CROP PRODUCTION AND SOIL PROPERTIES IN GINGER-BASED AGROFORESTRY SYSTEM IN MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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MZU REGN NO: 5758 of 2012

Ph.D REGN NO: MZU/Ph.D./774 of 19.05.2015

DEPARTMENT OF FORESTRY

SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCES MANAGEMENT

JUNE 2022

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Submitted

In partial fulfillment of the requirement of the Degree of

Doctor of Philosophy in Forestry of Mizoram University, Aizawl.

DEPARTMENT OF FORESTRY
MIZORAM UNIVERSITY
AIZAWL: MIZORAM
(A Central University Established by an Act of Parliament)
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Supervisor's Certificate

This is to certify that a Ph. D thesis entitled, **"Crop production and soil properties in ginger-based agroforestry system in Mizoram"** submitted by Ms. Lalhriatrengi Fanai, Research Scholar in the Department of Forestry, Mizoram University, Aizawl, embodied the record of original investigation under my supervision. The content of the thesis has not been submitted to for the award of any degree in this or any other University or Institute.

She is allowed to submit the Thesis for examination for the award of the Degree of Doctor of Philosophy in Forestry.

DECLARATION

I, **Ms. Lalhriatrengi Fanai**, 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 do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Forestry.

(Lalhriatrengi Fanai)

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ACKNOWLEDGEMENTS

My most sincere gratitude and deepest appreciation go to my supervisor Prof. Lalnundanga for his professional and endless support and patience for the completion of my study. This thesis was formulated with his precious suggestion, guidance, his constant support and encouragement.

I would also like to express my appreciation to Prof. Kalidas Upadhyaya, Head of Department and all the professors and staffs who are working in the Department for their encouragement, their valuable teaching and kind help in completing my research work.

My heartfelt thanks goes to my fellow research scholars and friends for offering me all possible help in all aspects of laboratory work.

I am highly indebted to my family for giving me constant encouragement, cooperation and helped me during the whole time of my study.

Lastly, I would like to thank the Almighty God for his unconditional blessings, guiding me and giving me good health in completion of my thesis.

(LALHRIATRENGI FANAI)

TABLE OF CONTENTS

Contents	**Page Number**
Inner Cover Page	i
Supervisor's Certificate	ii
Declaration	iii
Acknowledgements	iv
Table of Contents	v-vii
List of tables	viii-ix
List of figures	x
List of Notations and Abbreviations	xi

CHAPTER 1: INTRODUCTION **1-15**

1.1. Soil health and land use change in North East India 1-2
1.2. Impact of land use change in Mizoram 3-4
1.3. Agroforestry: an overview 5-8
1.4. Ginger 8-10
1.5. Rubber 10-14
1.6. Rationale of the study 14-15
1.7. Objectives 15

CHAPTER 2: REVIEW OF LITERATURE **16-30**

2.1. Scope and Potential of Agroforestry 16-17
2.2. Interaction of tree crop in agroforestry system 17-18
2.3. Effect of agroforestry system on soil health 18-20
2.4. Socio-economic benefits of agroforestry system 20-22
2.5. Intercropping of ginger and rubber with horticultural and/or tree species 22-27
2.6. Effect of intercropping on soil fertility 27-30

CHAPTER 3: MATERIALS AND METHOD **31-37**

3.1. General description of the study area 31-32

3.2. Description of the study sites 32-33

3.3. Experimental design and soil sampling 34-35

3.4. Laboratory analysis of soil properties 35-38

    3.4.1. Soil physical properties 35

    3.4.2. Analysis of soil chemical properties 36

    3.4.3. Estimation of soil microbial biomass carbon (MBC) 36

    3.4.4. Soil microbial population count 37

3.5. Ginger production analysis 38

    3.5.1. Growth Parameters 38

    3.5.2. Yield Parameters 38

3.6. Statistical analysis 38

CHAPTER 4: RESULTS **39-58**

4.1. Changes in soil physico-chemical properties across different treatments and sampling season 38-47

    4.1.1. Soil physical properties 38-39

    4.1.2. Soil chemical properties 40-43

    4.1.3. Soil biochemical properties 44-47

4.2. Changes in soil microbial population across different treatments and sampling season 48-50

4.3. Correlation between soil physical, biochemical and microbial population 50-54

4.4. Growth and yield parameters of ginger 55-58

4.4.1. Growth attributes of ginger 55-56

4.4.2. Yield attributes of ginger 56-58

CHAPTER 5: DISCUSSION **59-71**

5.1. Effect of different treatment and sampling season on soil physico-chemical properties 59-65

5.2. Effect of different treatment and sampling season on soil biochemical properties 65-67

5.3. Changes in soil microbial population across different treatment and sampling season 67-69

5.4. Growth and yield attributes of ginger 69-71

CHAPTER 6: SUMMARY AND CONCLUSION **72-77**

References 78-104

Photo plates 105-106

List of Tables

Table 4.1 Effect of different treatment (Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) on soil physical properties (0-30% slope).

Table 4.2 Effect of different treatment (Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) on soil physical properties (30% above slope).

Table 4.3 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil chemical properties (0-30% slope)

Table 4.4 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil chemical properties (30% above slope)

Table 4.5 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post- Harvest-PHV) on soil biological properties (0-30% slope).

Table 4.6 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil biological properties (30% above slope)

Table 4.7 Correlation coefficients (R) between pH, moisture content (MC), Soil Organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P_{avail}), Exchangeable Potassium (K_{exch}), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during pre-cultivation stage (PC).

Table 4.8 Correlation coefficients (R) between pH, moisture content (MC), Soil Organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P_{avail}), Exchangeable Potassium (K_{exch}), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during flowering stage (FS).

Table 4.9 Correlation coefficients (R) between pH, moisture content (MC), Soil Organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P_{avail}), Exchangeable Potassium (K_{exch}), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during post-harvest (PHV).

Table 5.0 Growth attributes of ginger (plant height and number of tillers) between as intercrop in rubber plantation and as sole crop at different stage of growth.

Table 5.1 Yield attributes of ginger between as intercrop in rubber plantation and as sole crop at different stage of growth.

List of Figures

Figure 3.1 Map of study sites

Figure 3.2 Experimental Block Design: Randomized Complete Block Design

Figure 4.1 Effect of different treatments ((Rubber+Ginger-RG, Sole Ginger-SG, and Control-CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post Harvest-PHV) on soil fungi population.

Figure 4.2 Effect of different treatments ((Rubber+Ginger-RG, Sole Ginger-SG, and Control-CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post Harvest-PHV) on soil bacterial population.

Figure 4.3 Effect of different treatments ((Rubber+Ginger-RG, Sole Ginger-SG, and Control-CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post Harvest-PHV) on soil actinomycetes population.

Figure 4.4 Tiller frequency of ginger between sole ginger and rubber+ginger at different stage of growth.

LIST OF NOTATIONS AND ABBREVIATIONS

NOTATIONS		ABBREVIATIONS	
%	Percent	ANOVA	Analysis of variance
cm2	Centimetre square	BD	Bulk density
e.g.	Exempli gratia	CFU’s	Colony forming units
et al	Et alia	CTRL	Control
etc	Et cetera	FS	Flowering Stage
ha	Hectare	K	Potassium
$p<0.01$	Significant level at 1 percent	LSD	Least significant difference
$p<0.05$	Significant level at 5 percent	MBC/ C_{mic}	Microbial biomass carbon
ºC	Degree Celsius	NH_4 – N	Ammonium nitrogen
Mha	Million hectares	NH_4	Ammonia
g	Gram	NO_3 – N	Nitrate nitrogen
mg	Milligram	NO_3	Nitrate
m^2	Metre square	P_{avail}	Phosphorus
kg	Kilogram	PC	Pre-Cultivation
km^2	Square kilometere	PHV	Post Harvest
$mgkg^{-1}$	Milligram per kilogram	RG	Rubber+Ginger plantation
R	Correlation coefficient	SE	Standard error
cm	Centimetre	SG	Sole Ginger
mm	Millimetre	SMC	Soil moisture content
m	metre	SOC	Soil organic carbon
$g\ cm^{-3}$	Gram per centimetre cube	SOM	Soil organic matter
t/ha	tonne per hectare	TN	Total Nitrogen
$\mu g\ g^{-1}$	Microgram per gram	TOC	Total organic carbon
$cmol\ kg^{-1}$	Centi mole per kilogram	WAP	Weeks after planting

CHAPTER 1

INTRODUCTION

1.1. Soil health and land use change in North East India

India's north-eastern area, one of the world's biodiversity hotspots, has some of the most diversified flora and wildlife in the entire nation. A total of 2,61000 km^2 in size, the North Eastern area of India has a variety of physiographic features and biodiversity, all of which are well-supported by favourable meteorological conditions. One particular location in India stands out due to its greater rainfall, which supports more vegetation both above and below ground (Chatterjee *et al*., 2006). These distinct characteristics of the region enhance lush vegetation growth. Over the last three decades, the forest cover has changed significantly as a result of people relocating to different locations, increased forest clearing, wide and varied farming practices, population growth, and increased economic behaviour.

Land use change in India's north-eastern region differs and exhibits a distinct trend when compared to the rest of the country's regions. The majority of the region is characterised by steep slopes and undulating terrain, with the exception of Assam, where the plain area accounts for approximately 84.4% of its geographical area, while the remaining states account for approximately 35% in terms of plain area and the remaining undulating terrains. The region's open and dense forest covers ranges from 40.27% in Assam to 72.99% in Arunachal Pradesh, occupying approximately 15.7% of its geographical area (NRCS, 2011). While shifting cultivation (Jhum) comprises about 2.88% (0.754 Mha), grasslands account for about 6.06% of the geographical area, wastelands represent roughly 6.22%, and water bodies represent roughly 4.53% of the total land area (Choudhury *et al*., 2014).

As a result of extensive deforestation, there has recently been a rapid change in land use in the North Eastern region. Massive conversion of forest areas into short-term agricultural practise has occurred, owing largely to shifting cultivation

(Jhum) combined with conversion of native forests and grasslands into horticulture and plantation areas (Choudhury *et al*., 2013), resulting in massive loss of vegetation in the region and increased loss of soil fertility. The burning of accumulated phytomass at 8.5 million tonnes per year during shifting cultivation (Das *et al*., 2011) and extensive cultivation on steep slopes under heavy and inconsistent rainfall conditions has increased soil erosion greater than 88 Mg ha-1 year-1, with an estimated annual loss of 6.0 million tonnes of organic carbon in soils and other nutrient content (Ghosh *et al*., 2009).

Out of the region's 4.0 Mha net sown areas, approximately 1.3 Mha of land is vulnerable to severe soil erosion. Deforestation caused by shifting cultivation is still the primary cause of forest cover loss in the region, and the resulting imbalance in the ecological process degrades the environments and the soil's buffering capacity in particular. As most agricultural practices in the region are rainfed, there is sporadic drought and water scarcity during the peak of crop growing season, which is another issue affecting crop productivity and sustainability. The North Eastern region's ecosystems are extremely vulnerable, and also more than 70% of the population is still highly dependent on basic survival, marginal, relatively low agriculture, low yield, and irrigated and non - irrigated agricultural practises. Furthermore, the vast majority of farmers have marginal land holdings, with approximately 40% living in poverty (Barah, 2007). All of these challenges, combined with the region's low socioeconomic status, increasing population, and traditional agricultural and cultivation practises, have resulted in a trend of land use change that is distinct from the rest of the country. In recent years, the rural population has been subjected to a number of challenges, putting sustainable agricultural yield and livelihood at risk. Land use change has a massive impact on soil fertility and, as a result, on sustainable agricultural production practices. As the problem continues, accepting the negative impact of land use change patterns and their interactions between anthropogenic practices and the environment on crop productivity and soil fertility are the most important challenges that must be addressed now in order to achieve sustainability goals through land management.

