvi) The arecanut plantation (82.79±2.5 mg/kg) had the lowest value of available calcium (Ca) content followed by secondary forest (100.82±2.88 mg/kg) and rubber (182.37±9.32 mg/kg) plantation.

xvii) The arecanut plantation (96.66±3.5 mg/kg) had the lowest value of available magnesium (Mg) content followed by secondary forest (105.80±3.67 mg/kg) and rubber (124.57±6.89 mg/kg) plantation.

xviii) The secondary forest (2.37±0.05 mg/kg) had the lowest value of available sulphur (S) content followed by rubber (2.92±0.05 mg/kg) and arecanut (4.05±0.08 mg/kg) plantations.

xix) The secondary forest (1.50±0.03 mg/kg) had lowest value of available sodium (Na) content followed by arecanut (2.57±0.11 mg/kg) and rubber (2.86±0.13 mg/kg) plantations.

xx) The secondary forest (1.19±0.04 ppm) had the lowest value of iron (Fe) content followed arecanut (3.59±0.05 ppm) and rubber (4.04±0.05 ppm) plantations.

xxi) The arecanut plantation (0.59±0.02 ppm) had the lowest value of manganese (Mn) content followed by secondary (0.61±0.04 ppm) forest and rubber (0.92±0.05 ppm) plantation.

xxii) The secondary forest (0.20±0.01 ppm) had the lowest value of zinc (Zn) content followed by arecanut (0.27±0.01 ppm) and rubber (0.34±0.02 ppm) plantations.

xxiii) The arecanut plantation (0.16±0.01 ppm) had the lowest value of copper (Cu) content followed by rubber (0.21±0.01 ppm) plantation and secondary (0.23±0.02 ppm) forest.

8.2. Soil Properties in Response to different Seasonal Variation

i) The lowest value of temperatures was measured 19.34±0.12°C during the post-monsoon season and highest was measured 26.76±0.17°C during monsoon season in the rubber plantation.

ii) The lowest value of sand content was measured 56.57±0.22% in the rubber plantation during monsoon season and the highest was measured 59.49±0.37% in the secondary forest during post-monsoon season.

iii) The lowest value of silt content was measured 17.30±0.22% in the secondary forest during post-monsoon season and the highest was measured 30.54±0.27% in the arecanut plantation during monsoon season.

iv) The lowest value of clay content was measured 10.93±0.28% in the arecanut plantation during post-monsoon season and the highest was measured 23.55±0.25% in the secondary forest during monsoon seasons.

v) The lowest value of BD was measured 1.15±0.03 g/cm^3 in the secondary forest during monsoon season and the highest was measured 1.27±0.01 g/cm^3 in the rubber plantation during pre-monsoon season.

vi) The lowest value of porosity was measured 52.37±0.48% in the rubber plantation during the pre-monsoon season and highest was measured 56.76±1.01% in the secondary forest during monsoon season.

vii) The lowest value of SMC was measured 17.42±0.23% in the arecanut plantation during pre-monsoon season and the highest was measured 26.45±0.59% in the secondary forest during monsoon season.

viii) The lowest value of WHC was measured 32.20±1.01% in the arecanut plantation during the post-monsoon season and the highest was measured 45.43±1.01% in the secondary forest during monsoon season.

ix) The lowest value of pH was measured 4.75±0.05 in the secondary forest during the post-monsoon season and the highest was measured 5.32±0.05 in the arecanut plantation during monsoon season.

x) The lowest value of EC was measured 0.22±0.02 dS/m in the arecanut plantation during monsoon seasons and the highest was measured 0.39±0.3 dS/m in the rubber plantation during monsoon season.

xi) The lowest value of SOC was measured 1.32±0.05% in the arecanut plantation and the highest was measured 2.14±0.05% in the secondary forest during monsoon season.

xii) The lowest value of SOM was measured 2.27±0.09% in the arecanut plantation and the highest was measured 3.68±0.09% in the secondary forest during monsoon season.

xiii) The lowest value of TN content was measured 0.89±0.06% in the arecanut plantation during pre-monsoon season and the highest was measured 2.38±0.10% in the secondary forest during post-monsoon seasons.

xiv) The lowest value of available P content was recorded 12.06±1.00 kg/ha in the soil of arecanut during the monsoon season and the highest was measured 23.93±1.25 kg/ha in the soil of secondary forest during post-monsoon season.

xv) The lowest value of available K content was measured 115.83±3.66 kg/ha in the soil of rubber plantation during monsoon season and the highest was measured 214.06±6.26 kg/ha in the soil of secondary forest during post-monsoon season.

xvi) The lowest value of available Ca content was measured at 78.67±3.98 mg/kg in the arecanut plantation during post-monsoon season and the highest was measured 245.04±21.73 mg/kg in the rubber plantation during pre-monsoon season.

xvii) The lowest value of available Mg content was measured at 73.73±2.88 mg/kg in the arecanut plantation during post-monsoon season and the highest was measured 187.15±16.33 mg/kg in the rubber plantation during pre-monsoon season.

xviii) The lowest value of available S content was measured 2.25±0.07 mg/kg in the soil of secondary forest during monsoon season and the highest was measured 4.67±0.10 mg/kg in the soil of arecanut plantation during post-monsoon season.

xix) The lowest value of available Na content was measured 1.34±0.04 mg/kg in the soil of secondary forest during monsoon season and the highest was measured 4.07±0.11 mg/kg in the arecanut plantation soil during post-monsoon season.

xx) The lowest value of Fe content was measured 0.90±0.07 ppm in the secondary forest during pre-monsoon season and the highest was measured 4.40±0.10 ppm in the rubber plantation during monsoon season.

xxi) The lowest value of Mn content was measured 0.53±0.06 ppm in the secondary forest during pre-monsoon season and the highest was measured 1.12±0.11 ppm in the arecanut plantation during post-monsoon season.

xxii) The lowest value of Zn content was measured 0.17±0.02 ppm in the secondary forest during pre-monsoon season and the highest was measured 0.36±0.03 ppm in the rubber plantation during post-monsoon season.

xxiii) The lowest value of Cu content was measured 0.16±0.01 ppm in the arecanut plantation during pre-monsoon and post-monsoon seasons and the highest was measured 0.32±0.04 ppm in the secondary forest during monsoon season.

8.3. Soil Properties in Response to Slope Gradient (%)

i) The lowest temperatures 24.76±0.09°C, 23.77±0.55°C was recorded in gentle slope and the highest 25.17±0.09°C, 24.51±0.51°C was recorded in steep slope of the arecanut and rubber plantations. The lowest temperatures 20.76±0.53°C was recorded in gentle slope and the highest 24.22±0.45°C was recorded in moderate slope of the secondary forest.

ii) The lowest sand content 54.47±0.12%, 55.18±0.10% was recorded in gentle slope and the highest 63.18±0.09%, 58.25±0.15% was recorded in steep slope of the arecanut and rubber plantations. The lowest sand content 57.48±0.18% was recorded in a moderate slope and the highest 62.49±0.17% was recorded in steep slope of the secondary forest.

iii) The lowest silt content 28.35±0.06% was recorded in steep slope and the highest 32.78±0.09% was recorded in gentle slope of the arecanut plantation. While the lowest silt content 26.48±0.15% was recorded on a moderate slope and the highest 28.59±0.11% was recorded on steep slope of the rubber plantation. In the secondary forest, lowest value silt content was recorded in steep slope and the highest 24.98±0.15% was recorded in gentle slope.

iv) The lowest clay content 8.47±0.06%, 13.16±0.12% was recorded in steep slope and the highest 12.75±0.06%, 17.78±0.73% was recorded in gentle slope of the arecanut and rubber plantations. While the lowest clay content 21.78±0.15% was recorded on a steep slope and the highest 24.98±0.15% was recorded on moderate slope of the secondary forest.

v) The lowest BD in arecanut plantation 1.20±0.02 g/cm³ was recorded in a gentle slope and the highest 1.26±0.01 g/cm³ was recorded in moderate slope. In rubber plantation, the lowest 1.20±0.02 g/cm³ was recorded in moderate slope and the highest 1.26±0.02 g/cm³ was recorded in steep slope. In secondary forest, the lowest 1.16±0.02 g/cm³ was recorded in moderate slope, and the highest 1.17±0.02 g/cm³ was recorded in steep slope.

vi) The lowest porosity in arecanut plantation 52.54±0.58% was recorded in moderate slopes and the highest 54.74±0.63% was recorded on a gentle slope. In rubber plantation, the lowest 52.73±0.57% was recorded in steep slope, and the highest 54.80±0.82% was recorded in moderate slopes. In secondary forest, the lowest 56.19±0.67% was recorded in steep slopes, and the highest 56.53±0.69% was recorded in moderate slope.

vii) The lowest value of SMC 17.84±0.40%, 17.73±0.23% was recorded in gentle slope and the highest 19.64±0.36%, 20.05±0.73% was recorded in moderate slope of the arecanut and rubber plantations. While the lowest value 24±0.64% was recorded in a moderate slope and the highest 26.92±0.82% was recorded in steep slope of the secondary forest.

viii) The lowest value of WHC in arecanut plantation 32.56±0.89% was recorded in steep slope and the highest 33.35±0.92% was recorded in moderate slope. The lowest value in rubber plantation 31.29±0.71% was recorded in a gentle slope and the highest 37.76±1.04% was recorded in moderate slope. The lowest value in secondary forest 38.61±1.04% was recorded in gentle slope and the highest 45.31±1.02% was recorded in steep slope.

ix) The lowest value of pH in arecanut plantation 5.02±0.04 was recorded in steep slope and the highest 5.28±0.04 was recorded in a gentle slope. While the lowest value 4.96±0.06, 4.86±0.05 was recorded in gentle slope and the highest 5.28±0.04, 4.96±0.05 was recorded in steep slope of the rubber plantation and secondary forest.

x) The lowest value of EC in the arecanut plantation 0.20±0.02 dS/m was recorded in steep slope and the highest was recorded 0.34±0.04 dS/m in gentle slope. The lowest value in the rubber plantation 0.33±0.03 dS/m was recorded in gentle slope and the highest was recorded 0.35±0.03 dS/m in steep and moderate slopes. The lowest value in the secondary forest 0.25±0.02 dS/m was recorded in gentle slope and the highest was recorded 0.33±0.03 dS/m in steep slope.

xi) The lowest value of SOC in the arecanut plantation 1.65±0.06% was recorded in steep slope and the highest 1.76±0.08% was recorded in a moderate slope. The lowest value in the rubber plantation 1.68±0.06% was recorded in moderate slope and the highest 2.17±0.07% was recorded in gentle slope. The lowest value in the secondary forest 1.95±0.06% was recorded in steep slope and the highest 2.21±0.06% was recorded in gentle slope

xii) The lowest value of SOM in the arecanut plantation 2.85±0.11% was recorded in steep slope and the highest 3.03±0.15% was recorded in a moderate slope. The lowest value in the rubber plantation 2.90±0.10% was recorded in moderate slope and the highest 3.74±0.12% was recorded in gentle slope. The lowest value in secondary forest 3.36±0.10% was recorded in steep slope and the highest 3.81±0.10% in gentle slope

xiii) The lowest value TN content in the arecanut plantation 1.08±0.14% was recorded in a moderate slope and the highest 1.72±0.17% was recorded in steep slope. The lowest value in the rubber plantation 0.91±0.02% was recorded in steep slope and the highest 0.97±0.03% was recorded in moderate slope. The lowest value in secondary forest 1.97±0.09% was recorded in moderate slope and the highest 2.51±0.09% was recorded in gentle slope.

xiv) The lowest value of available P content 11.81±0.95 kg/ha was recorded in a gentle slope and the highest 16.30±0.83 kg/ha was recorded in steep slope of the arecanut plantation. While the lowest values 17.01±0.86 kg/ha, 17.48±0.86 kg/ha was recorded in steep slope and the highest 21.01±0.93 kg/ha, 24.72±1.24 kg/ha was recorded in gentle slope of the rubber plantation and the secondary forest

xv) The lowest value of available K content 153.63±5.87 kg/ha, 135.32±4.73 kg/ha, 196.26±6.16 kg/ha was recorded in steep slope and the highest 182.60±6.35 kg/ha, 168.09±10.15 kg/ha, 219.08±6.67 kg/ha was recorded in gentle slope of the arecanut and rubber plantation, and the secondary forest.

xvi) The lowest value of Ca content in the arecanut plantation 78.12±3.39 mg/kg was recorded in a gentle slope and the highest 92.08±3.47 mg/kg was recorded in moderate slope. The lowest value in the rubber plantation 153.40±10.75 mg/kg was recorded in moderate slope and the highest 210.12±17.85 mg/kg was recorded in steep slope. The lowest value in the secondary forest 93.68±3.57 mg/kg was recorded in gentle slope and the highest 107.73±5.33 mg/kg was recorded in steep slope.

xvii) The lowest value of Mg content in the arecanut plantation 86.60±3.83 mg/kg was recorded in steep slope and the highest was recorded 103.57±7.24 mg/kg in moderate slope. The lowest value in the rubber plantation 105.68±6.52 mg/kg was recorded in a moderate slope and the highest 150.01±16.50 mg/kg was recorded in steep slope. The lowest value in the secondary forest 88.66±6.3 mg/kg was recorded in gentle slope and the highest 119.73±6.44 mg/kg was recorded in steep slope.

xviii) The lowest value of available S content 3.62±0.14 mg/kg, 2.67±0.08 mg/kg was recorded in steep slope, and the highest 4.27±0.12 mg/kg, 3.22±0.05 mg/kg in a gentle slope of the arecanut and rubber plantations. While the lowest value in the secondary forest 2.25±0.07 mg/kg was recorded in gentle slope and the highest 2.59±0.09 mg/kg was recorded in moderate slope.

xix) The lowest value of Na content 2.33±0.17 mg/kg was recorded in steep slope and the highest 2.93±0.18 mg/kg was recorded in a gentle slope of the arecanut plantation. The lowest value in the rubber plantation was recorded 2±0.17 mg/kg in gentle slope and the highest 3.55±0.22 mg/kg was recorded in moderate slope. The lowest value in the secondary forest 1.32±0.05 mg/kg was recorded in moderate slope and the highest 1.62±0.05 mg/kg was recorded in gentle slope.

xx) The lowest value of Fe content 3.15±0.06 ppm was recorded in steep slope and the highest 3.87±0.08 ppm was recorded in a gentle slope of the arecanut plantation. The lowest value in the rubber plantation 3.76±0.08 ppm was recorded in gentle slope and the highest 4.20±0.10 ppm was recorded in moderate slope. The lowest value in the secondary forest 1.09±0.06 ppm was recorded in moderate slope and the highest 1.36±0.07 ppm was recorded in steep slope.

xxi) The lowest value of Mn content 0.84±0.06 ppm was recorded in a moderate slope and the highest 1.04±0.11 ppm was recorded in gentle slope of the arecanut plantation. The lowest value in the rubber plantation 0.56±0.04 ppm was recorded in gentle slope and the highest 0.64±0.04 ppm was recorded in steep slope. The lowest value in the secondary forest 0.54±0.05 ppm was recorded in gentle slope and the highest 0.65±0.08 ppm was recorded in steep slope.

xxii) The lowest value of Zn content 0.26±0.02 ppm was recorded in a gentle slope and the highest 0.28±0.02 ppm was recorded in steep slope of the arecanut plantation. The lowest value in the rubber plantation 0.31±0.02 ppm was recorded in moderate slope and the highest 0.35±0.03 ppm was recorded in steep and gentle slopes. The lowest value in the secondary forest 0.19±0.01 ppm was recorded in moderate slope and the highest 0.21±0.02 ppm was recorded in steep and moderate slopes.

xxiii) The lowest value of Cu content 0.14±0.01 ppm was recorded in steep and moderate slopes, and the highest 0.21±0.01 ppm was recorded in a gentle slope of the arecanut plantation. The lowest value in the rubber plantation 0.21±0.01 ppm was recorded in moderate and gentle slopes, and the highest 0.22±0.01 ppm was recorded in steep slope. The lowest value in the secondary forest

0.14±0.02 ppm was recorded in steep slope and the highest 0.28±0.05 ppm was recorded on a moderate slope.

From the study, it was possible to conclude that the shift in land use systems from secondary forest to other plantation systems show detrimental effect on soil physical and chemical properties. The physico-chemical properties of soil significantly vary among the studied land-use systems. The particle size composition of soil in the arecanut and rubber plantations were categorized under sandy loam textural class while the secondary forest was dominated by sandy clay loam texture. The strongly acidic nature of the studied soils could result from the high rainfall which is adequate to remove basic cations out of the surface horizons of the soils. In addition, the higher values of soil porosity, moisture content, soil organic carbon, and organic matter contents, total nitrogen, available phosphorus, and available potassium were obtained under the soil of secondary forest as compared to arecanut and rubber plantations soil at both depths.

Topography and slope gradients are one of the important factors that have influenced the process of drainage, runoff and soil erosion, thereby affecting soil properties through the redistribution of soil and soil organic matter. The sand content, moisture content, pH and exchangeable magnesium content declined downslope, implying decreased availability of plant nutrients in the gentle slope segment. The moderate slope had higher available iron on account of the higher moisture. On the other hand, soil organic matter content is highest in the gentle slope, presumably due to the higher clay content of soils in this slope segment. Furthermore, total nitrogen content, available phosphorus, available potassium, available sulphur, and available copper contents reflect the higher status in the gentle slope. However, the detrimental effects of slope gradient were higher in steep slope areas as compared to gentle slope areas.

According to the fertility test based on the calculated nutrient indices, nitrogen, phosphorus, and potassium attained medium value in all three land uses. Status of calcium attained medium value in secondary forest and low in arecanut and rubber plantations. Status of magnesium attained high and sulphur attained low values in all land uses. On the other hand, the soil micronutrients (Fe, Mn, Zn, and Cu) varied significantly among the studied land uses. A relatively low level of micronutrients was observed in all land-use systems that indicate no contamination as it always had retained its natural concentration of chemicals in the environment.

Thus, the soil fertility management that focuses on enhancing the organic matter and nitrogen levels, and reducing the effects of high slope gradient in the study area are required for improving crop production on a sustainable basis. It can be concluded that proper management of arecanut and rubber plantations could maintain soil under good conditions.

8.4. Recommendations

From the findings of the present study, the following recommendations were made to improve soil physicochemical properties:

i) Introduction of suitable intercrops which helps minimize the effects of erosion in relation to the addition of nutrients in the soil.

ii) Proper land management practices with the application of Green Manures and Farm Yard Manure (FYM) at regular intervals.

iii) Use of vegetative barriers to create natural terraces against runoff.

iv) Mulching should be adopted to protect the soil surface against raindrops.

v) Weeding and thinning should be done regularly to provide adequate space for the remaining plants to grow efficiently.

vi) Soil conservation and agricultural production no longer should be regarded as separate activities. It must be an integral part of agriculture development and should start with an improved farming system.

vii) Community nurseries should be promoted by providing training and technical support to farmers for improve quality of planting material

viii) Due to the steepness of hill slopes most of the rainwater losses as runoff and very less amount of rainwater remained for utilization during the dry seasons. Application of proper water storage and harvesting techniques, which contribute to agricultural development and resource conservation are required.

ix) To create awareness regarding the utility of the arecanut sheaths for commercial purposes such as plates and bowls this will enhance the income of the growers. Many crafts products can be made from each part of the arecanut plant which is biodegradable and eco-friendly.

Appendix I. Pearson's Correlation Matrix for Selected Soil Properties in Arecanut Plantation

	Sand	Silt	Clay	BD	SMC	pH	OM	TN	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
Sand	1.00																	
Silt	-.951**	1.00																
Clay	-.951**	.809**	1.00															
BD	.215**	-.220**	-.189*	1.00														
SMC	0.03	-0.05	-0.01	0.03	1.00													
pH	-.309**	.286**	.302**	-0.05	.387**	1.00												
OM	0.01	-0.05	0.03	.261**	0.05	-0.04	1.00											
TN	-0.14	0.16	0.12	.215**	0.03	-0.08	.315**	1.00										
P	.190*	-.183*	-.179*	0.00	.474**	.180*	-.169*	-.266**	1.00									
K	-.295**	.301**	.260**	-.251**	0.06	0.08	-.402**	-.261**	.188*	1.00								
Ca	0.04	-0.04	-0.04	-0.05	.394**	0.13	.194*	-0.12	.434**	0.12	1.00							
Mg	-0.12	0.07	0.16	0.09	.168*	0.08	.176*	-.196*	.299**	0.15	.355**	1.00						
S	-.224**	.230**	.196*	0.05	0.09	-0.02	.260**	.337**	-0.02	0.00	.221**	0.06	1.00					
Na	-.186*	.192*	0.16	-0.09	0.16	.275**	-.315**	-.282**	.204*	.294**	0.05	.280**	-.449**	1.00				
Fe	-.478**	.499**	.411**	-0.11	0.10	.246**	0.03	0.13	-0.15	0.05	0.02	-.205*	0.06	0.09	1.00			
Mn	-0.13	0.15	0.09	-0.06	-0.10	-0.01	-.339**	-0.02	0.03	.191*	-.199*	-0.04	0.10	0.02	0.01	1.00		
Zn	0.06	0.01	-0.13	-.317**	-0.01	-0.01	-.435**	-.211*	.170*	0.10	-0.03	-.320**	0.01	0.08	0.09	.367**	1.00	
Cu	-.321**	.384**	.227**	-.234**	-.201*	0.09	-.225**	-0.09	-0.16	.229**	-0.16	-0.07	0.06	0.14	.316**	.329**	.443**	1.00