1.2. Impact of land use change in Mizoram

Mizoram is a hilly region with a geographical area of 21, 087 km 2 and 85% forest cover, ranking second in the country in terms of forest cover per geographical area (Forest Survey Report, 2017). It is a bio diverse region where, in addition to shifting agriculture, land use change is a common occurrence (Tripathi *et al*., 2016; Grogan *et al*., 2012). Land use change, particularly shifting cultivation and plantations, has a significant impact on Mizoram's tropical and subtropical forests, affecting soil fertility and crop productivity.

The majority of Mizoram's rural population still relies on agriculture and allied industries, animal husbandry, and other small scale or cottage industries for basic survival and economic benefits. Agriculture and the allied sector are the most important activities on which rural people depend heavily, and they form the rural livelihoods (Grogan *et al*., 2012). Shifting cultivation (Jhum) is the most common type of cultivation in the state, and given the state's harsh topography, it may be the only viable option. Shifting cultivation, or Jhum, covers approximately 1.5% of the total area in Mizoram each year (Maithani, 2005b). Shifting cultivation has been practised since time immemorial and is regarded as the dominant land use system, accounting for 19 to 45% of forest area.

The disadvantage of shifting cultivation is that once the cultivation process is completed and the yield is harvested, the land area is left barren. Under such steep topography, with such a high incidence of erratic rainfall each year, soil health deterioration is accelerated, lengthening the process of soil reclamation and recovery, but this fundamental problem is rarely considered. Furthermore, the productivity of the land during the succeeding cultivation is reduced on this specific patch of land (Tripathi *et al*., 2017), resulting in low output per unit area. This form of land use system is not only destructive but also unproductive and necessitates a lot of labour. As a result, the state has suffered significant losses in soil fertility, natural forest, wildlife, and wildlife, as well as the depletion of underground water that causes rivers and springs to dry up. A policy known as the New Land Use Policy (NLUP), which was implemented in bits and pieces from 1985 to 1992, was developed by the Government of Mizoram to address this problem and uplift the farmers of the state, who make up around 70% of the entire population. Due to the fact that this was a novel idea that had never been tried before in the state in its history, this policy experienced some problems, with the implementation being called off on multiple times. However, motivated by the struggles that the state's citizens experienced, the strategy evolved into a more significant attempt from 1993 to 1998, when it was implemented on a much larger scale than it had been during the previous tenure and involved roughly 35000 households over a two-year period (Zothansanga and Bobby, 2019). Later in 2011, the policy was brought back into effect and demonstrated more effective and promising plans and framework compared to earlier periods, taking the Government of India's recommendations into consideration. Following the adoption of the NLUP, shifting farming has undergone significant modifications in the state of Mizoram. In the years 2010 to 2011, there were 68433 families and 28,562 acres of shifting agriculture lands. However, from 2015 to 2016, the area and the number of jhum-practicing households fell to 19,851 hectares and 48,417, respectively, representing increases of around 30.50% and 29.25%. (Zothansanga and Bobby, 2019).

Monoculture rubber and oil palm plantations have spread throughout the region (Economic survey report, Mizoram 2016-2017) in order to sustain the state's productivity and economic growth. The state's forest area has grown significantly as a result of increased regeneration of bamboo species and plantations, according to the Forest Survey Report, (2017). Furthermore, due to the region's land capability, suitability, and sloppy terrain, a large portion of natural forest has been converted to Oil Palm and Rubber plantations. Forest cover has recently declined as a result of increased settled agriculture systems and a decrease in jhum cultivation area. This is most likely due to the implementation of a new land use policy (NLUP) by the Mizoram government.

1.3. Agroforestry : an overview

Forests are nature’s most bountiful and versatile renewable resources, providing simultaneously an oversized range of economic, social, environmental and cultural benefits and services. Even as the global woodland useful resource shrinks due to overharvesting, deforestation, and perpetual conversion to various types of land use in many tropical regions, or attribute to woodland decline associated with airborne pollution in temperate climate zones, the global demand for their various features and outputs grows with the growing population.

Forest does not solely support life system, however conjointly generate it. Tropical rain forests produce wood for industrial and fuel purposes, as well as non-timber forest products (such as drugs, ornamental plants, wildlife, raw materials, rattan, bamboo, and so on), as well as shielding soil, retaining moisture, and providing environmental services and benefits such as hydrologic water cycle balance, soil erosion prevention, and carbon sequestration.

To avoid deeper pressure on tropical forests, various aspects of sustainable management may be applied as a solution. As a technology, complex agroforestry is regarded as a long-term land management approach that boosts output and ecological stability while also promoting long-term development. Both local farmers and government can benefit from this approach in the short, medium, and long term. This system provides cash income to the farmers and a diverse range of products. Agroforestry provides environmental benefits such as soil and water conservation, improved microclimate, carbon sequestration, and a high degree of spontaneous regeneration, which allows for the preservation of a percentage of the original forest biodiversity.

As per FSI latest assessment (2021), forest cover of the country is 80.9m ha, which is 24.62% of the geographical area of the country. Since the focus of the government is not just to conserve the forests quantitatively but to enrich it qualitatively, growing more trees in non-forest regions and adopting agroforestry practises on sections of agricultural lands and wastelands at the national level are urgently needed to motivate the Indian public to conserve forests and/or alleviate the pressure on forests for diverse demands.

There are various methods to define agroforestry (Nair, 1989). According to the ICRAF's current definition, woody perennials are collectively referred to as land-use systems and practises that intentionally coexist with crops and/or animals on the same land-management unit. The integration may take place in a temporal or spatial mixture. Agroforestry typically involves interactions between the woody and non-woody parts on both an ecological and financial level. This definition has been helpful in establishing agroforestry as a distinct field of agricultural research (Sanchez, 1995).

Agroforestry systems blend annual and perennial crops, allowing farmers to benefit while long-term income-generating crops grow. Improve productivity per unit area, time, and inputs as a result of more effective use of resources such as sunshine, soil water, and labour, in addition to reducing the chance of total crop failure. The main goal of agroforestry is to create a more sustainable system of land use that can increase farm output and the well-being of rural communities.

Agroforestry practices are classified into two types: those which are sequential, such as fallows, and those which are simultaneous, such as alley-cropping (Cooper *et al*., 1996). Nair (1993) identified 18 different agroforestry practises, each with an infinite number of variations. Currently, agroforestry is viewed as a collection of stand-alone technologies that, when combined, form a variety of land-use systems in which trees are integrated sequentially or simultaneously with crops and/or livestock. Practices are frequently applied in agroforestry research after diagnosis and design, participatory research, or characterization studies, as appropriate, depending on the social, economic, and environmental problems in a given area.

Agroforestry practices nonetheless offer many advantages like crop and livestock protection, soil and stream conservation and protection, diversification of agricultural revenues through the assembly of timber and non-timber forest products, promotion of biodiversity, landscape enhancement and carbon sequestration. Agroforestry, in brief, can provide a wide range of environmental goods and services that are consistent with the goal of integrated rural management.

Agroforestry systems have enormous potential for improving the productivity and sustainability of agricultural lands or land resources, which have never been put into service due to so many factors, can be better used by adopting different agroforestry practices like inclusion of ginger cultivation in it for high remuneration and useful combination, if properly managed could increase the production potential sufficiently. Hence, such systems need to be made popular among farmers for sustainable livelihood.

Because economic rewards are dependent on specific tree species, intercropping is critical (the performance of the intercrop is affected by root system, canopy, allelopathic effect of litter, etc of the tree crop). Technical considerations such as agro-climatic and edaphic environments also influence crop selection. Agroforestry systems with careful crop, tree, and grass blending meet the majority of mankind's and livestock's essential needs.

Water, nutrients, and sunshine are used more efficiently when two or more crops with various roots systems, different patterns of water and nutrient demands, and varied above-ground habits are planted together. Therefore the blended yields of vegetation grown as intercrops may be better than the yield of the same crop grown as natural stand.

The benefit of agroforestry is that it enhances tree cover by planting trees on private land, while also reducing pressure on scrub forests, allowing them to improve and eventually be promoted to forest with higher crown density.

Agroforestry is required not only to increase tree cover, as previously stated, but also to ensure that the State's continued agricultural activities are environmentally and economically viable. Farmers can benefit from agricultural activities combined with agroforestry in times of low rainfall or drought.

Initiatives like the Cauvery Calling Movement can help in this regard. Farmers are encouraged to adopt agroforestry through this project. Farmlands are in desperate need of trees since they are not only environmentally and economically advantageous to the farmer, but they help enrich the soil and boost crop yield quality.

Agroforestry trees should provide feed, fodder, fruits, lumber, fuelwood, medicines, resins, gums, and green manure, in addition to indirect benefits such as biological nitrogen fixation, soil erosion reduction, increased water percolation, improved microclimate, and so on.

1.4. Ginger

Ginger (*Zingiber officinale* Rosc) a member of Zingiberaceae family, is a perennial herbaceous monocotyledon, typically grown as an annual, and is known to human generations as a medicinal and spice crop. Ginger is one in all the foremost important cash crops in Mizoram, and is usually grown in Jhum land. It is crucial to Mizo farmers livelihood stability and income. Because Mizoram’s agro-climatic conditions are favourable for ginger cultivation, cultivars do not use manures, fertilisers or pesticides. Its cultivation as a harvest within the state is known to have started in late 1970s. Thingpui, Thingria and Thinglaidum are the three major varieties of ginger grown in Mizoram of which Thinglaidum is the most popular. However, this variety of ginger does not seem to have any implication in the price fetched and hence, most of the farmers are unaware of the quality of the variety they grow.

Ginger is used throughout the world for flavouring in beverages, liquors, ice cream, candies, baked goods, curry powder blends, sauces, and various condiments. Ginger is also used in traditional medicine to treat several ailments including nausea, dyspepsia, motion sickness, migraine and to reduce flatulence and colic. It is a spice or fresh condiment for cuisine. Pickles and confectionary are made with early harvested young rhizomes.

The fibrous roots of the ginger plant develop from the branched rhizomes. Closely grouped unbranched, pseudo stems or aerial shoots are produced from the rhizomes. The pseudo stems reach a height of 50-120cm. The leaves are alternating and about 25cm long, simple, lanceolate and smooth. The plants are small, speckled, yellowish and borne on a spike. They have a purple speckled lip. Since time immemorial, ginger has been grown in India as a fresh vegetable as well as a dried spice.

The planting season of ginger in Mizoram starts during the month of April-May that coincides with onset of monsoon. The first two weeks of April is the best time for planting ginger. The stored rhizome of ginger for planting should be sorted with large, shiny; disease-free, spots, marks, bud or eye injury should be selected for planting. The seed rhizome can be planted whole or broken into parts, with each cutting bearing 2-4 sprouts.

For cultivation, ginger demands a warm, humid region with heavy rainfall of 1500-3000 mm per year or enough of irrigation. However, it can be grown in a wider range of environments than most other spices. It may be grown up to 1500 metres above sea level. It grows well in sandy loam as well as clay loam soil with adequate humus content and good drainage.

Extensive cultivation methods like heavy spading, earthing up, crop cultivation along with slope, slash and burn caused soil loss from the hill slope for cultivation of different crops. The hilly people cultivate ginger, turmeric, aroid and jhum rice along the slope land of the hill. They usually harvest the rhizome from soil by spade. Thus, soils become loose and soil erosion occurs in hilly areas that causes appreciable depletion in organic matter content resulting nutrient exhaustion in soil. This accelerates soil erosion and causes flash floods.

Ginger can be grown as a sole crop under open or shades apart from as a component in mixed and undercropping systems. Ginger is intercropped with vegetables (cabbage, tomato, chillies, french bean and lady’s finger), pulses (pigeon pea, black gram and horse gram), cereals (maize, finger millet), oilseeds (castor, soybean, sunflower and niger) and other crops (sesbania, tobacco and pineapple). Intercropping with soybean (Quimbo *et al.*, 1977; AICRPS, 1992 a), lady’s finger (Chowdhury, 1988) and pineapple (Lee, 1972) was advantageous and it is stated that ginger was the most favoured crop component under agroforestry (Singh *et al.*, 1991).

Ginger is rotated with other crops in Kerala like tapioca, chillies, dry paddy in rainfed area and ground nut, vegetables maize in irrigated areas. In Karnataka, ginger is also cultivated mixed with ragi, red gram and castor. Ginger is also known as an inter-crop in coconut, arecanut, coffee, litchi and orange plantations.

In hilly areas especially H.P, ginger crop being shade loving crop, farmers are often growing tomato, chillies, maize, tobacco and amaranthus along with ginger. The ginger crop is not cultivated on the same piece of land for at least 2-3 years and rotated with other crops like paddy depending on the severity of diseases like rhizome rot, yellow ginger and pest maggots and nematodes, ginger is also cultivated as an inter-crop in apple, pear and citrus young orchards and young forest plantations. In North-Eastern states, ginger is grown under shifting cultivation system (Jaidka *et al*., 2018).

Ginger is one of the most suitable vegetables for intercropping in agroforestry systems in pre humid- sub humid and semi humid-semiarid regions from lowlands (%00mt) to medium elevation (500-1000mt) (Nair 1993). The crop requires short or long day length for its growth (Hackett and Carolane, 1982). Ginger is cultivated under irrigated and rainfed conditions. The crop needs regular irrigation in areas receiving less rainfall. The ginger crop is sensitive to water logging, frost and salinity and tolerant to wind and drought (Hackett and Carolane, 1982). A partially shaded field are ideal for ginger and is an excellent crop for intercropping. Partial shade also increases rhizome yield (Jayachandran *et al*., 1991). Ginger crop prefers light shade for good growth, however shade is not absolutely necessary (CSIR, 1976). Shading is helpful in reducing water loss and general cooling of water plant (Lawrence, 1984). Growing ginger completely exposed to sun resulted in higher yield (Aiyadurai, 1966) and oleoresin (KAU, 1992) than in shade.

1.5. Rubber

The rubber tree (*Hevea brasiliensis)* belonging to the Euphorbiaceae family is a native of the Amazon basin and introduced to tropical countries of Asia and Africa during the 19th century. It is a quick-growing, erect tree with a straight trunk and an open leafy crown. Typically the bark is greyish and rather smooth. Rubber tree grows on many types of soil, provided they are deep and well drained. A warm, humid equable climate and fairly distributed annual rainfall are necessary for the optimum growth. It requires deep and lateritic fertile soil with an acidic pH of 4.5 to 6.0 and highly deficient in available phosphorous. Tropical climate with annual rainfall of 2000 – 4500 mm is suited for cultivation. Minimum and maximum temperature should be ranged from 25 to 34°C with 80 % relative humidity is ideal for cultivation. Regions prone to heavy winds and high sandy soils should be avoided.

Rubber is extracted from the bark of the trunk. In the wild, the trees can reach a height of more than 40 metres and have a lifespan of more than 100 years. However, because of the restriction in growth caused by latex harvesting by tapping, farmed plants rarely reach a height of more than 25- 30 m. (Webster and Paardekooper, 1989). Moreover, the trees are usually replanted after about 30 years when yield falls to an uneconomic level. Young plants have a distinct growth pattern that alternates between fast elongation and consolidation. The tree has an annual leaf fall and is deciduous. Wintering is followed by refoliation and flowering. The leaves are grouped into levels. Each story produces a cluster of spirally arranged, trifoliate glabrous leaves. The petioles are lengthy, usually around 15 cm, and have extra floral nectaries in the leaflet insertion region. (Premakumari and Saraswathyamma, 2000). The trees have a strong tap root and large lateral roots, generating a root system that accounts for around 15% of the mature rubber tree's total dry weight.

During the initial six to seven years of rubber cultivation, or till the period of closing up of the rubber canopy, usually leguminous cover crops or certain inter crops such as pineapple or banana are planted. Generally in rubber fields, the weeds are regularly monitored and are not allowed to grow profusely. As the canopy of rubber closes, the weeds growth rate generally retards, however, most of the farmers regularly control them either by mechanical or chemical means. This sort of ‘clean-weeding’ is a common practice among most of the farmers in the state in the mature phase of rubber cultivation.

However, some of the rubber farmers in the state are of the opinion that the regular ‘clean-weeding’ practice is not required in the case of rubber plantations in the mature phase, since rubber is a forest species and a perennial crop. As the canopy of rubber closes, the weeds cannot grow to a higher level and its control is not required. When the weeds or all the under flora are allowed to remain in the field for long period, regular recycling of nutrients through litter fall can occur and do not pose a threat to the crop. Other advantages of such a practice are claimed to be the interception of rain drops through multi-layer canopy and wide spread root network of under flora can considerably reduce run off and erosion, instead it favours infiltration and increase the ground water level and soil moisture status. Above all, such a strategy can improve rubber plantation biodiversity. Based on these rationale, many of the rubber fields are kept un-weeded in the mature phase except for a minimal slashing in the platform region so that the tapping (crop harvesting) personnel can move around. Though, these advantages are claimed in these fields, no systematic or scientific investigations had been carried out, hence this study.

Weeding is a regular practice in any agriculture system, when the unwanted species interferes with the growth and yield of the crops cultivated. In the case of rubber cultivation, during the initial years, it is experienced that the weed growth affects the growth of the plants. However, in the later years, when the rubber plants turn out to be ‘trees’ closes their canopy, it is not certain whether the under-flora affects or benefits its growth or yield. Though, traditionally the under-flora in the mature rubber plantations is well controlled, which is not based on any clear indication of getting higher growth or yield, but obviously for conveniently carrying out the operations such as harvesting or fertilizer application. It is warranted in such a situation to study whether the practice of allowing the under-flora to grow, without controlling them in a mature rubber plantations affects soil quality and rubber yield. Laid out experiments for such purposes may take long time to produce the results, hence a case study is undertaken to investigate the effect of allowing or not allowing growth of under-flora in mature rubber plantations on soil properties and rubber yield.

The main source of commercial natural rubber is *Hevea brasiliensis*. Natural rubber is one of the most important biological macromolecules, formed in the milky cytoplasm (latex) of specialised cells called laticifers and used as an industrial raw material in the creation of thousands of goods. Despite the fact that natural rubber can be found in the latex of over 2,000 plant species, *Hevea brasiliensis* is the only cultivated species used as a commercial source of natural rubber due to its abundance, excellent quality, and ease of harvesting. Other species, besides *Hevea brasiliensis*, are not grown in India.

Rubber plantations hold around 500 trees in one hectare land and thus provide a thick green closed canopy on even on barren/fallow lands which would otherwise be without any vegetation cover, especially in Non-Traditional rubber growing tracts including the North-East. In other words, the afforestation effect due to rubber tree plantation enables effective drought proofing as the soil in a rubber planted area is not exposed to sunlight and rain drop impact, resulting check in evaporation & soil erosion and enhanced infiltration & water conservation. Being a deciduous tree, the mulching effect on land due to the leaf-litter fall of about 7 tons per ha per year is an added advantage.

Large-scale rubber plantations may be found along India's western coasts, with Kerala leading the way, followed by Agartala. During British colonial authority, commercial rubber plantations were established in the northeast. Rubber plantations have been established in a few north-eastern states since then, but not as substantially as in the southern part of India. As traditional rubber planting areas such as Kerala become saturated, northeast India is becoming a focus area for increasing commercial rubber output. Northeast India is predicted to be able to afford to plant rubber on 350,000 hectares of land.

Rubber plantations have been established in Mizoram since the 1960s. However, due to a lack of decent saplings, a lack of technical expertise, and a poor set of methods, the plantations were only planted in small spots by a few people. Previously, it was discovered that Mizoram has over 5,75,000 hectares of land suitable for rubber plantation, with the Soil and Water Conservation Department taking up initiatives on 50 hectares of land. Under the State Government's flagship programme of NLUP (New Land Use Policy), around 1,117 hectares of land were anticipated to be covered for rubber plantation in Phases I and II of NLUP. Since 2010, the state's Soil and Water Conservation agency has been establishing budwood and seedling nurseries at six different locations as part of the NLUP to increase rubber seedling self-sufficiency. A number of families who are starting a rubber plantation under the NLUP are likely to succeed because they have been given high-quality rubber seedlings - RRIM. (Lallianthanga *et al.*, 2014).

1.6. Rationale of the study

Ginger (*Zingiber officinale* Rosc.) is considered one of the most promising crops in Mizoram. It is known as medicinal and spice crop. Soil loss from the hill slope was induced by extensive farming methods such as severe spading, earthing up, crop cultivation along with slope, slash and burn. On the slopes of the hill, the hilly people grow ginger, turmeric, aroid, and jhum rice. They dig the rhizome out of the ground with a spade. As a result, soils become loose, and soil erosion occurs in steep places, resulting in a significant loss of organic matter and nutrient exhaustion in the soil. Soil erosion and flash floods are accelerated as a result. For decades, the Department of Agriculture has worked to encourage farmers to grow ginger. However, they gave up since ginger was believed to be one of the numerous causes of soil loss as ginger is commonly harvested from the ground with a spades, making the soil loose, causing soil erosion and nutrient depletion. Despite the fact that ginger contributes to soil erosion, there is no empirical proof of how much soil is lost along steep slopes. The state's climatic features, which include evenly distributed rainfall and a location in the tropics and temperate zone with a variety of soil types, have all contributed to a varied range of flora and animals. As a result of these natural features and resources, a range of plantation tree crops can be grown (Lalnunmawia and Lalzarliana, 2013). Rubber plantations are a cost-effective alternative to shifting agriculture, and have long been used as a cash crop in Mizoram's Kolasib District. Adoption of such economically valuable tree crop plantations in areas where agriculture is the mainstay for about 60% of the population and is characterised by a high reliance on rainfall has provided farmers with an opportunity to embrace the mainstream and settled agricultural system that contributes a significant portion of earnings. However, there are often questions regarding the plants' long-term survival in such out-of-the-way locations. As a result, the research will concentrate on obtaining scientific data on crop production, changes in soil physico-chemical, and biological properties at various slopes in Mizoram's ginger-based agroforestry system.