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Appendix II. Pearson's Correlation Matrix for Selected Soil Properties in Rubber Plantation

	Sand	Silt	Clay	BD	SMC	pH	OM	TN	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
Sand	1.00																	
Silt	0.15	1.00																
Clay	-.551**	-.909**	1.00															
BD	-0.03	0.05	-0.03	1.00														
SMC	0.13	0.03	-0.08	-.272**	1.00													
pH	.268**	-.372**	.200*	0.14	0.02	1.00												
OM	-.185*	-.199*	.246**	.222**	-0.12	-0.04	1.00											
TN	-0.02	-0.04	0.05	-.178*	.239**	-0.05	-0.02	1.00										
P	-.250**	0.13	0.00	0.11	-0.03	-.183*	0.15	0.06	1.00									
K	-.173*	-.616**	.593**	0.10	-.213*	.284**	.521**	-0.08	-0.04	1.00								
Ca	0.12	-.287**	.191*	.203*	-.312**	.283**	.360**	-.252**	-0.15	.593**	1.00							
Mg	0.11	-0.15	0.08	0.14	-.253**	.169*	.204*	-.188*	-0.13	.404**	.834**	1.00						
S	-.207*	-0.11	.176*	0.06	-.183*	0.04	.244**	-0.08	.167*	.224**	0.10	-.197*	1.00					
Na	.195*	-.286**	0.16	-.321**	.188*	0.13	-.406**	0.15	-.235**	-.242**	-0.07	0.05	-.291**	1.00				
Fe	0.13	-0.06	-0.01	0.07	0.11	.171*	-.315**	0.05	-0.03	-.365**	-.283**	-.203*	-0.16	.390**	1.00			
Mn	0.16	-.227**	0.13	.172*	-0.10	.241**	0.10	-0.14	-0.08	.283**	0.10	-0.06	0.06	-0.16	-0.06	1.00		
Zn	0.08	.579**	-.522**	-0.15	.333**	-.341**	-0.15	0.07	.235**	-.485**	-.463**	-.351**	-0.01	-.214**	0.02	-.276**	1.00	
Cu	0.04	.378**	-.339**	0.08	0.10	-0.16	-.169*	-0.12	0.05	-.232**	-.237**	-.266**	0.08	-.306**	-0.05	-0.12	.396**	1.00

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Appendix III. Pearson's Correlation Matrix for Selected Soil Properties in Secondary Forest

	Sand	Silt	Clay	BD	SMC	pH	OM	TN	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
Sand	1.00																	
Silt	-.804**	1.00																
Clay	-.842**	.357**	1.00															
BD	0.01	-0.05	0.03	1.00														
SMC	.240**	-0.16	-.230**	0.13	1.00													
pH	0.05	-0.04	-0.04	-0.04	0.16	1.00												
OM	-.214**	.281**	0.08	-0.08	0.05	-0.15	1.00											
TN	-0.11	.267**	-0.07	-.181*	-.245**	0.02	-0.02	1.00										
P	-.206*	.262**	0.09	0.02	-.199*	-0.10	.205*	.196*	1.00									
K	-.185*	.260**	0.06	.191*	0.03	-0.01	0.11	-0.12	.236**	1.00								
Ca	0.16	-.255**	-0.02	0.02	-0.09	0.09	-0.04	-.167*	-0.12	0.06	1.00							
Mg	.210*	-.221**	-0.13	-0.09	-0.09	-.285**	0.04	-0.01	-.225**	-.220**	.203*	1.00						
S	-0.10	0.01	0.14	0.04	-0.05	0.11	0.01	-0.09	0.05	0.10	0.14	0.05	1.00					
Na	.287**	-0.04	-.414**	0.00	.170*	-0.13	0.09	0.07	-0.01	-0.08	-0.02	.199*	-0.03	1.00				
Fe	.202*	-.166*	-.167*	-0.12	-0.13	-0.09	-0.03	.210*	0.09	-.181*	-0.07	.269**	0.05	.172*	1.00			
Mn	0.13	-0.08	-0.14	.177*	.317**	.275**	-.234**	-0.07	-0.01	.164*	-.266**	-.315**	-0.11	0.03	-0.03	1.00		
Zn	0.03	-0.03	-0.02	0.07	.307**	0.14	-.208*	0.03	0.02	0.07	-.361**	-.403**	-.183*	-0.10	-0.02	.531**	1.00	
Cu	-.288**	.203*	.268**	-0.12	-0.15	0.03	0.12	0.03	0.12	-0.06	-0.05	0.11	.164*	-.164*	.200*	-.258**	0.00	1.00

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Appendix IV. Rating Limits for Available Soil Nutrie

Nutrient	**Low**	**Medium**	**High**
TN (%)	< 0.76	0.76 - 1.5	> 1.5
P (kg/ha)	< 25	25 - 50	> 50
K (kg/ha)	< 108	108 - 280	> 280
Ca (mg/kg)	< 150	150 - 300	> 300
Mg (mg/kg)	< 40	40 - 80	> 80
S (mg/kg)	< 10	10 - 20	> 20
Fe (mg/kg)	< 5	5 - 7	> 7
Mn (mg/kg)	< 2	2 - 4	> 4
Zn (mg/kg)	< 0.6	0.6 - 1.2	> 2
Cu (mg/kg)	< 0.2	0.2 - 0.4	> 0.4

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EDUCATIONAL QUALIFICATIONS

Sl. No	Name of Examination	Year of Passing	Name of the Board/ University	Percentage/Grade
1	All India Secondary School Examination (Class 10th)	2006	CBSE	71.6
2	All India Senior School Certificate Examination (Class 12th Science)	2008	CBSE	68.4
3	Bachelor of Science (Zoology)	2011	NEHU	56.6
4	Master of Science (Environmental Science)	2013	Mizoram University	76.17

LIST OF PRESENTATION IN CONFERENCE/SYMPOSIUM/SEMINAR

1. "Effect of Rubber and Arecanut Plantations on Soil Properties with comparison to Secondary Forest of Kolasib District, Mizoram" in the 3rd National Seminar on Natural Resource Management for Sustainable Development. Organized by the Department of Geography & Resource Management, Mizoram University on 7th-8th Nov 2019.

2. "Changes in Soil Properties under Different Land Use Covers in Parts of Kolasib District, Mizoram". Seminar Proceeding (International Conference on Natural Resources Management for Sustainable Development and Rural Livelihoods. Department of Geography and Resource Management, Mizoram University on 26th-28th Oct 2017).

3. "Soil Changes Induced by Arecanut and Rubber Plantation Establishment: Camparison with Secondary Forest Soil in Kolasib District, Mizoram". Seminar Proceeding (International Conference on Natural Resources Management and Technology Trends. Department of Life Sciences, Manipur University on 27th-29th March 2017).

4. "Variability in Physical and Chemical Properties of Soil along a Toposequence under Rubber and Arecanut Plantations in Kolasib District, Mizoram". Seminar Proceeding (International Conference on Global Biodiversity, Climate Change and Sustainable Development. Faculty of Life Science, Rajiv Gandhi University, Arunachal Pradesh on 15th-18th Oct 2016).

LIST OF SEMINAR/SYMPOSIUM/CONFERENCE/WORKSHOPS ATTENDED

1. "Advanced Biostatistical Training Course" organized by Northpole Institution of Professional Training, Guwahati held on 15th-21th July 2017.
2. "North East Workshop on Design of Experiments" jointly organized by Statistical Quality Control & Operation Research Unit, Indian Statistical Unit, Kolkata and Department of Statistics, Arya Vidyapeeth College. Guwahati on 3rd-5th Nov 2016.
3. "National Symposium on Ethnobotanical Importance in North East India" organized by the Department of Environmental Science, Mizoram University in collaboration with Society for Ethnobotanist NBRI, Lucknow and National Medicinal Plant Board, New Delhi on 13th-15th Oct 2015.
4. "One week course on Applied Statistics" sponsored by UGC Human Resource Development Centre, Mizoram University held on 7th-12th Sept 2015.

PAPER PUBLICATION

1. Effect of Rubber and Arecanut Plantations on Soil Properties with comparison to Secondary Forest of Kolasib District, Mizoram. *Natural Resource Management for Sustainable Development*. Today and Tomorrow's Printers and Publishers, New Delhi. pp. 361-374.
2. Effect of Rubber Plantations on Soil Properties with Comparison to Secondary Forest of Kolasib District, Mizoram. *Journal of Hill Agriculture*, 9 (2): 217-224.
3. Effect of Slope Gradient on the Selected Soil Physico-Chemical Properties in Arecanut Plantation of Kolasib District, Mizoram. *International Journal of Scientific Research and Reviews*, 6(4), 128 – 138.

PARTICULARS OF THE CANDIDATE

NAME OF CANDIDATE	: Manzamawii
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DEPARTMENT	: Environmental Science
TITLE OF THESIS	: Nutrients and Fertility Status of Soil under Rubber and Arecanut Plantations in Kolasib District, Mizoram
DATE OF ADMISSION	: 27-07-2014
APPROVAL OF RESEARCH PROPOSAL	
1. BOS	: 14-05-2015
2. SCHOOL BOARD	: 19-05-2015
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Effect of Slope Gradient on the Selected Soil Physico-Chemical Properties in Arecanut Plantation of KolasibDistrict, Mizoram.

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ABSTRACT

The present study was carried out to investigate the effect of slope gradient on physico-chemical properties of soil and to provide the basic information about its fertility status under Arecanut Plantation in Kolasib District of Mizoram, North-East India. Soil samples were collected from three slope gradients, namely, gentle slope (0-15%), moderate slope (15-30%) and steep slope (>30 %) in four replications. The collected samples were air dried, sieved and analyzed for various soil fertility parameters such as bulk density, pH, organic carbon, primary nutrients (N, P, K) and secondary nutrients (Ca, Mg, S). Results revealed that soil reaction in the study area varied from strongly acidic to moderately acidic with pH values ranged from 5.07, 5.33 and 5.64 along the slope gradients. The data on various parameters were categorized into low, medium and high classes based on soil fertility ratings and nutrient index was calculated. Soil fertility in the studied area was high with respect to nitrogen and medium in all others. However, the detrimental effects of slope gradient are higher at steep slope as compared to gently slope areas. All the soil properties were significantly affected by slope gradient except for soil porosity and available potassium. Therefore, there is a need to restore and sustain the nutrient balance along the different slope gradients by adopting proper management like application of Farm Yard Manure (FYM) and green manures at regular intervals and balanced intercropping etc.

KEYWORDS: soil properties, slope gradient, effect, soil nutrient and fertility, Mizoram.

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INTRODUCTION

The Arecanutpalm (*Areca catechu* Linn.) belonging to family Arecaceae is a traditionally important commercial crop in India. The economic produce is the fruit called 'betel nut' or 'supari' and is used mainly for masticatory as well as value added products. It plays a prominent role in the religious, social and cultural functions and economic life of people in India[1]. It is predominantly grown in humid tropics of West coast and North-East regions of India namely Karnataka ranks first with an area of 23,60,000 ha, Kerala ranks second with an area of 8,80,000 ha, Assam ranks third with an area of 7,33,000 ha, Meghalaya ranks fourth with an area of 11.2'000 ha, West Bengal ranks fifth with an area of 9.3'000 ha, Tamil Nadu ranks sixth with an area of 4.8'000 ha, Andaman and Nicobar Islands ranks seventh with an area of 4.4'000 ha, Tripura ranks eight with an area of 3.4,000 ha, Maharashtra ranks ninth with an area of 2.2,000 ha, Goa ranks tenth with an area of 16,000 ha, Mizoram ranks eleventh with an area of 13,000 ha, Andhra Pradesh ranks twelfth with an area of 0.1'000 ha and Pondicherry ranks thirteenth with an area of 0.3,000 ha respectively[2]. India is the largest producer and consumer of arecanut. The total production of arecanut in India is 1, 38, 50,000 million ton with an area of 51, 00,000 ha with productivity of 224.1 kg per ha[3].

Arecanut has been cultivated as a cash crop inthe state of Mizoram for quite a long time. Adoptions of such economically high valued tree plantations to these areas where agriculture is the mainstay for about 60% of the population andcharacterized by high dependence on rainfall has come as an opportunity for the farmers who typically practiced shifting cultivation a chance to enhance and diversify their livelihood. Owing to its tropical location, undulant hilly ranges and its moderate climate the area under arecanut cultivation has doubled in Mizoram from 5,010 ha in 2011-12 to 10,740 ha in 2014-15, but with a decline in the production from 12,390 ton to 7,270 ton[2-4]. Continuous cultivationof these plantation cropson the same land results in soil fertility depletion. For optimum arecanut production soil properties play a dominant role in addition to climatic conditions and water resourcesfacilities[5]. In the study area, cultivation on steep slopes is the dominant factor for runoff and erosion that adversely affect the soil physico-chemical properties and crop productivity. Thus, there is a need to restore and sustainthe nutrient balancealong the different slope gradients. This study aimed to investigate the effect of slope gradient on selected soil physico-chemical properties and to provide the basic information about the fertility status ofArecanut Plantation soils.The present study will be the first of its kind to be undertaken in the state of Mizoram, North-East India (Indo-Burman Hotspot region).

MATERIAL AND METHODS

Study Area

Mizoram is one of the eight state of the North-East India, situated in the extreme end of the Himalayan range covering a total area of 21,087km^{2}within altitude ranging from 500 m to 2157m. Kolasib is an important and potential district ofMizoram for agriculture production. The total geographical area of Kolasib district is 1382.51 km^2, which is about 6.56% of the state area. It is situated between 23˚5’ and 24˚35’ N Latitude and 92˚3’ W– 93˚E Longitude. It comes under the tropical monsoon climate zone and experiences direct impact of monsoon. The average rainfall is 2703 mm per annum. The average temperature ranges between 11˚ C - 34˚ C with relative humidityvaries from 69% - 80%[6].

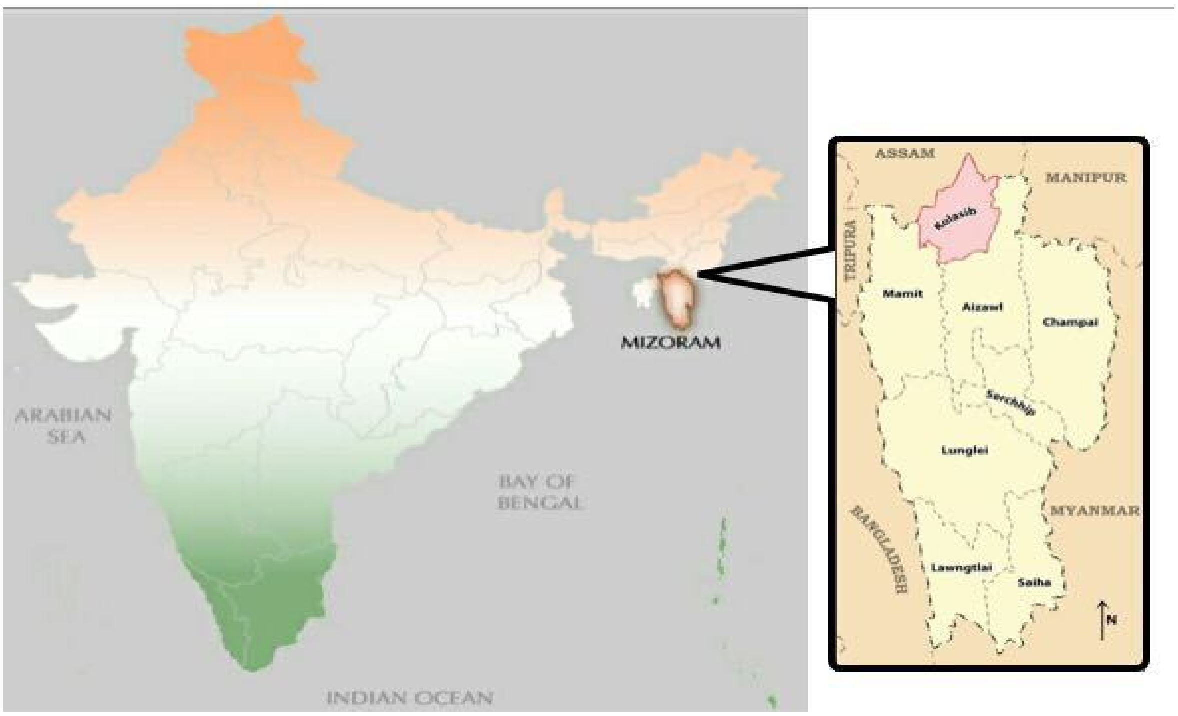

Fig1: Map of Kolasib District of Mizoram, showing study area

Sample collection and analysis

Soil samples were collected from three different classes of slope gradient: gentle slope (0-15%), moderate slope (15-30%) and steep slope (>30%) gradients from two subsequent depths (i.e. 0- 20 cm and 20-40 cm). The soil samples were air dried, grind and screened using a 2 mm sieve. The processed soil samples were analyzed for bulk density and soil pH[7], organic carbon[8], total nitrogen[9], available phosphorus[10], potassium ions by flame photometer, calcium and magnesium by EDTA titration[11] and sulfur ions by spectrophotometer[12].

Data analysis

Statistical comparisons of soils under different slope gradient were performed by one way analysis of variance (ANOVA) at 0.05 significance level. All data were analyzed using MS excel and SPSS (v. 16.0) software.

RESULTS AND DISCUSSION

Physical properties of soils

The data on table2 revealed that effect of slope gradient on soil bulk density (BD) was significant ($p<0.05$). BD was recorded the lowest on the gentle slope area (1.25 g/cm^3) andhighest on the steep slope area (1.31 g/cm^3) (Table 1).The higher value of soil BD maybe due to low clay and high sand content as well as low amount of organic carbon[13].Soils BD under the study area were found to be less than 1.6 g/cm^3, which indicates that the soils are not compacted[14]. Soil porosity is the ratio of the volume of soil pores to the total soil volume. The bulk density of a soil is inversely related to the porosity[15]. Prior to which the lowest total porosity (50.69%) was recorded on steep slope area, while the highest total porosity (52.66%) was recorded on gentle slope area (Table1).

Chemical properties of the studies soils

Soil pH varied significantly under the effect of slope gradients ($p< 0.01$) (Table2). The value of soil pH ranged from 5.07, 5.33 and 5.64 along the slope gradients (Table1). The pH reaction of the studied soils is attributed to the acidic nature of the parent rock coupled intensive leaching of bases. Soil organic carbon (OC) is the carbon (C) stored in soil organic matter (OM). OM is a heterogeneous, dynamic substance that varies in particle size, C content, decomposition rate, and turnover time[16]. OM is different to OC in that it includes all the elements (hydrogen, oxygen, nitrogen, etc) that are components of organic compounds, not just carbon[15]. Organic matter (OM) content of the soil was rated medium (< 2%)[17]. There is a statistically significant effect ($p<0.05$) of slope gradient on both OC and OM (Table2). The lowest OC (1.72%) and OM (2.96%) was recorded in soils of the steep slope area, whereas the highest OC (2.14%) and OM (3.69%) was recorded in soils of the gentle slope area respectively (Table1). However, the difference in OC and OM content along the slope gradients may be attributed to insufficient canopy cover to suppress runoff from steep slope which resulted in loss of plant nutrient and deposition of organic materials in the gentle slope that resulted in better biomass production and moisture storage.

Total Nitrogen (TN) is the sum of nitrate (NO3), nitrite (NO2), organic nitrogen and ammonia. Similar with OM, TN was significantly affected ($P<0.05$) by slope gradient (Table2). The lowest (1.55%) and highest (2.95%) total nitrogen were recorded in steep and gentle slopes respectively (Table1). The unexpected high content of total nitrogen was attributed to low mineralization of the organic matter. This is supported by high, positive and significant correlation with OM (r= 0.71**) (Table 3). The high amount of TN in the soils helps to improve soil quality which in the long-run encourages plant growth and agricultural productivity and sustainability[18-19].