1.7. Objectives

The current study was established to meet the following key objectives, while keeping the above mentioned principles in mind.

1. To study the physico-chemical characteristics of soil in ginger based agroforestry system.
2. To study the biological characteristics of soil in ginger based agroforestry system.
3. To analyze ginger production at different systems.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Scope and Potential of Agroforestry

Agroforestry is defined by the National Agroforestry Policy (2014) as a combination of land use systems that include trees and shrubs on farmland and rural landscapes, with or without livestock, to improve productivity, profitability, diversity, and ecosystem sustainability. NAP goes on to say that it is a dynamic, ecologically oriented natural resource management system that diversifies and sustains output while also building social institutions through the integration of woody perennials on farms and in the agricultural landscape. India was the first country in the world to approve a National Agroforestry Policy (CSE, 2014) to promote the growth of agroforestry in the country. One of NAP's primary policy objectives is '... conserving the natural resources and forests; protecting the environment and providing environmental security and increasing the forest/tree cover...' (MoA, 2014).

It is difficult to generalise the impacts of an agroforestry system on soil fertility. Soil fertility improvement is dependent on the species and management strategy used. Agroforestry systems with the right characteristics have been shown to improve soil physical properties, retain soil organic matter, and increase nutrient cycling. One of the key services provided by trees in an agroforestry system is soil conservation (Misra, 2011).Agroforestry has a lot of promise in terms of productivity enhancement, soil fertility improvement, soil conservation, nutrient cycling, microclimate amelioration, carbon sequestration, bio drainage, bio-energy, bio-fuel, and so on, because of its broad scope and numerous benefits. On the other hand, agroforestry offers an excellent opportunity to integrate water and soil conservation (Dhyani *et al*., 2016).

Agroforestry helps to ensure that half of the C stock contained in the forest is available, and new studies show that the area under agroforestry in India will grow dramatically in the future (NRCAF, 2006). Many studies have indicated that the agroforestry system is a fantastic method of carbon sequestration, with the most efficient role being the storage of carbon biomass above ground (Mukherjee *et al*., 2015) as well as the storage of carbon biomass below ground (Nair *et al*., 2010).

According to studies, adopting an agroforestry system allows farmers to diversify their agricultural without using additional land, while also improving soil quality, reducing soil erosion, carbon emissions, improving microclimate, changing ecosystems, and improving gender parity (Rao, 2017).

2.2. Interaction of tree crop in agroforestry system

The interaction between tree and crop in an agroforestry system is influenced by the type of model, species selection, variety composition, and the nature of the family, which is influenced positively by mutualism, adversely by allelopathy, and neutrally by neutral competition. Crop interaction in trees is mainly the consequence of competition between multiple forms of a component, yet a single form of a variable can also affect the system (Nair, 1993).

The study of interaction in the agroforestry system is critical because positive interaction boosts production while negative interaction lowers productivity, allowing us to select the best model for increasing land productivity. Increased productivity, soil conservation, higher soil fertility, nutrient cycling, and reduced environmental pressure are all beneficial interactions in agroforestry. The main negative effect of interaction is competition for light, nutrients, space, and moisture, which gradually diminishes yield. The link and complementarily between positive and negative interactions are critical for ecological sustainability and tree crop combination success (Sarvanan *et al*., 2013).

Tree crop interaction experiments were conducted at NRCAF, Jhansi, in an 8-year-old neem plantation to calculate neem growth concept and output, as well as a below-canopy crop called black gram (*Phaseolus mungo*).Wood volume and fruit yield of neem trees yielded higher economic returns in this interaction, whereas crop yield under the tree cover declined. The potential returns from neem trees in terms of nitrogen, phosphorus, potassium, and calcium are 2.25, 32, and 131 kg per hectare, respectively (Pandey *et al*., 2012).

Food security, poverty reduction, environmental security, soil protection, and carbon sequestration are all key benefits of agroforestry. Old-style farming and its monitoring, such as the agroforestry system, provide chances to increase income by synchronising food, fodder, and firewood production and reducing the influence of climate change (Tiwari *et al*., 2017).

2.3. Effect of agroforestry system on soil health

Agroforestry has been proved to be an effective land management strategy for improving soil quality and conserving water resources (Murthy *et al*., 2013).

According to a study conducted at Central Research Institute for Dryland Agriculture in Hyderabad, India, physicochemical parameters such as soil pH and organic carbon were significantly affected by diverse land-use patterns (Sharma *et al*., 2019).

Gupta *et al*., (2013) conducted study at farms in Central Punjab, India, in a poplar (*Populus deltoids* Bartr.) based agroforestry plantation with wheat (*Triticum aestivum*) in the winters and green gram (*Vigna radiata*) in the summers. They found out that the average soil organic carbon increased from 0.36% in monocrop soils to 0.66% in agroforestry soils (2.9–4.8 Mg ha^{-1} higher), and this increased with tree age.

In rainfed agroforestry systems in Karnataka, studies of soil enrichment services through litter fall from Ficus trees (*Ficus benghalensis*) revealed that the Ficus litter could give roughly 20% of the required phosphorus, 77% of the requisite nitrogen, and 67% of the required potassium (Dhanya *et al*., 2013).

According to Young (1989) through the maintenance of organic matter and the actions of roots, agroforestry systems retain more favourable soil physical qualities than agricultural systems, such as soil structure, porosity, and water holding capacity.

Bhatt *et al.*, (2016) in their study found that soil organic carbon and nutrient (N, P, and K) concentrations were considerably higher in agroforestry plots compared to agriculture land.

Kaur *et al*., (2000) also found that in agroforestry systems, the rate of mineralization of soil microbial biomass carbon rose significantly. When compared to solitary cropping, agroforestry systems have a larger proportion of microbial carbon in the total soil organic pool, indicating higher nutrient availability to the plants. Potassium availability is also higher in agroforestry than in treeless farming systems due to improved nutrient recycling through biochemical processes, as stated by Hasan and Ashraful Alam (2006).

Singh *et al*., (2018) in their study observed that the soil organic carbon and available nitrogen was significantly higher under the agroforestry system as compared to the agriculture field. Higher SOC content was observed under agroforestry systems not only in surface but in all the soil depths as compared to the agricultures and uncultivated lands. Several researchers have reported that root biomass addition in an agroforestry system is generally higher than agriculture or agriculture fields (Sharma *et al*., 2009).

Also, trees generally have lignified cells in its plant parts such as litter, small branches, bark, roots etc. which may lead to the biochemical stabilization of organic carbon in the soil and hence leads to the improvement in SOC content of soil under agroforestry as concluded by Six *et al*., (2002). The findings of earlier researchers (Kaur *et al*., 2000) who also observed that the rate of mineralization of soil microbial biomass carbon increased significantly under agroforestry systems provided considerable support for Singh *et al*., (2018).

Similarly, Yadav *et al*., (2011) found that under agroforestry, soil microbial biomass carbon was higher, ranging from 262-320 µg g^{-1}; whereas under treeless control, soil microbial biomass C was lower (186 µg g^{-1}). The likely reason is that various organic inputs from trees in the form of litter fall, fine root biomass recycling, and pruning debris contributed significantly to the organic matter pool under agroforestry, improving the microbial population and carbon mineralization rate.

The effects of five multi-purpose tree species (MPTs) on soil in agroforestry farms in India's north-eastern Himalayan region were studied by Saha *et al*., (2010), who discovered that all soil hydro-physical properties were considerably enhanced. Short rotation woody crops that may remediate polluted soil and groundwater are used in agroforestry systems to help with phyto and dendro remediation, rehabilitation of degraded landscapes to improve soil qualities and limit weed invasion in the open field, and give the scenario to indigenous (Rockwood *et al*., 2014). Invasive leguminous trees (Acacia sp.) were used by farmers in the Palani Hills in southern India to improve fallows by preventing negative plant invasions into productive agroforestry systems (Tassin *et al*., 2012). Agroforestry systems typically produce more biomass, which is converted into litter with the help of various microorganisms, increasing soil organic carbon (Aldeen *et al*., 2013), rhizosphere effects conserve various types of nutrients while increasing land fertility (Saha *et al*., 2010), water absorption quality and quantity of the soil increase, and native people's income by agroforestry practises in the same unit of land (Anderson *et al*., 2015).

According to a study by Raj *et al*., (2014), agroforestry practises increase the quantity of microorganism in the soil, which improves the microbiological action of land, contributes to the recycling of agroforestry lands' fertility, improves the environmental condition of the field, and ensures the socio-economic sustainability of native region cultivators.

2.4. Socio-economic benefits of agroforestry system

A significant social benefit through agroforestry affects marginal and small landholdings of the farmers because of the limitation of the land and increase the productivity by the agroforestry system in the same piece of field. The enrolment of the women and children in the agroforestry system more benefitted because of the more care of the cultivation with the head of the family found in the Rajasthan, Uttar Pradesh, and Gujarat in India, where agroforestry was introduced found that more benefits to women conditions (Bose 2015).

The socioeconomic conditions of agroforestry farmers and non-agroforestry farmers comparison in Bangladesh reported that farmers adopting agroforestry are better off than those adopting non-agroforestry, both socially and economically (Chakraborty *et al*., 2015) and similarly reported in Eastern Uttar

Pradesh (Singh and Ramchandra, 2019). Similarly, a study in the Nilgiris Biosphere Reserve, Kerala find that those farmers are engaged with the cultivation of any kind of agroforestry system practices received significant returns as like food, security of livelihood, additional income, and reduced climatic pollution (Kumar, 2010).

The socio-economic benefits through agroforestry are very important in at last determined by farmers as a possible alternative practice to conventional 'modern' agricultural practices (Saha *et al*., 2010). Agroforestry systems are reserves of a variety of timber species which are not give earlier benefits, which means growth time is higher. After two decades, these timber species give better results in comparison to initial stages (Dagar *et al*., 2014).

A study gives results the combination of Psidium spp. and local agriculture crop adopted based agroforestry system total cost and benefits of the net returns find approximately three times more than similar agriculture sole crop system in the study area in India (Murthy *et al*., 2013). Agriculture compared with adoption of agroforestry system generally gives more quickly benefits because of the income generated directly with the agriculture sole crop system every year (Rodríguez *et al*., 2011). Still, more studies showed that after the rotation of tree species increased the profitability of different agroforestry system like silvopastoral (Benavides *et al*., 2013) and silvo-arable systems compared to agricultural monoculture systems.

Eucalyptus-based agroforestry system is more popular with the combination of the paddy, wheat and other higher rate of irrigation crops in the sporadic form in the boundary and bund plantation in the irrigated field. Eucalyptus hybrid is the most valuable spp. Because fast-growing, coppices well, capable of over-topping weeds, fire hardy, browse resistant and adapt a wide range of edapho-climatic conditions. Eucalyptus plantation can reduce pressure on natural forest, supply a good quantity of pulp and fire-wood, timber, maintain biodiversity and litter decomposition improves soil water holding capacity, porosity, texture, nutrient, and yield improvement. Eucalyptus boundaries based agroforestry plantations produce a short rotation harvestable tree crop within four to six years (Jhariya *et al*., 2016).