Phosphorus (P) plays an important role in energy transformations and metabolic processes in plants[20]. The levels of available P were lowest in (10.33 kg/ha) steep slope and highest (16.38 kg/ha) in gentle slope areas (Table1). P in soil is unavailable to plants because they are highly insoluble. Plant uptake, erosion, leaching and fixation can be accounted for lower amount of P in all the soils[21]. The Pearson's result (Table3) indicates that OM (r= -0.36**) and TN (r= -0.57**) had negative but significant relation with P while it showed significantly positive correlation with pH (r = 0.51**). Potassium (K) is one of the three major nutrients after N and P required for the build-up of biomass in plants. Differences of slope gradient among the areas did not significantly ($P>0.05$) affect available K. In addition to which OM (r= -0.39) and TN (r= -0.48) is found to have negative and significant relation with K (Table3). The value of K in the studied soils varied between 95.5 kg/ha and 274.55 kg/ha (Table1) and were rated low to medium according to Methods Manual of Soil Testing in India[22]. Less use of FYM, no addition of chemical fertilizers and poor recycling of nutrients from litter residues may also have resulted in low K content[21]. The lowest values of available K were recorded for moderate slope and almost similar values were recorded in gentle and steep slopes. Secondary nutrients (Ca, Mg and S) are nutrients that slightly limit crop growth and are moderately required by plants. All the studied secondary nutrients were significantly ($p<0.05$) affected by slope gradient (Table2). Magnesium (Mg) and Sulfur (S) showed similar pattern of variation along the slope gradients, found to be lowest in steep slope and highest in moderate slope areas (Table1). The Pearson's result further depicts a positive and insignificant relation between Mg and S (r= 0.11). In Table3 showed negative and significant relation between Mg with TN (r= -0.54**) whereas S had high, positive relation with OM (r= 0.58**). Calcium (Ca) was recorded to be lowest (3.47 mg/kg) in the sleep slope and highest (4.20 mg/kg) in moderate slope areas (Table1). The output of the correlation matrix revealed that Ca and Mg have high, positive and significant (r= 62**) correlation. It also share positive and significant association with soil porosity (r= 0.26*), P (r= 0.54**, r=0.58**) and K (r= 0.41**, r= 0.46**). However, these variations among the secondary nutrients may be due to differences in parent material and losses due to erosion.

Table 1: Summary of the descriptive statistics for selected soil physico-chemical properties.

Soil Properties	Slope Gradients (%)	Mean	Std. Deviation	Std. Error	CV (%)	Min	Max
Bulk density (g/cm^3)	Steep (>30%)	1.31	0.06	0.01	4.91	1.13	1.41
	Moderate (15-30%)	1.29	0.1	0.02	7.52	1.06	1.51
	Gentle (0-15%)	1.25	0.08	0.02	6.74	1.13	1.54
Porosity (%)	Steep (>30%)	50.69	5.45	1.11	10.75	41.89	60.23
	Moderate (15-30%)	51.32	4.41	0.9	8.59	43.89	60.35
	Gentle (0-15%)	52.66	4.04	0.82	7.66	44.62	62
pH	Steep (>30%)	5.07	0.47	0.1	9.35	4.43	6.07
	Moderate (15-30%)	5.33	0.53	0.11	9.89	4.59	6.4
	Gentle (0-15%)	5.64	0.46	0.09	8.19	4.94	6.38
Organic Carbon (%)	Steep (>30%)	1.72	0.48	0.1	27.78	1.05	2.45
	Moderate (15-30%)	2.06	0.57	0.12	27.67	1.25	3.08
	Gentle (0-15%)	2.14	0.59	0.12	27.71	1.35	3.06
Organic Matter (%)	Steep (>30%)	2.96	0.82	0.17	27.79	1.81	4.22
	Moderate (15-30%)	3.55	0.98	0.2	27.67	2.16	5.31
	Gentle (0-15%)	3.69	1.02	0.21	27.73	2.33	5.28
Total Nitrogen (%)	Steep (>30%)	1.55	1.61	0.33	104.08	0.14	4.67
	Moderate (15-30%)	1.95	2.1	0.43	107.93	0.15	5.85
	Gentle (0-15%)	2.94	1.83	0.37	62.04	1.28	5.8
Phosphorus (kg/ha)	Steep (>30%)	10.33	10.83	4.81	0.98	4.88	20.33
	Moderate (15-30%)	12.5	12.50	5.66	1.15	5.48	24.00
	Gentle (0-15%)	16.38	16.38	6.35	1.30	6.90	25.44
Calcium (mg/kg)	Steep (>30%)	66.07	18.79	3.84	28.44	29.02	88.71
	Moderate (15-30%)	89.36	16.05	3.28	17.96	61.61	116.96
	Gentle (0-15%)	90.10	17.19	3.51	19.08	57.14	117.41
Magnesium (mg/kg)	Steep (>30%)	86.13	33.52	6.84	38.92	33.50	138.00
	Moderate (15-30%)	132.22	56.09	11.45	42.42	38.60	214.00
	Gentle (0-15%)	122.47	51.35	10.48	41.93	62.00	248.00
Sulfur (mg/kg)	Steep (>30%)	3.47	1.00	0.20	28.87	2.09	5.10
	Moderate (15-30%)	4.20	1.19	0.24	28.24	2.25	6.07
	Gentle (0-15%)	4.13	0.89	0.18	21.58	2.96	5.80
Potassium (kg/ha)	Steep (>30%)	167.03	48.33	9.86	28.93	97.23	240.55
	Moderate (15-30%)	150.53	29.66	6.05	19.70	122.75	223.16
	Gentle (0-15%)	166.74	52.67	10.75	31.59	95.50	274.55

Table 2: ANOVA for selected soil physico-chemical properties.

		Sum of Squares	df	Mean Square	F	Sig.
Bulk density (g/cm^3)	Between Groups	0.04	2.00	0.02	3.19	0.05
	Within Groups	0.48	69.00	0.01		
	Total	0.52	71.00			
Porosity (%)	Between Groups	48.68	2.00	24.34	1.12	0.33
	Within Groups	1504.85	69.00	21.81		
	Total	1553.52	71.00			
pH	Between Groups	3.92	2.00	1.96	8.20	0.00
	Within Groups	16.47	69.00	0.24		
	Total	20.38	71.00			
Organic Carbon (%)	Between Groups	2.43	2.00	1.21	4.03	0.02
	Within Groups	20.81	69.00	0.30		
	Total	23.24	71.00			
Organic Matter (%)	Between Groups	7.21	2.00	3.61	4.02	0.02
	Within Groups	61.92	69.00	0.90		
	Total	69.13	71.00			
Total Nitrogen (%)	Between Groups	24.67	2.00	12.34	3.58	0.03
	Within Groups	237.99	69.00	3.45		
	Total	262.67	71.00			
Phosphorus (kg/ha)	Between Groups	388.70	2.00	194.35	6.10	0.00
	Within Groups	2196.87	69.00	31.84		
	Total	2585.57	71.00			
Calcium (mg/kg)	Between Groups	8963.53	2.00	4481.76	14.84	0.00
	Within Groups	20844.13	69.00	302.09		
	Total	29807.66	71.00			
Magnesium (mg/kg)	Between Groups	28321.77	2.00	14160.88	6.15	0.00
	Within Groups	158848.90	69.00	2302.16		
	Total	187170.67	71.00			
Sulfur (mg/kg)	Between Groups	7.83	2.00	3.91	3.66	0.03
	Within Groups	73.78	69.00	1.07		
	Total	81.61	71.00			
Potassium (kg/ha)	Between Groups	4281.91	2.00	2140.96	1.07	0.35
	Within Groups	137769.63	69.00	1996.66		
	Total	142051.54	71.00			

Table No. 3: Pearson's correlation matrix for selected soil physico-chemical properties

	Porosity	pH	OM	TN	P	Ca	Mg	S	K
Porosity	1								
pH	0.23*	1							
OM	-0.05	-.42**	1						
TN	-0.17	-0.15	0.71**	1					
P	0.38**	0.51**	-0.36**	-0.57**	1				
Ca	0.26*	0.37**	0.11	-0.2	0.54**	1			
Mg	0.26*	0.2	-0.10	-0.54**	0.58**	0.62**	1		
S	0.03	-0.14	0.58**	0.49**	-0.1	0.32**	0.11	1	
K	0.25*	0.36**	-0.39**	-0.48**	0.53**	0.41**	0.46**	-0.16	1

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

Nutrient Index of Soils in the Study Area

The nutrient index (NI) values of selected soil nutrients viz. N, P and K were calculated using on the following equation[23].

$$\text{Nutrient Index (NI)} = (NL*1 + NM*2 + NH*3)/ NT$$

Where, NL, NM and NH are number of samples falling in low, medium and high classes of nutrient status respectively and NT is the total number of samples analyzed for a given area.These nutrient index values were then characterized as Nutrient Index category I, II and III. Based on Table No. 4, the fertility index along with the corresponding nutrient index categories for the soil under study area are given in Table No. 5. According to the information given in Table No. 5, status of N was found to be high. In line with this finding, Motsar[24] reported high nitrogen fertility status in Mizoram (NI= 2.72). A higher quantity of N corresponds to higher amounts of OM[21]. In the other hand P and K attained a medium status. Increased soil fertility under mature scattered trees has also been reported by other researchers[3-25].

Table No. 4: Nutrient Index with Range and Remarks

Nutrient Index	Range of soil nutrients	Fertility Level
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Table No. 5: Soil fertility status of the study area with respect to soil nutrient index

Nutrients	NI values	NI	Fertility Status
N (%)	2.8	III	High
P (kg/ha)	1.67	II	Medium
K (kg/ha)	1.94	II	Medium

CONCLUSION

All the soil properties were significantly affected by slope gradient except for soil porosity and available potassium. The result of the present study indicated that soil reaction varied from strongly acidic to moderately acidic. According to the soil fertility tests based on the calculated nutrient index of N, P and K, the soils of Arecanut Plantation showed high to low fertility status. However, the declined in soil physico-chemical properties were observed from steep slope to gentle slope which could be due to past soil erosion and runoff effect that removed soil organic matter and other plant nutrients. The unexpectedly high contents of organic matter and total nitrogen may be due to management factors like application of Farm Yard Manure (FYM) and green manures at regular intervals by the growers[26]. Furthermore, in relation to the addition of nutrients in the soil and minimizing the effects of erosion the residues from the clearing of grasses/under growths should be used to cover the soil surface[27], proper management practices such as proper land leveling, balanced intercropping, applications of FYM and green manuring at regular interval, terracing should be considered. Therefore, the overall data indicated that arecanut plantation has the capability to recover soil to its original condition in both physical and chemical properties for improved production on sustainable basis.

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RESEARCH PAPER

Effect of rubber plantations on soil properties with comparison to secondary forest of Kolasib district, Mizoram

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ABSTRACT A detailed soil survey was undertaken at Kolasib district of Mizoram, North-East India with the aim to examine the effects of slope gradient and land use changes from secondary forest to rubber plantation on soil properties and also to provide the basic information about its fertility status using nutrient index values. Soil samples were collected and analyzed for soil bulk density, pH, organic matter, primary nutrients (N, P, K) and secondary nutrients (Ca, Mg, S) using standard procedures. The pH values studied soils were found to be strongly acidic. The result further revealed that secondary forest had higher soil organic matter (OM) and macronutrients (N, P, K, Ca and Mg) contents than in rubber plantation soils except for sulphur. Based on the fertility ratings and nutrient indices, the studied soils had high N in secondary forest and low P in rubber plantation, while others attained medium values. However, the decline in quality of soil properties was observed from steep to gentle slopes. Therefore, there is a need to restore and sustain the nutrient balance along the different slope gradients. Proper management of rubber plantation like balanced intercropping, increased use of organic nutrients, mulching etc. could help minimize the land deterioration and maintained soil under good conditions.

KEYWORDS Soil properties, land-use change, slope gradient, soil nutrient and fertility, Mizoram

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INTRODUCTION

The rubber tree, *Hevea brasiliensis* (Willd ex. Adr. de Juss.) Muell. Arg belonging to the family *Euphorbiaceae* is the most economically important member of the genus *Hevea* because it is the primary source of natural rubber. Natural rubber is a coherent elastic solid harvested mainly in the form of latex. It is used as raw material for a variety of purposes from erasing pencil marks to manufacturing tyres, sports goods, shock absorbers, gaskets, tubes and a large number of industrial products (Mondal 2004). It is a native of the Amazon basin of South America and introduced to tropical and sub-tropical regions of Asia and Africa during the 19th century. It can be termed as the most successful introductions in plant history resulting in plantations over 9.3 million ha, across the globe in Asia (RubberBoard 2002). Asia continues to dominate the world supply of natural rubber, with 92 % of total world production in 2016. India is now considered to be the fourth largest producer of natural rubber, next to Thailand, Indonesia and Malaysia (IHS 2017). Large scale rubber plantations are found along the western coasts of India, Kerala being the largest producer, accounts for 80 % of the total rubber production in the country (Prasad 2016). The state had produced 6.48 lakh tonnes of rubber in 2013-14 and drop down to 4.39 lakh tonnes in 2015-16. Tripura is the second largest rubber producer in the country for shot up from 39,000 tonnes in 2013-14 to 44,245 ton in 2015-16 which is 7.9 % of the total production. Karnataka had produced 35,230 tonnes in 2013-14 to only 29,400 tonnes in 2015-16, while the production in Tamil Nadu also dropped from 25,000 ton to 19,495 tonnes during the same period. Similarly, Assam recorded a notable uptick in production during the period from 13,600 to 14,560 tonnes. The other major rubber producing states are

Meghalaya, Nagaland, Manipur and Mizoram (Thomas 2017).

Rubber plantations in traditional areas are getting saturated and considering the long-term requirements of natural rubber, India ventured into extension of rubber plantations in non-traditional areas such as the north-eastern part of the country to increase its economic production. The tropical agro-climatic conditions such as the undulant hilly ranges, direct monsoon exposure and other moderating influences are extremely favourable for rubber cultivation. It has been estimated that North-East India can afford to plant rubber in 350,000 ha of land (Mithisnortheast 2011). This initiative has come as an opportunity to farmer who typically practiced shifting cultivation, a chance to embrace mainstream settled agricultural system and also contributes a significant proportion of earnings.

In Mizoram, rubber plantation had been initiated early in the 1960s but due to unavailability of good saplings, lack of technology, poor package of practices and need of long duration, the plantations were taken up in small patches by very few individuals (Lallianthanga et al. 2014). Encouraged by the success obtained from rubber plantation in the neighbouring Assam and Tripura state, Mizoram government also had started taking initiatives to carry out rubber plantation in a broader scale. Mizoram had about 5,75,000 ha for rubber plantation but government had planned to add about 7000 ha more of land under rubber plantation under various schemes, meanwhile, only 50 ha had been cover by the state Soil and Water Conservation department and individuals (Manipur Mail 2013).

The soil is a major factor in determining the availability of nutrients required for plant growth in any other forest tree like rubber plantation (Orimoloye et al. 2010, Njar 2011). A proper understanding of soil quality is a necessary tool in determining the sustainability and environmental impact of agricultural ecosystems. Since this problem is persistent mostly with the changing land use, therefore, this study evaluates the effects of slope gradient and land use changes from secondary forest to rubber plantation on soil properties of the studied area.

MATERIAL AND METHODS

Study area: This study was conducted in 2014-2015 at Kolasib, district of Mizoram. It comes under tropical monsoon climate zone and experiences direct impact of monsoon. Average rainfall is 2703 mm per annum and temperature ranges from 11 - 34 °C with relative humidity varying from 69 – 80 %. It covers the total geographical area of 1382.51 km^2, which is about 6.56 % of the state area. It is located within coordinates of 23°5’ and 24°35’ N latitude and 92°93’ and 93° E longitude.

Sampling : Soil samples were collected from three different classes of slope gradient: gentle (0-15 %), moderate (15-30 %) and steep slope (>30 %) gradients from two subsequent depths (i.e. 0 - 20 and 20 - 40 cm). Soil samples were air dried, ground and screened using a 2 mm sieve. Processed soil samples were analyzed for bulk density and soil pH, organic carbon, total nitrogen, available phosphorus, potassium by flame photometer, calcium and magnesium by EDTA titration and sulphur ions by spectrophotometer (Walkley and Black 1934, Bray and Kurtz 1945, Black 1965, Bremner and Mulvaney 1990, Anderson and Ingram 1993, Basak 2010).

Statistical analysis : An analysis of variance (ANOVA) was used to test effects of land use and slope position on soil properties. Pearson’s correlation was also used to determine the nature of association between the selected soil properties. All tests were conducted using the software SPSS v. 12.0.

RESULTS AND DISCUSSION

Soil bulk density (BD) is a basic soil property that gives information about soil compaction. The ANOVA revealed that effect of slope gradients on soil BD of secondary forest and porosity of both secondary forest and rubber plantation varied significantly ($p<0.05$) whereas soil BD in rubber plantation did not vary ($p>0.05$) (Table 2). Bulk densities was lower in secondary forest soils than in rubber plantation with mean values of 1.12 and 1.28 g/cm^3 respectively (Table 1), while, its porosity was higher in secondary forest than in rubber plantation soils, with mean values of 57.71 and 51.77 %. Soil porosity is the ratio of volume of soil pores to total soil volume (Chaudhari et al. 2013). Accordingly, lowest BD (1.05, 1.25 g/cm^3) were recorded on gentle slope, while highest BD (1.17, 1.29 g/cm^3) were in steep slope, of both secondary forest and rubber plantation. Differently, lowest porosity was recorded in steep (55.8 %) and moderate (51.04 %) slopes, while highest was observed in gentle slopes (60.17, 52.77 %) of secondary forest and rubber plantation. Thus, the BD of the studied soil was inversely related to the porosity.

Reduction in porosity at the surface causes reduction in infiltration and percolation that propagate surface runoff, soil erosion and ultimately serious land degradation (Giertz et al. 2005). Soils BD under the two studied land uses were found to be less than 1.6 g/cm^3, which indicates that the soils are not compacted (Aytenew 2015). Moreover, higher BD in rubber soils possibly result from continuous cultivation over a year’s period, human activities like trembling, weeding, tillage etc. gradually will lead to reduction in the formation of large pores. Further incorporation of organic matter in the form of dead leaves, branches or development of fine roots into the soil is suggested that will help decrease BD (Yasin et al. 2010).

Table 1 Mean and standard errors of selected soil properties under different land uses in the study area

Soil Properties	Slope position	Secondary forest	Rubber
BD (g/cm³)	Steep (>30 %)	1.17±0.02	1.29±0.01
	Moderate (15-30 %)	1.13±0.03	1.29±0.01
	Gentle (0-15 %)	1.05±0.04	1.25±0.01
	Total	1.12±0.02	1.28±0.01
Porosity (%)	Steep (>30 %)	55.8±0.80	51.51±0.39
	Moderate (15-30 %)	57.15±1.05	51.04±0.37
	Gentle (0-15 %)	60.17±1.4	52.77±0.35
	Total	57.71±0.67	51.77±0.23
pH	Steep (>30 %)	4.65±0.08	5.38±0.08
	Moderate (15-30 %)	4.92±0.06	5.26±0.06
	Gentle (0-15 %)	4.8±0.04	5.24±0.04
	Total	4.79±0.04	5.29±0.04
OC (%)	Steep (>30 %)	2.02±0.08	1.77±0.12
	Moderate (15-30 %)	2.12±0.09	1.83±0.05
	Gentle (0-15 %)	2.37±0.09	2.29±0.08
	Total	2.17±0.05	1.96±0.06
OM (%)	Steep (>30 %)	3.48±0.14	3.06±0.21
	Moderate (15-30 %)	3.65±0.15	3.16±0.09
	Gentle (0-15 %)	4.08±0.16	3.94±0.13
	Total	3.74±0.09	3.39±0.10
TN (%)	Steep (>30 %)	2.08±0.17	0.21±0.02
	Moderate (15-30 %)	2.17±0.21	0.32±0.04
	Gentle (0-15 %)	2.98±0.16	0.46±0.09
	Total	2.41±0.11	0.33±0.03
P (kg/ha)	Steep (>30 %)	16.59±1.46	14.78±1.23
	Moderate (15-30 %)	19.6±1.28	18.41±1.21
	Gentle (0-15 %)	27.23±2.11	18.74±1.12
	Total	21.14±1.08	17.31±0.71
K (kg/ha)	Steep (>30 %)	187.12±11.37	140.43±8.71
	Moderate (15-30 %)	203.89±9.5	159.2±8.75
	Gentle (0-15 %)	206.87±12.27	222.8±12.13
	Total	199.29±6.41	174.14±7.06
Ca (mg/kg)	Steep (>30 %)	130.15±7.37	93.3±5.96
	Moderate (15-30 %)	118.74±9.14	112.8±5.96
	Gentle (0-15 %)	87.45±4.74	125.48±12.65
	Total	112.11±4.68	110.53±6.51
Mg (mg/kg)	Steep (>30 %)	148.8±8.43	57.94±4.65
	Moderate (15-30 %)	126.41±7.47	69.02±7.3
	Gentle (0-15 %)	108.97±10.37	92.14±12.77
	Total	128.06±5.39	73.03±5.34
S (mg/kg)	Steep (>30 %)	2.33±0.11	2.63±0.11
	Moderate (15-30 %)	2.68±0.16	3.04±0.10
	Gentle (0-15 %)	2.32±0.09	3.23±0.09
	Total	2.44±0.07	2.97±0.06

Soil pH measures the activity of the hydrogen ion (H^+) and hydroxyl ion (OH^-), which indicates whether the soil is acidic, neutral or alkaline in reaction (Hazelton and Murphy 2007). The value of soil pH in secondary forest showed significant effect ($p<0.05$) of slope gradient. However, soil pH in rubber plantation did not differ significantly ($p>0.05$) on reaction (Table 2). Table 1 showed the soils under secondary forest (pH 4.65-4.92) and rubber plantation (pH 5.24-5.38) were rated as strongly acidic (GOI 2011). Howsoever, soils in tropical forest have been reported to thrive at acidic (pH 4.5 - 5.5) conditions (Shamshudin and Fauziah 2010). Lowest and highest pH values (pH 4.65, pH 4.92) were recorded on steep and moderate slopes of secondary forest. On the other hand, the lowest and highest pH values was recorded on gentle and steep slopes of (pH 5.24, 2.38) rubber plantation. Reaction of the studied soil pH may be attributed to the acidic nature of the parent rock coupled intensive leaching of bases due to high rainfall. Rubber trees are essentially adapted to high rainfall areas which often are associated with leaching and acidity. Hence, the optimum range for rubber is within range of pH 4-6.5 without any liming (Akamigbo and Asadu 1983, Dharmakeerthi et al. 2005, Orimoloye et al. 2011).