The socioeconomic status and livelihood support through predominant traditional agroforestry systems were agri-silviculture, agri-horticulture and agri-horti-silviculture in Garhwal Himalaya, India. The adult literacy rate was 43% in marginal, 54% in miniature, and 73% in medium-large landholding families, while the child education rate was 86, 98, and 100%, respectively. The livestock was kept by 37 to 56% of families, and each family had 2 to 4 mulch animals, and only 8 to 18% of families kept oxen. The average fuelwood consumption was 84.41 to 538.45 kg/day/village, which is supplemented by existing agroforestry up to 156.75 to 701.01 kg/ day/village considerable extent. The utilization of tree fodder in summer and winter was 305.02 to 1015.17 and 659.53 to 2015.52 kg/day/village, respectively, which is supplemented by traditional agroforestry trees. Agroforestry practice is reported to be supportive and sustainable practice in this area and plays a significant role in the different facets of the household for their sustenance (Bijalwan *et al*., 2011).

Small landholdings farmers take more benefits as well as improve our livelihood by the adoption of agroforestry systems and grows the same field like medicinal plants, fruit trees, nuts, fodder when non-availability of the grass, fuelwood, timber, additional diversified income (World Agroforestry Centre 2010).Agroforestry systems reported in the studied area increase their income, easy availability of firewood, timber on the farmland to farmers, conservation of natural forest, and socio-economic livelihood of rural population (World Agro-forestry Centre 2010).

2.5. Intercropping of Ginger and Rubber with horticultural and/or tree species

In India coconut+ginger system under rainfed conditions gave good returns as ginger performed well under shade where a few other crops could do as the yield of ginger was 11-27% higher than the open field. (Jayachandran *et al*., 1998)

Jain and Raut (2007) observed maximum incremental height of mango with intercrop paddy and the minimum with intercrop ginger. However, the paddy equivalent yield of ginger under shade was significantly higher compared to other intercrops viz., blackgram and pigeon pea.

Prajapati *et al*., (2007) studied the growth and productivity of Ginger (*Zingiber officinale)* under Kapok *(Ceiba pentandra)* based agrisilviculture system. The result revealed that the intercropping of Ginger under *Ceiba pentandra* gave higher yield and income under unpruned condition with FYM @ 30 t/ha as compared with 25% pruned and lowest as a sole crop.

Vanlalhluna and Sahoo (2010) examined the performance of three tree species viz., *Alnus nepalensis, Melia azedirach* and *Gmelina arborea* and their interactive effects on ginger and turmeric crop yield during establishment period. Maximum height, collar diameter and yield of ginger and turmeric were found under tree-crop association than pure crops after three years of period.

A field trial was conducted on medium black soil during 2003-2004 to study intercropping of ginger in tamarind plantation compared to sole cropping under irrigated condition. Significantly higher plant height and number of tillers per clump were recorded at harvest by ginger tamarind intercropping compared to sole cropping. Yield attributes of ginger, viz., number of primary rhizomes and length of primary rhizomes were higher in tamarind shade (5.80 and 5.35 cm, respectively) compared to sole cropping (3.13 and 4.33 cm, respectively).Significantly higher numbers of rhizomes were recorded under intercropping compared to sole cropping. Ginger grown as intercrop in tamarind plantation recorded higher yield (173.89 g/ plant) compared to sole crop in open area (117.17 g/plant) (Kumar *et al*., 2010).

Bari and Rahim (2010) studied growth and productivity of ginger under sissoo based Multistrata Agroforestry System (MAF).Results revealed that multistrata agroforestry systems with different tree spacing significantly influenced the rhizome yield of ginger. The rhizome yield was reduced at closer spacing of *Dalbergia sissoo* as compared to that of wider spacing. The highest yield (25.76 t/ha in 2005 and 25.47 t/ha in 2006) was recorded under wider spacing of sissoo+guava based MAF during both the years. The lowest yield (12.64 t/ha in 2005 and 11.15 t/ha in 2006) was recorded in narrower spacing of sisoo+lemon based MAF in both season, which was followed by the narrower spacing of sissoo+guava based MAF and sole cropping of ginger. The yield under wider spacing of sissoo+guava based MAF was increased by 39.24 per cent in 2005 and 52.15 per cent in 2006 over sole cropping of ginger. Among the treatments, it was found that the highest benefit-cost ratio of 3.73 was recorded from the wider spacing of sissoo+guava based MAF and the lowest benefit-cost ratio of 1.43 was observed in sole cropping of ginger.

Ghosh and Hore (2011) asserted that planting with 25-30g seed rhizome at 20x15cm spacing may be recommended for ginger as an intercrop in coconut plantation for maximizing the yield.

Lyocks *et al*., (2013) concluded that sole fresh ginger rhizome yield was comparable to that obtained when intercropped with maize at density of 24,074 plants per hectare (10.84 tha^{-1}). Therefore ginger intercropped with maize at 24,074 plants per hectare is recommended. This maize/ginger intercrop combination will enable farmers to obtain the benefits of the two crops in the intercrop without losing out.

Vardhan *et al*., (2018) reported that ginger under poplar accumulates a large bulk of its final weight during the later months prior to reaching maturity, early harvests result in lower yields. Shade grown ginger remained greener and therefore, physiologically active for a longer time, despite having relatively lower essential oil and oleoresin concentrations compared to monoculture of ginger in open field. The cost-benefit ratio was high and the system also gave indirect benefits in erosion control and maintenance of soil fertility.

Pandey *et al*., (2017) conducted a field experiments under support irrigated conditions at the Agronomy Farm (Block-E), ASPEE College of Horiculture and Forestry, Navsari Agricultural University, Navsari (Gujarat). They concluded that growing of ginger crop with Sapota + Jatropha or Jatropha only resulted in significant increase in the growth as well as yield as compared to growing ginger as a sole crop or under sole Sapota based agroforestry systems. Significantly maximum plant height, length of rhizome, width of rhizome and survival percent was observed under intercropping with Jatropha as compared to sole crops.

Significantly maximum fresh rhizome yield and total number of fingers per plant of ginger was registered under Sapota + Jatropha agroforestry systems.

Kumar *et al*., (2018) carried out a field experiment at farmers plot of ormo village of Peterwar block of Bokaro district under Krishi Kigyan Kendra Bokaro, Jharkhand in year 2013-2014 and 2014- 2015 to overcome the problem of low system productivity in vegetable based cropping system under irrigated condition. The experiment consisted of 4 treatments, where one with sole ginger as mono crop and in the remaining spinach, cauliflower and bitter guard were included as intercrops with the ginger. The experiment was laid out in the randomized block design with four replications. Sole crop of ginger recorded the highest performance for all the growth characters, yield attributes and yield. Whereas the gross yields, net return and B: C ratio comes into question, it showed T4- Ginger + Spinach (Mixed cropping) + Cauliflower+ Bitter Guard perform best. So, from the overall point of view it may be concluded that intercropping in all the cases proved beneficial compared to that of mono culture.

Hossain *et al*., (2019) in their study concluded that the growth and quality of ginger varied by the effect of different Agroforestry systems, ginger varieties and interaction between them. Ginger was grown better and gave maximum yield at the floor of mango woodlot. The rhizome growth was highest under litchi tree and dry weight of rhizome was highest under control condition. Moreover, deshi ginger with mango based agroforestry was an effective production system. Interestingly, the relationship between light intensity and fresh ginger rhizome yield was inversely proportional. It was meant that the fresh rhizome ginger yield was increased with the decreasing rate of light intensity. Ginger rhizome yield was highest under mango woodlot when light intensity was lower there than of control treatment. On the other hand, in open field, ginger rhizome yield was lowest when light intensity was highest there. Finally it might be ranked in the context of growth and quality performance that mango> litchi >Ghoraneem> open field (control).

Wangkiat *et al*., (1998) stated that ginger (*Zingiber officinale.* Rosc) grown under intercropping with rubber tree 18 years old where rubber plantation areas located near water resource. The intercropped plants received water by irrigation and sell their product as flower.

Some studies have shown an improved performance of rubber both in Sri Lanka (with banana: Rodrigo *et al*., 1997; with sugarcane: Rodrigo *et al*., 2000) and elsewhere (with banana and pineapple: Jessy *et al*., 1997; with banana and seasonal crops: Keli *et al*., 1997; with banana, pineapple and capsicum: Rosyid *et al*., 1997).

Intercropping with short-term crops provided a significant additional income during the long immature period of rubber growth when no latex in produced. Much evidence has demonstrated that the growth of young rubber is unaffected by the presence of an intercrop. Similarly, intercrop plants is little affected by the rubber on shading during the young growth stage before tapping (Rodrigo *et al*., 2005).

Gou *et al*., (2006) studied on economic analyses of rubber and tea plantation and rubber-tea intercropping in China. They found that rubber-tea intercropping generated higher land expectation value (economic return) than rubber and tea monoculture.

Sarkar *et al*., (2011) in their study observed that during the initial years of a rubber plantation when the interspaces receive plenty of sunlight, a variety of intercrops can be cultivated. Intercrops should be planted at least 1.5 m away from bases. In addition, in immature rubber plantation growers can cultivate various crops/fruits like banana, pineapple, tea, ginger, turmeric, agar etc. Those growers who are interested in intercropping basically produce banana and pineapple. However, since thorough digging of the soil is required for the cultivation of ginger and turmeric crops they may be grown only on level and near level lands. They may be grown for the initial two years.

Suthikarnanothai (2016) reported that rubber-coffee single row intercropping system within rubber 8-10 years old, sunlight reduced in the third year of intercropping and it effect on growth of coffee in comparison with coffee grown without rubber tree.

A study by Jongrungrot, V. (2021) reported that Gnetums under the shade of rubber trees grew well and produced good-tasting leaves. Pineapple and sala under rubber trees grew well and were good quality fruits. However, mangosteen and longgong under rubber trees were characterized taller shapes with less harvesting than the typical monoculture.

2.6. Effect of intercropping on soil fertility

Several researchers have studied the impact of land use changes on soil properties (Lalnunzira & Tripathi, 2018; Hauchhum & Tripathi, 2017; Singha & Tripathi, 2017; Wapongnungsang *et al*., 2017; Suma *et al*., 2011; Joshi, 2002). Studies have confirmed that land use changes in tropical areas cause considerable change in soil physico-chemical and biological properties (Shepherd *et al*., 2000; Lal, 1996).

Soil organic matter (SOM) is an important indicator for soil quality assessment and soil fertility evaluation in the tropical regions (Paniagua *et al*., 1999). GoI, (2009) found a significant decrease in SOC and TN due to conversion of natural forest to continuous cultivation land.

The amount of nutrients absorbed by ginger varies greatly depending on the soil type, weather, amount of nutrients in the soil, variety used, etc. A strong ginger crop can take up to 500 kg of potassium and 35–50 kg of phosphorus per hectare. In contrast to rhizome, which retain N, P and K until harvest, leaf and pseudo stem uptake increases to 180 days. Ginger rhizomes mostly exhausted nitrogen and potassium, were intermediate in the removal of phosphorus and magnesium, and were least effective in the removal of calcium. (Nagarajan and Pillai, 1979).