Soil organic carbon (OC) is the amount of carbon stored in soil organic matter (OM) – plant and animal materials in the soil that are in various stages of decay. Soil OC is the basis of soil fertility and the main source of energy for soil microorganisms. Likewise, OM is an important source of nutrients for plants. OM is different to OC in that it includes all the elements (hydrogen, oxygen, nitrogen, etc.) that are components of organic compounds, not just carbon (Chaudhari et al. 2013). The proportion of OC was found to be greater in secondary forest soil than in rubber plantation, with the mean values of 2.17 % and 1.96 % respectively. In like manner, the content of OM was even greater in secondary forest than in rubber plantation soil with mean values of 3.74 % and 3.39 % respectively (Table 1). This finding was in agreement with earlier works (Hongemei et al. 2012, Oku et al. 2012, Iwara et al. 2013). The abundance and diversity of litter which were accumulated for over a long period provides adequate cover to ground floor thereby decomposes to form nutrient and encourages high soil OM content in the secondary forest while low content of OM in rubber plantation soil may be due to anthropogenic influence, low moisture storage, less biomass production and by the effect of slope gradient which suppress runoff resulting in the loss of plant nutrients. Soils OM under the two studied land uses were rated medium (2.59 - 5.17 %) (Tekalign 1991). Furthermore, OC and OM showed statistical significant effect ($p<0.05$) of slope gradient on both land uses (Table 2). The lowest (2.02, 3.48 %) and highest (2.37, 4.08 %) values of soil OC and OM were obtained in steep and gentle slopes of secondary forest. Consonantly, the lowest (1.77, 3.06 %) and highest (2.29, 3.94 %) values of soil OC and OM were obtained in steep and gentle slopes of rubber plantation.

Total nitrogen (TN) is the sum of nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N) and organically bonded nitrogen. The mean concentration of TN was very much higher in secondary forest soil than rubber plantation soil, with mean values of 2.41 % and 0.33 % respectively (Table 1). Soils TN under the two studied land uses were rated high (>0.25 %) (Tekalign 1991). As OM content is an indicator of N status of soils, greater input of N in secondary forest may occur through higher decomposition rate of litter fall. This is supported by the Pearson's result (Table 4) which imply a positive and significant correlation of TN with OM (r = 0.38**), S (r = 0.23*) but negative significant relation with Ca (r = -0.32**) and Mg (r = -0.36**). In addition, TN was significantly affected (p<0.05) by slope gradient in both land uses (Table 2). The lowest (2.08 %) and highest (2.98 %) values of TN was recorded in steep and gentle slopes of secondary forest. Similarly, in rubber plantation lowest (0.21 %) and highest (0.46 %) values of TN were observed in steep and gentle slopes.

Phosphorus plays an important role in energy transformations and metabolic processes in plants (Rai et al. 2012). Differences of slope gradient among the land uses significantly (p<0.05) affect available P (Table 2). Soil P contents was found to be higher in secondary forest than rubber plantation with mean values of 21.14 kg/ha and 17.31 kg/ha respectively (Table 1). Higher content of P in secondary forest may be due to rapid recycling of nutrients by decomposition and mineralization of litters.

Less use of FYM, no addition of chemical fertilizers, higher leaching loss from the surface and poor recycling of nutrients from litter residues may also have resulted in low P content in the soils of rubber plantation (Chase and Singh 2014, Chauhan et al. 2014). The lowest P (19.60, 14.78 kg/ha) was recorded on steep slope, while highest P (27.23, 18.74 kg/ha) was in gentle slope of both secondary forest and rubber plantation. Available P contents under the soils of studied land uses were rated medium (10−25kg/ha) (Methods Manual of Soil Testing in India 2011).

Potassium (K) is a major mineral that exists within soil and plays a major role in plant growth (Tandy et al. 2012). Available K in secondary forest showed no significant affect (p>0.05) by slope gradient, while it varied significantly (p<0.05) in rubber plantation (Table 2). Available K was be fairly high in secondary forest than in rubber plantation soil (199.29 and 174.14 kg/ha, respectively).

Table 2 ANOVA for selected soil properties under different land uses in the study area

Parameter		df	Secondary forest		Rubber	
			F	Sig.	F	Sig.
BD (g/cm^3)	Between Groups	2				
	Within Groups	69	4.07	0.02	2.61	0.08
	Total	71				
Porosity (%)	Between Groups	2				
	Within Groups	69	4.07	0.02	5.83	0.01
	Total	71				
pH	Between Groups	2				
	Within Groups	69	2.11	0.13	1.43	0.25
	Total	71				
OC (%)	Between Groups	2				
	Within Groups	69	4.22	0.02	10.13	0.00
	Total	71				
OM (%)	Between Groups	2				
	Within Groups	69	4.23	0.02	10.11	0.00
	Total	71				
TN (%)	Between Groups	2				
	Within Groups	69	7.20	0.00	4.68	0.01
	Total	71				
P (kg/ha)	Between Groups	2				
	Within Groups	69	10.97	0.00	3.41	0.04
	Total	71				
K (kg/ha)	Between Groups	2				
	Within Groups	69	0.92	0.40	18.67	0.00
	Total	71				
Ca (mg/kg)	Between Groups	2				
	Within Groups	69	9.14	0.00	2.13	0.13
	Total	71				
Mg (mg/kg)	Between Groups	2				
	Within Groups	69	5.10	0.01	3.84	0.03
	Total	71				
S (mg/kg)	Between Groups	2				
	Within Groups	69	2.89	0.06	9.32	0.00
	Total	71				

Table 3 Pearson's correlation matrix for selected soil properties in secondary forest

	Porosity	pH	OM	TN	P	K	Ca	Mg	S
Porosity	1								
pH	0.147	1							
OM	-0.057	-0.199	1						
TN	-0.128	-0.026	0.225	1					
P	0.072	-0.212	0.203	0.091	1				
K	-0.041	-0.131	0.175	-0.13	0.183	1			
Ca	-0.128	0.206	-0.207	0.044	-.244*	0.018	1		
Mg	-0.199	-0.101	0.201	0.028	-.322**	0.119	0.126	1	
S	-0.06	0.157	-0.02	-0.007	-0.031	0.082	0.15	-0.036	1

** Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).

Table 4 Pearson's correlation matrix for selected soil properties in rubber plantation

	Porosity	pH	OM	TN	P	K	Ca	Mg	S
Porosity	1								
pH	-0.103	1							
OM	0.058	-0.049	1						
TN	0.071	-0.038	.382**	1					
P	0.046	0.199	0.069	0.152	1				
K	-0.034	0.112	.393**	-0.061	-0.161	1			
Ca	0.125	0.036	.377**	-.318**	-0.088	.580**	1		
Mg	0.197	0.031	0.142	-.359**	-0.045	.552**	.796**	1	
S	-0.162	0.057	.252*	.234*	-0.037	.399**	.355**	0.21	1

** Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)

Availability of K in these soils was regulated by the content of OM decomposition as humus and soil pH (Yasin et al. 2010, Kavitha and Sujatha 2015). This is supported by a positive and significant correlation (r = 0.393**) with OM in secondary forest (Table 4). The lowest (187.12 kg/ha) and highest (206.87 kg/ha) contents of available K were observed in steep and moderate slopes in secondary forest soil. Likewise, lowest (140.43 kg/ha) and highest (222.8 kg/ha) available K were observed in steep and gentle slopes in rubber plantation soil. Available K contents under the soils of studied land uses were rated medium (108−280 kg/ha).

Calcium (Ca), magnesium (Mg), and sulphur (S) are essential plant nutrient called "secondary" macronutrients because they are moderately required by plants but are just as important as N, P, and K. In soil, Ca and S are required by the rhizobia bacteria in legumes for nitrogen fixation and convert it into a form that plants can use. S is an essential building block in chlorophyll development and protein synthesis as well. Furthermore, Mg serves as an activator for many enzymes required in plant growth processes, photosynthesis and stabilizes the nucleic acids. Among the studied soil, Ca and Mg in secondary forest were significantly ($p<0.05$) affected by slope gradient except for S (Table 2). Both Ca (r = -0.244*) and Mg (r = -0.322**) showed negative and significant correlation with P content (Table 3). On other hand, Mg and S in rubber plantation soil varied significantly ($p<0.05$) along the slope gradients, while Ca did not vary. Table 4 showed negative and significant relation between Mg with TN (r = -0.359**) whereas positive relation with K (0.552**) and shared high, positive relation with Ca (r = 0.796**). Furthermore, S had positive and significant correlation with OM (r = 0.252*), TN (r = 0.234*), K (0.399**) and Ca (0.355**). Ca in secondary forest soils also shared positive and significant association with OM (r = 0.377**) and K (0.580**) whereas negative and significant relation with TN (r = -0.318**) (Table 4). Ca content in secondary forest soil was recorded to be lowest (87.45 mg/kg) in gentle slope and highest (130.15 mg/kg) in steep slope (Table 1). Correspondingly, the lowest (108.97, 2.32 mg/kg) and highest (148.8, 2.68 mg/kg) values of Mg and S was observed in gentle and moderate slopes of secondary forest soil whereas Ca, Mg and S content in rubber soil was found to be lowest (93.3, 57.94 and 2.63 mg/kg) in steep slope and highest (125.48, 92.14 and 3.23 mg/kg) in gentle slope. Secondary nutrients (Ca, Mg and S) contents under the soils of studied land uses were rated medium (Brajendra et al. 2014, Kavitha and Sujatha 2015).