Guruprasad *et al*., (1997) reported that the nutrient content in ginger varies with the plant part whereas the nutrient removal varies with plant part as well as with variety.

Guo & Gifford, (2002) found a significant increase in soil carbon stocks with conversion of cropland to pasture, tree plantation and secondary forest. Losses in soil organic carbon due to conversion of natural forest to secondary vegetation is well recognized (Yan *et al*., 2012).

Nwaogu and Muogbu (2015) carried out a study and found out that relatively higher values of soil available P, total organic carbon and exchangeable Mg were recorded when the grain legumes were sole cropped than when intercropped with ginger. Among the ginger/grain legume intercrops evaluated, ginger/Mung-bean intercrop produced better results in terms of soil chemical improvement irrespective of the growth period of measurement. For all soil fertility parameters assessed, planting one row of ginger to two rows of grain legume crops yielded higher responses. Inclusion of grain legume crops into ginger system without any definite crop arrangement (i.e. control) resulted in lower soil exchangeable cations (K, Ca and Mg) response comparative to when an ordered spatial planting arrangement was followed. They further concluded that these grain legume crops when planted in mixture with ginger, resulted not only in increased nutrient status of the Guinea Savanna soil but also in enhanced ginger growth, rhizome yield and yield variables relative to when ginger was grown sole.

Zeng *et al*., (2020) observed that intercropping turmeric and ginger with *Pogostemoncablin (*patchouli) can improve soil microbial abundance, diversity, and community structure by boosting the number of dominant bacteria, and by improving soil bacterial metabolism and the activities of soil enzymes. They also modify the soil physical and chemical properties through changes in enzyme activity, soil pH, and soil exchangeable Ca.

Greater MWD in rubber-based agroforestry system compared to other agroforestry systems was reported by Chen *et al*., (2017). They further report increased in the proportion of >5 mm and 2-5 mm fractions and reduced in the proportion of 0.5-1 mm, 0.25-0.5 mm, and 0.053-0.25 mm fractions under rubber-based agroforestry system.

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.

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.

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 Das Chaudhuri, 2012).

In general, soil carbon content in rubber plantation is medium to high, however, depletion of soil carbon by continuous rubber plantation compared to adjoining natural forest was observed by Ulaganathan *et al*., (2012).

It has been reported that the litter fall of rubber tree plantation is less than that of oil palm, jungle rubber and natural forest, amounting to an average of only 3.84 mg ha-1 while that of natural forest was 9.04 mg ha^{-1}. This clearly results in a lower nutrient return to the soil (Kotowska *et al*., 2016).

Kiriya and Sukanya (2019) showed that the soil pH, total N, exchangeable K and Ca, OM, NO3G, soil moisture and soil microorganisms tended to increase with the increasing age of the rubber trees, while the soil bulk density tended to decrease.

In the studied plots of Khon Kaen province, Northeastern Thailand, Souliyavongsa *et al*., (2019) concluded that rubber tree plantations were found to improve soil fertility, especially soil organic carbon as well as total N, and exchangeable K in comparison with a sugar cane system. Available P in sugarcane plantation was higher than in rubber tree plantation most likely because of the effect of fertilization. In this specific agro ecosystem, rubber tree plantations did not appear to have a negative impact on soil fertility relative to previously established sugarcane crops.

CHAPTER 3

MATERIALS AND METHODS

3.1. General description of the study area

One of the eight sister states of North-East India, Mizoram is situated in the southernmost portion of the region with Aizawl as its capital city and has a total size of 21,081 km^2. Mizoram is a state of hills that is blessed with a wide variety of biodiversity and a thick canopy of greenery. The State shares interstate boundaries with Assam and Manipur in the north and Tripura in the west. It is located between 21°56'N and 24°31'N latitude and 92°16'E to 93°26'E longitude. The tropic of cancer runs through the state nearly at its middle. The maximum north-south distance is 285 km, while maximum east-west stretch is 115 km. The state also borders Bangladesh and Myanmar internationally. Despite having a highly literate population and an agricultural economy, Mizoram experiences shifting cultivation, or slash-and-burn farming, and low crop yields. In recent years, a significant horticultural and bamboo products industry has steadily replace the jhum farming methods.

The state's physiography is characterized by undulating, rough, steep hills and a series of interspersed valleys. Moist tropical to moist subtropical is the climate pattern. Monsoons have an impact on the area, bringing heavy rain from May to September and minimal rain in the winter, making this time of year cold and dry. The state experiences an average annual rainfall of 2100-3000 mm, while the winter and summer months' temperatures, respectively, and range from 11°C to 24°C and 18°C to 29°C. The majority of the region falls into the land use capacity classes II to IV, necessitating competent land management (Mizoram SAPCC, 2012-17). The state's most abundant soil type is an inceptisol, which is often made up of sandy loam and clay loam soil with significant levels of organic carbon (Colney and Nautiyal, 2013). Due to changing agriculture brought on by shorter fallow periods, changes in land use have a substantial impact on the region's soils. Due to unpredictable and erosive rainfall patterns, cultivation on steep slopes with little soil conservation measures results in soil losses through surface runoff.

Tropical wet-evergreen forests are the most common form of forest, with semi-evergreen forests and tropical-moist deciduous forests also occurring sometimes. Pockets of bamboo forests may also exist. In the middle and lower stories of the evergreen forest, bamboos proliferate in profusion. The state's most prevalent bamboo forest is *Melocanna baccifera* (MIRSAC, 2007). In the state, there is a forest cover that covers 18,005.51 km^2, or 85.41% of the state's overall land area. From 86.27% (ISFR, 2017) to 85.41% (ISFR, 2019), the state had a decline in forest cover, a loss of 180.49 km2 or so relative to the previous ISFR (2017) report.

3.2. Description of the study sites

The study was conducted at Kawnpui, Mizoram where ginger (*Zingiber officinale* Rosc.) and rubber (*Hevea brasiliensis)* are intercropped. Kawnpui town is located in the central part of Kolasib district, Mizoram, in north-east India. With a total area of 156.50 sq km., the town is located between 92° 36.358‘E to 92° 44.210‘E longitudes and 23° 57.293′N to 24° 07.543′N latitudes. It falls under Survey of India toposheet No. 83D/12 and 84A/9. The climate of the study area ranges from moist tropical to moist sub-tropical. The entire district is under the direct influence of south west monsoon, with average annual rainfall of 2908.40 mm. The soils found in the study area were mostly of red and yellow loamy. They were also acidic in nature due to heavy rainfall. They contained high amount of organic carbon and were high in available nitrogen, low in phosphorus and potassium content. (MIRSAC, 2009).

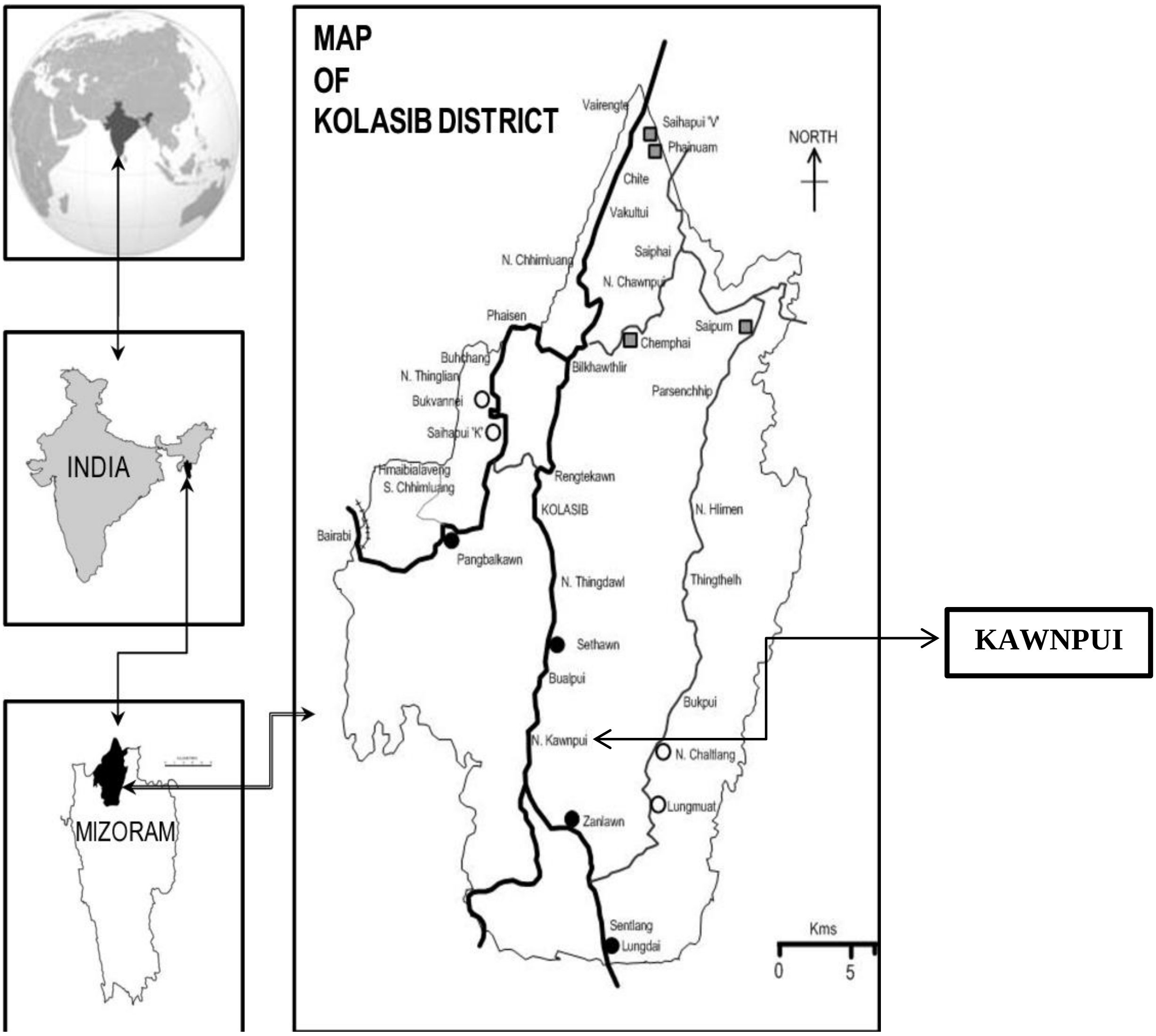


Figure 3.1. Map of study sites

3.3. Experimental design and soil sampling

To study the physico-chemical and biological characteristics of soil under indigenous cultivation method of *Zingiber officinale* Rosc., the experiment was carried out from three different experimental plots assigned in randomized complete block design as: (i) Intercropping of ginger under Rubber+Ginger based agroforestry (C_1); (ii) Sole Ginger (C_2) and (iii) Control (C_3) characterized by bamboo and shrubs vegetation with numerous undergrowth.

Treatment:

Crops (C) : Rubber + Ginger (C_1)
Sole Ginger (C_2)
Barren – Control (C_3)

Slope % (S) : 0 – 30 (S_1)
30 and above (S_2)

T_1 : S_1 + C_1
T_2 : S_1 + C_2
T_3 : S_1 + C_3
T_4 : S_2 + C_1
T_5 : S_2 + C_2
T_6 : S_2 + C_3

Fig. 3.2. Experimental Block Design: Randomized Complete Block Design

Replicate 1			Replicate 2			Replicate 3	
T_2	T_5		T_1	T_4		T_3	T_6
T_3	T_4		T_2	T_6		T_1	T_5
T_1	T_6		T_3	T_5		T_2	T_4

Soil samples of three replicates at a depth of 0-15cm was collected at an interval of (i) Pre-cultivation (May/June); (ii) Flowering stage (Sept/Oct); and (iii) Post Harvest (Mar/April) during 2016-2018. After that, samples were brought to the laboratory for additional processing while being contained in zip locks with the appropriate labels. The soil samples were then separated into two sub-samples, one of which was air dried and stored and the other of which was kept in a zip-lock bag at -20° C for analysis.

3.4. Laboratory analysis of soil properties

3.4.1. *Soil physical properties*

Bulk density was estimated by core method (Blake, 1965). The gravimetric method was followed to determine the soil moisture content. Soil sample were weighed before and after the sample was oven dried at 105°C until the constant weight was attained. Total porosity was calculated using dry bulk density assuming a particle density of 2.65 g cm^{-3} (Danielson and Sutherland, 1986). Soil texture was determined by Hydrometer method (Bouyoucos, 1926) using the USDA textural classification chart.

3.4.2. *Analysis of soil chemical properties*

Soil pH was measured in a soil-water suspension (1:2.5 soil-water ratios) with pH analyzer. Soil organic carbon (SOC) and total nitrogen (TN) were determined on finely grounded air-dried soils by dry combustion in a CHNS/O Elemental Analyzer with auto-sampler and TCD detector –Euro Vector, Model: EuroEA3000 at Central Instrumental Laboratory, Mizoram University. Available phosphorous (Pavail) was analyzed following Allen et al. (1974) method. Nitrate nitrogen (NO3-N) was estimated by phenol disulphonic acid method (Harper, 1924) and ammonium nitrogen (NH4-N) by indophenol-blue method (Rowland, 1983). Exchangeable cations[potassium (K)] were determined using the Agilent 4100 Microwave Plasma-Atomic Emission Spectrometer (MP-AES).

3.4.3. *Estimation of soil microbial biomass carbon (MBC)*

Fresh soil samples were used for the analysis of soil microbial biomass carbon (MBC) following the chloroform-fumigation extraction method as outlined by Brookes and Joergensen (2006). For the estimation of MBC, 50 g of freshly collected soil samples were divided into two equal parts of 25 g each and placed in a 50 ml beaker. One part of the samples was placed in the air tight dessicator containing chloroform vapours and the other part was kept as control without chloroform for 24 hours. Both the samples were then extracted using 0.5 M K2SO4 (1:4 ratio of soil to extractant) and shaken for 30 minutes. The samples were then filtered through Whatman no. 42 filter papers. Further, 10 ml of the supernatant aliquots were used for the estimation of C by wet oxidation method similar to the SOC estimation method described by Walkley and Black (1947). Thereafter, the difference between the fumigated and non-fumigated samples was taken out and MBC was calculated (Vance et al., 1987; Wu et al., 1990; Dilly and Munch, 1998).

3.4.4. *Soil microbial population count*

Soil microbial population was estimated using 1 g of freshly collected soil samples through serial dilution method outlined by Martin (1950). Soil sample of 1 gram of soil was added to the initial test tube containing 10 ml (dilution factor 10^{-1}) of distilled water. After mixing well, 1 ml of the solution from the first test tube was transferred to the subsequent test tube which contained 9 ml of distilled water which was labelled as dilution factor 10^{-2}. The same process was carried out to acquire dilution factors of 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6} and 10^{-7}. Dilution plate technique experiment was carried out for obtaining colony forming units for the count of microbial population method given by Waksman (1922). The agar based media used for the population count was different for each of the different targets (fungi, actinomycetes and bacteria). Potato dextrose agar (PTA) was mixed with antibiotic ~ 0.08% of penicillin and chloramphenicol along with rose Bengal for the estimation of Fungi population. For the estimation of actinomycetes population count, starch casein agar (SCA) mixed with nystatin (~0.08%) as antibiotic was used as the medium. Nutrient agar added with 0.08% of nystatin and actidione was used as media for assessment of bacterial population. Dilution of 10-3 to 10-5 were used for isolation of fungi, 10-4 to 10-6 for actinomycetes and 10-5 to 10-7 were used for bacterial isolation. After media preparation, 1 ml of each dilution was transferred into the petri-plates containing the solid media. Following, the media plates were incubated at 28±10C for fungi and 25±10C for bacteria and actinomycetes. Actinomycetes and bacteria population count was carried out after 24 hours of incubation has been completed while for fungi, it was incubated for 72 hours prior to population count. All the glassware's and media which were used were sterilized in an autoclave for 20 minutes at 1200C.

3.5. Ginger Production Analysis: The productivity of ginger will be determined using two parameters:

3.5.1. Growth Parameters: Growth attributes of ginger (plant height, number of tillers, tiller frequency) was recorded at monthly intervals in different systems.

3.5.2. Yield Parameters: The yield attributes of ginger (number of finger, finger size, ginger yield) was calculated from different systems at the end of harvest following standard methods.

Statistical analysis

All the data obtained are presented as mean (average) and standard error (SE). The resulting data's were subjected to two-way analysis of variance (ANOVA). Significant differences among soil variables, aggregate size fractions and microbial population were determined and least significant difference (LSD) were calculated to determine significant differences between means at $p \leq 0.05$. All statistical analysis was carried outusing open source OPSTAT (free Online Agriculture Data Analysis Tool developed by O.P. Sheoran, Computer Programmer at CCS HAU, Hisar, India). Again, Pearson correlation analysis between various soil properties was carried out using OPSTAT.

CHAPTER 4

RESULTS

4.1. Changes in soil physico-chemical properties across different treatments and sampling season

4.1.1. *Soil physical properties*

The studied soil physical properties such as BD, sand, silt and clay content were significantly different ($p<0.05$) across the different treatments (Table 4.1). Bulk density (BD) values ranged from 1.08 g cm^{-3} - 1.36 g cm^{-3} with maximum density in RG and minimum in CTRL. Soil porosity level across the different treatment ranged from 56.7%-79.4%. Porosity was higher in SG followed by CTRL and RG. The soil texture of all the study sites was sandy loam with percent of sand, silt and clay ranging from 59.82%- 66.97%, 28.77%-23.94% and 19.82%- 12.36% respectively. The sand and silt percent was higher in RG plantation sites compared to other treatment whereas the clay percent was high in CTRL soils (Table 4.1).

Table 4.1 Effect of different treatment (Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) on soil physical properties (0-30% Slope)

	Soil Physical properties					
Treatment	**BD (g/cm^3)**	**Porosity (%)**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Textural class**
RG	1.36±0.02	56.7±0.2	17.83±0.96	28.77±0.79	66.97±0.99	Sandy loam
SG	1.27±0.06	79.4±0.5	12.36±1.32	23.94±0.82	67.19±0.64	Sandy loam
CONTROL	1.08±0.06	61.3±0.3	19.82±1.59	27.93±0.44	59.82±1.45	Sandy loam
LSD$_{0.05}$						
T=	0.202	8.717	4.658	2.509	3.82	

Note:T= Treatment, LSD$_{0.05}$: $p<0.05$, NS=Non-significant.

The ANOVA revealed that effect of slope gradient on particle size distribution, bulk density and total porosity was significant ($p<0.05$) (Table 4.2). Accordingly the lowest sand content (55.3%) was recorded on steep sloping area, while the highest sand (66.9%) was recorded on moderately steep area of RG plot. Similarly, the lowest silt fraction (19.4%) was recorded at SG of steep sloping area, while the highest silt content (28.7%) was in RG of moderately sloping area. The highest clay content (19.8%) was recorded in moderately sloping area of Control site, whereas the lowest clay content (9.75%) was recorded in steep slope area. The minimum and maximum bulk density values were recorded for soils from gently sloping (1.08 g cm^{-3}) and steep slope (1.41 g cm^{-3}) from control and RG study site respectively. The lowest total porosity (52.7%) was recorded on strongly steep area of RG intercropped site (Table 4.2), while the highest total porosity (79.4%) was on moderately sloping area of sole ginger cultivation site (Table 4.1).

Table 4.2 Effect of different treatment (Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) on soil physical properties (30% above Slope).

	Soil Physical properties					
Treatment	**BD (g/cm^3)**	**Porosity (%)**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Textural class**
RG	1.41±0.04	52.7±0.88	13.97±0.18	24.67±0.86	61.67±0.43	Sandy loam
SG	1.32±0.08	73.27±0.61	9.75±0.92	19.40±1.24	60.52±3.04	Sandy loam
CONTROL	1.40±0.12	58.64±1.01	16.78±0.71	21.26±0.83	55.33±1.61	Sandy loam
$LSD_{0.05}$						
T=	0.12	3.06	4.23	2.48	3.17	

Note:T= Treatment, $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

4.1.2. *Soil chemical properties*

The soil moisture content (SMC) content in RG soil ranged from 20.18% to 27.37% with highest SMC during Flowering Stage (FS) and was followed by Pre-Cultivation. In SG, the soil moisture content ranged from 12.19% - 24.88% and was followed in decreasing order FS>PC>PHV, whereas, in CTRL the soil moisture content ranged from 17.37% - 21.08% with the values highest in FS followed by PC and PHV (Table 4.3). Soil moisture content was found to be significantly ($p<0.05$) affected by different treatment (T), season (S) and an interaction (TxS) of both factors. The soil pH values in RG ranged from 4.9 to 5.26 during different sampling season, 5.05 – 5.36 in SG treatment and 4.05 – 5.07 in CTRL site. No significant variations were recorded in soil pH during the sampling season, however, statistically significant ($p<0.05$) between treatments and their interaction was observed (Table 4.4). The lowest pH value (4.72) was recorded on soils of strongly steep slope gradient of RG treatment during Pre-Cultivation stage, whereas the highest pH (6.27) was obtained on Control treatment during the Pre-Cultivation stage as well (Table 4.4). The soil pH was strongly acidic in all the treatment during different sampling season. However, greater soil acidity was observed during Pre-Cultivation in all the treatments. Soil organic carbon (SOC) concentration was highest during the flowering stage (FS) season and were significantly different ($P<0.05$) across the treatments. The values ranged from 1.59% - 2.79% in all the three treatments (Table 4.3). SOC concentrations were found to be significantly ($p<0.05$) affected by different treatment (T), season (S) and an interaction (TxS) of both factors. The amount of SOC were considerably higher in Control during the three sampling season as compared to RG and sole ginger. In RG treatment, the SOC concentration ranged from 1.59% - 2.69%; 1.43% - 2.63% and 2.43% - 2.79% in SG and Control treatment respectively (Table 4.3) in all the three sampling season. The maximum concentration was found in flowering stage of control treatment and lowest during the post-harvest of sole ginger treatment. There was statistically significant effect ($P < 0.05$) of slope gradient on soil organic carbon. The minimum SOC was recorded in soils of the strongly steep areas (1.28%) during the PHV stage of SG treatment, whereas the maximum SOC was recorded in soils of the moderately sloping area

(2.79%) during the FS stage of control treatment (Table 4.4). Similar trend to SOC was observed in TN concentrations during sampling season with higher concentration in control treatment and less concentration in cultivation site.