NUTRIENT INDEX

The nutrient index (NI) values of selected soil nutrients viz N, P and K were calculated using following equation (Ramamoorthy and Bajaj 1969).

$$\text{Nutrient Index (NI)} = (NL*1 + NM*2 + NH*3)/ NT$$

where, NL, NM and NH are number of samples falling in low, medium and high classes of nutrient status respectively and NT is the total number of samples analyzed for a given area.

Table 5 Soil nutrient index with range and remarks

Nutrient Index (NI)	Range of soil nutrients	Fertility Level
I	Below 1.67	Low
II	1.67-2.33	Medium
III	Above 2.33	High

Table 6 Soil fertility status of the studied land uses with respect to soil nutrient index

Soil Nutrients	Secondary Forest Soil			Rubber Soil		
	NI values	NI	Fertility Status	NI values	NI	Fertility Status
N (%)	3	III	High	2.26	II	Medium
P (kg/ha)	2.12	II	Medium	2.08	II	Medium
K (kg/ha)	1.99	II	Medium	2.03	II	Medium
Ca (mg/kg)	2.04	II	Medium	2.03	II	Medium
Mg (mg/kg)	2.07	II	Medium	1.49	I	Low
S (mg/kg)	1.89	II	Medium	1.92	II	Medium

These nutrient index values were then characterized as Nutrient Index category I, II and III. Nutrient index analysis for the study area revealed that

N attains a high status in secondary forest and medium in rubber plantation (Table 5, 6). In line with this finding, high nitrogen fertility status (NI= 2.72) was reported in Mizoram (Motsar 2002). Correspondingly, available P, K Ca, and S were found to have medium value in both land uses. In the other hand, Mg acquired a medium value in secondary forest and low in rubber plantation respectively. Therefore, higher availability of soil nutrients and fertility status were found in secondary forest soils which could be due to abundance of leaf litter that covers the ground floor and hold plant nutrients for a long period in the standing biomass leading to extended period of nutrient cycling. Soil fertility thus depends on the soil OM furnished by the natural vegetation and the nutrient cycling (Chase and Singh 2014). Comparatively lower fertility status was recorded in rubber plantation than secondary forest which may be due to biomass burning practices during replanting which lead to leaching loss that caused higher soil acidity conditions, no addition of organic mineral fertilizers and continuous cultivation.

CONCLUSION

We can conclude that land-use change can result in changes in the availability of soil nutrients. When compared to secondary forest which is in its natural state, the result from the study revealed that forest had lower soil bulk densities, higher organic matter (OM) and macronutrients (N, P, K, Ca and Mg) contents than rubber plantation except for sulphur. Therefore, soils in rubber plantation showed statistically significant decreases in the amount of nutrients responsible for soil fertility. According to the fertility test based of the calculated nutrient indices of N, P, K, Ca, Mg and S, the secondary forest showed fertility status from high to medium category and medium-low-medium category in rubber plantation. Here, soils of secondary forest attained a high TN value and rubber a lower Mg values. The soil pH was strongly acidic in both land uses. Analysis of variance showed significant ($p<0.05$) effect of slope gradient on soil porosity, OM, TN, P, K and Mg in both land uses except for pH. Whereas, K and S contents in secondary forest, BD and Ca contents in rubber plantation do not vary along the slope gradient. However, in general the decline in quality of soil properties was observed from steep to gentle slopes which could be due to leaching, erosion or run-off that removed soil organic matter and other plant nutrients. Therefore, there is a need to restore and sustain the nutrient balance along the different slope gradients. Proper management of rubber plantation could minimize the land deterioration and maintained soil under good conditions. This also suggests balanced intercropping, increased use of organic nutrient like Farm Yard Manure (FYM) and green manures at regular intervals, mulching around the base of the rubber trees, contour terracing or construction of silt pits in areas where slope gradient is higher than 10 % (Orimoloye et al. 2010) and adoption of appropriate agronomic practices etc. would help minimize soil exposure to erosion and nutrient leaching.

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NUTRIENTS AND FERTILITY STATUS OF SOIL UNDER RUBBER AND ARECANUT PLANTATIONS IN KOLASIB DISTRICT, MIZORAM

Abstract of the Thesis

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Abstract:

Plantation tree crops are high-value crops of great economic importance and have gained widespread acceptance in tropical countries. They are now cultivated on a diversified range of soils and landforms, with increasing proportion of marginal soils. It is among the oldest organized industries in India and continue to expand rapidly replacing secondary forests and land under shifting cultivation. Shifting or *jhum* cultivation has been the way of life and integral part of the cultural ethos of the people in the north-eastern hilly region of India since time immemorial. However, with changing requirements of high population pressure on land, *jhum* cultivation becomes very devastating in nature causing a drastic decline in crop yield, loss of forest wealth, soil fertility, biodiversity and environmental degradation. Due to shortening of *jhum* cycle and continuous cropping, quite often, the secondary forests also do not get adequate time to regenerate. Over the past decades, traditional forms of land use in many of these areas have evolved into more intensive agricultural systems.

The arecanut, *Areca catechu* (L.) also commonly known as ‘betel nut’ or ‘supari’, is the seed of *A. catechu* palm tree. It is one of the most popular plantation crops because of its extensive use by masses for mastication as well as value-added products. It belongs to Arecaceae family and thrives well in regions of 28° N and 28° S of the equator of the tropical Pacific, Asia, and parts of east Africa. India is the largest producer and consumer of arecanut in the world. According to Horticultural Statistics Division (2017). It is grown in an area about 4,74,000 ha with a production of 714,000 tons contributing to about 54.1% in global production. Karnataka and Kerala together account for 70% of both area and production in the country.

The rubber tree, *Hevea brasiliensis* (Willd ex. A. Juss.) Mull. Arg. is a native tree species in the Amazon basin of South America, located within 5º Latitude of the equator and dominated with the wet equatorial type of climate. It belongs to the Euphorbiaceae family and considered the most economically important member of the genus *Hevea*. It remains the only cultivated species as commercial source of natural rubber (latex) and has many uses due to being highly waterproof, resilient, tough, stretchy, low heat buildup property and convenience in harvesting. India is currently the 6^{th} largest rubber producer, with 5% of world production. It continues to be the 2^{nd} largest consumer of natural rubber, with 8.2% of world consumption (Narasimhan, 2017). The growing demand of natural rubber, coupled with the limited scope of area expansion in traditional region has necessitated an increase in production from the non-traditional region of North-East India.

Arecanut and Rubber plantations are an affordable alternative for shifting cultivation and have been cultivated as a cash crop in the district of Kolasib District of Mizoram for quite a long time. It is situated in the northern most regions of the state surrounded by Aizawl district in the south and east and Mamit district in the west and Assam state in the north. The geographical area of the district is 1,38,251 ha which 6.56% of the state area is. It is situated in between 23°-5′ to 24°-35′ N Latitude and 92°-3′ to 93° E Longitude. The climatic condition of the state with well-distributed rainfall and location in tropics and temperate zone with various soil types had widely contributed to the occurrence of a wide spectrum of rich and varied flora and flora. Thus, these natural features and resources have offer opportunities for growing a variety of plantation tree crops. However, adoptions of such economically high valued tree crop plantations to these areas where agriculture is the mainstay for about 60% of the population and characterized by high dependence on rainfall has come as an opportunity for the farmers to embrace the mainstream and settled agricultural system that contributes a significant proportion of earnings. But the concerns about the long-term viability of these plantations in such non-traditional areas often arise. Changes in the land use cause significant modifications in soil properties in which agriculture has a major contribution and especially on the amount and distribution of nutrients, which may rapidly diminish in soil quality. Successful agriculture requires the sustainable use of soil resources because the soil is the most vital source of infinite life and not renewable over a short period of time. Hence, evaluation of fertility status of soils is needed in relation to these land uses to ensure longer-term sustainability, crop production or maintain soil quality under the study area.

A reconnaissance survey was carried out during 2015-2017 in the selected sites for sampling which includes: 24 years old Arecanut Plantation, 22 years old Rubber Plantation and 25 years old Secondary Forest. The plantation sites are a monoculture land, while the secondary forest is characterized by dense vegetation (bamboo/shrubs) with numerous undergrowth. The Arecanut Plantation site is located at 21̥̊ 19"08.3" N and 92̊ 42'47.7" E in Bilkhawthir village which is along National Highway 54. The Rubber Plantation site is located at 24̊ 14'45.7" N and 92̊ 39'51. 3" E which is 10 km away from

Arecanut Plantation site along the Bairabi Village and the Secondary Forest is located at 24˚11’54.6” N and 92˚35’58.3” E in Pangbalkawn village. Soil samples from were collected from two subsequent depths (i.e. 0- 20 cm and 20-40 cm) along the three slope positions, gentle (0-15%), moderate (15-30%), and steep (< 30%) slope gradients. The sieved soil samples were stored in polythene bags with proper labeling for subsequent analysis.

From the study, it was possible to conclude that soil physicochemical properties significantly vary among the studied land-use systems. The particle size composition of soil in the arecanut and rubber plantations were categorized under sandy loam textural class while the secondary forest was dominated by sandy clay loam texture. The strongly acidic nature of the studied soils could result from the high rainfall which is adequate to remove basic cations out of the surface horizons of the soils. In addition, the higher values of soil porosity, moisture content, soil organic carbon, and organic matter contents, total nitrogen, available phosphorus, and available potassium were obtained under the soil of secondary forest as compared to arecanut and rubber plantations soil at both depths. However, the higher availability of soil nutrients and fertility status in secondary forest soils could be due to an abundance of leaf litter that covers the ground floor and hold plant nutrients for a long period in the standing biomass leading to an extended period of nutrient cycling. Comparatively, the lower availability of soil nutrients in arecanut and rubber plantations may be due to changes in soil moisture and temperature regimes, and continuous cultivation resulting in the loss of biomass, and anthropogenic influence that eventually increase bulk density. Therefore, the shift in land use systems from secondary forest to other plantation systems show a detrimental effect on soil physical and chemical properties.

Soil fertility problems in the area under study relate to poor cultivation practices and landslides which are common features during the monsoon seasons. Slope steepness is the dominant factor where the soil eroding agents remove the finer soil particles including soil organic matter and plant nutrients. They face greater degradation consequences compared to soils in ground areas as they generally have limited nutrient and water storage capacities which affect the soil properties and crop productivity. Thus, the proper soil fertility management that focuses on enhancing the organic matter and nitrogen levels, and reducing the effects of high slope gradient in the study area are required for improving crop production on a sustainable basis.