Table 4.3 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil chemical properties (0-30% slope)

Treatment with season		**Soil Chemical Properties**					
RG		**SMC (%)**	**pH**	**Soil Organic Carbon (%)**	**Total Nitrogen (%)**	**P_{avail}**	**K_{exch}**
	PC	24.27±1.84	4.9±0.18	1.88±0.06	0.21±0.008	10.56±0.33	0.22±0.02
	FS	27.37±0.49	5.23±0.04	2.69±0.09	0.27±0.005	12.98±3.51	0.23±0.02
	PHV	20.18±0.81	5.26±0.11	1.59±0.07	0.17±0.02	7.47±0.11	0.21±0.01
SG							
	PC	17.98±2.94	5.05±0.06	1.74±0.08	0.22±0.009	13.26±0.56	0.18±0.01
	FS	24.88±2.75	5.16±0.08	2.63±0.04	0.28±0.01	10.38±0.49	0.14±0.01
	PHV	12.19±0.40	5.36±0.07	1.43±0.05	0.15±0.01	5.88±0.08	0.09±0.01
CONTROL							
	PC	19.58±0.91	4.05±0.15	2.43±0.07	0.24±0.006	13.87±0.54	0.24±0.01
	FS	21.08±0.54	5.07±0.10	2.79±0.11	0.34±0.02	16.77±0.04	0.24±0.018
	PHV	17.37±0.49	5.09±0.05	2.61±0.04	0.28±0.02	14.98±0.02	0.26±0.02
$LSD_{0.05}$							
T		2.707	0.195	0.132	0.027	NS	0.032
S		2.707	NS	0.132	0.024	2.556	NS
T x S		4.688	0.338	0.229	NS	4.427	NS

Note: T= Treatment; S= stages/season; T x S= Treatment x stages/season $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

TN concentration were found to be significantly ($P<0.05$) affected by different treatment (T) and season (S), however, the interaction of treatment (T) and season (S) in TN concentration was observed to be non-significant. The TN percent ranged from 0.21% - 0.24% during PC; 0.27% - 0.34% during FS and 0.15% - 0.28% during PHV in all the three treatments (RG, SG and Control). In general, soils of the control treatment site showed higher SOC and TN concentrations as compared to cultivation sites (RG and SG treatment). The minimum and maximum values of total nitrogen were recorded for moderately steep (0.15%) and strongly sloping (0.30%) areas, during the PHV and FS of both SG and Ctrl treatment respectively (Table 4.4).

P_{avail} concentrations in soil was also found to be significantly affected by different season (S) as well as an interaction (TxS) of both factors ($P<0.05$), however, the effect of different treatment (T) on P_{avail} concentration was found to be non-significant. The control treatment show consistent high P_{avail} concentration during the three sampling season ranging from 13.87 mg g^{-1} to 16.77 mg g^{-1}. In RG treatment, the P_{avail} concentration ranged from 7.47 mg g^{-1} to 12.98mg g^{-1}; 5.88 mg g^{-1} to 13.26mg g^{-1} and 13.87 mg g^{-1} to 16.77 mg g^{-1} in SG and Control treatment respectively in all the three sampling season i.e., PC, FS and PHV. Thers is a sharp decrease of P_{avail} concentration during the post-harvest season of both RG and SG treatment (Table 4.3). Differences of slope gradient among the areas did not significantly ($P > 0.05$) affect Olson available P. However, numerical variations were observed among the slope gradients. The relatively lowest (4.86 mg g^{-1}) and highest (16.77 mg g^{-1}) contents of P_{avail} were recorded in soils of strongly sloping and moderately sloping areas, respectively. Although it is not statistically significant, the variation is highly associated with the variation of organic matter content in each slope gradient. Exchangeable K showed no significant effect between the Season (S) and their interaction (TxS), while it varied significantly between treatments (T) ($p<0.05$). There was no notable trend observed in Control and RG treatment during the sampling season. However, K_{exch} values decreased abruptly during the post-harvest stage in sole ginger treatment. The K_{exch} content was consistently low in SG during all the sampling season ranging from 0.09 mg g^{-1} to 0.18 mg g^{-1} (Table 4.3).

Table 4.4 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil chemical properties (30% above slope)

Treatments with seasons	**Soil chemical characteristics**					
R+G	**SMC (%)**	**pH**	**Soil Organic Carbon (%)**	**Total Nitrogen (%)**	**P_{avail}**	**K**
PC	25.93±0.85	4.72±0.17	1.68±0.10	0.15±0.20	8.72±0.95	0.19±0.09
FS	29.29±1.39	5.30±0.03	2.30±0.12	0.21±0.03	10.63±0.89	0.21±0.051
PHV	18.88±1.31	5.87±0.11	1.66±0.13	0.11±0.06	6.97±0.69	0.16±0.048
SG						
PC	20.70±1.81	5.63±0.40	1.53±0.05	0.17±0.07	10.89±0.75	0.14±0.01
FS	25.66±3.02	5.28±0.22	2.51±0.09	0.22±0.11	8.92±0.82	0.10±0.06
PHV	17.70±0.55	5.45±0.24	1.28±0.04	0.10±0.09	4.86±0.05	0.06±0.10
CONTROL						
PC	19.29±1.86	6.27±0.15	2.26±0.17	0.21±0.008	11.39±0.52	0.20±0.01
FS	27.48±1.98	5.89±0.36	2.30±0.02	0.30±0.40	13.16±0.12	0.17±0.07
PHV	21.62±1.05	6.03±0.39	2.01±0.06	0.23±0.23	5.28±0.57	0.22±0.08
$LSD_{0.05}$						
T=	1.812	0.312	0.132	0.025	NS	0.029
S=	1.521	NS	0.132	0.020	2.099	0.019
T x S=	2.635	0.54	0.229	NS	4.126	NS

Note: T= Treatment; S= stages/season; T x S= Treatment x stages/season $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

4.1.3. *Soil biological properties*

The level of NH_4^+-N concentration was relatively higher in both RG and Control treatment as compared to SG treatment. Soil of the NH_4^+-N concentration varied from 7.26 mg g^{-1} to 13.98 mg g^{-1} in RG treatment followed by 5.81 mg g^{-1} to 10.07 mg g^{-1} in Control treatment and the least in SG treatment ranging from 2.31 mg g^{-1} to 5.46 mg g^{-1} during the three sampling season (Table 4.5). Different treatment (T), season (S) and their interaction (TxS) significantly ($p<0.05$) influenced soil NH_4^+-N concentration in all the study sites. The NH_4^+-N concentration in all the studied treatment tends to increase first and then decrease, showing obvious seasonal change, with the highest during the flowering stage (FS) and the lowest in post-harvest (PHV) in all the three treatment i.e., RG, SG and Control. The post-harvest (PHV) season of the SG treatment show minimum NH_4^+-N concentration (2.31 mg g^{-1}) and the flowering stage (FS) of the RG treatment show maximum NH_4^+-N concentration (13.98 mg g^{-1}) (Table 4.5). Similar trend of $NH4^+$-N concentration was observed for NO_3-N concentration. The values of NO_3-N in RG treatment ranged from 2.69 mg g^{-1} to 6.43 mg g^{-1} during PC, FS and PHV.

Similarly the NO_3-N concentration in all the study site tends to increase first and then decrease with respect to seasonal change, with the highest during the flowering stage in each treatment and the lowest in post-harvest (PHV). The minimum value of NO3-N concentration was observed in SG treatment ranging from 1.33 mg g^{-1} to 4.38 mg g^{-1} during the sampling season (Table 4.5). The different treatment (T), season (S) and their interaction between treatment and season (TxS) show significant ($p<0.05$) effect in NO_3-N concentration. In control treatment, the NO_3-N values ranged from 4.70 mg g^{-1} to 5.85mg g^{-1} with respect to sampling season. The highest concentration of NO_3-N was found during the flowering stage (FS) of RG plot (6.43 mg g^{-1}) and the lowest during the PHV of SG plot (1.33 mg g^{-1}) (Table 4.5).

Different treatment (T), Season (S) and their interaction (TxS) significantly ($p<0.05$) influenced soil microbial biomass carbon in all the study sites (Table 4.5). Mean MBC varied from 431.3 µg g^{-1} to 596.6 µg g^{-1} in RG treatment, 273.7 µg g^{-1} to 364.5 µg g^{-1} in SG treatment and 435.8 µg g^{-1} to 634.9 µg g^{-1} in control treatment across the sampling season. During PHV season, MBC showed a decreasing trend in all the three treatment while the highest concentration of MBC was observed during the flowering stage of the sampling season. The microbial biomass carbon exhibited a significant difference ($p<0.05$) between the sampling season in all the three treatment. Soil of the control treatment (634.9 µg g^{-1}) during the flowering stage had the highest mean value of soil microbial biomass carbon followed by RG (596.6 µg g^{-1}) during the flowering stage as well and lowest in SG (273.7 µg g^{-1}) during the PHV stage (Table 4.5).

Table 4.5 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil biological properties (0-30% slope)

Treatments with seasons		**Soil biological characteristics**		
		NH_4-N (mg g$^{-1)}$	**NO_3-N (mg g$^{-1)}$**	**MBC (µg g$^{-1)}$**
R+G	**PC**	10.15±0.64	4.59±2.27	464.7±3.2
	FS	13.98±0.65	6.43±0.21	596.6±4.05
	PHV	7.26±0.05	2.69±0.12	431.3±13.5
SG	**PC**	2.87±0.08	1.72±0.09	332.9±6.4
	FS	5.46±0.37	4.38±0.12	364.5±16.8
	PHV	2.31±0.006	1.33±0.05	273.7±4.2
CONTROL	**PC**	7.17±0.09	4.70±0.05	539.7±2.8
	FS	10.07±0.03	5.85±0.28	634.93±26.4
	PHV	5.81±0.006	4.81±0.02	435.85±3.78
$LSD_{0.05}$				
T=		0.578	0.241	19.95
S=		0.578	0.241	25.31
T x S=		1.001	0.418	34.56

Note: T= Treatment; S= stages/season; T x S= Treatment x stages/season $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

NH_4^+-N concentration in RG soil ranged from 7.1 mg g^{-1} to 11.72 mg g^{-1} during PC, FS and PHV, 1.63 mg g^{-1} to 5.49 mg g^{-1} in SG treatment and 5.97 mg g^{-1} to 10.59 mg g^{-1} in Control treatment (Table 4.6). The soil of RG showed higher concentrations of NH_4^+-N than other land uses during pre-monsoon whereas CTRL showed the maximum NH_4^+-N concentration during mid-monsoon and post-monsoon as compared to SG treatment. The level of NH_4^+-N and NO_3-N were relatively lower in all the treatments (RG, SG and CTRL) as compared to below 30% slope but could not meet the level of significance in some treatment. However, variations were significant with the sampling season i.e. PC, FS and PHV. The value of NO_3-N ranged from 2.12 mg $g^{-1}$to 4.45 mg g^{-1} during PC, 2.69 mg g^{-1} to 6.19 mg g^{-1} during FS and 1.55 mg g^{-1} to 4.88 mg g^{-1} during PHV (Table 4.6). Flowering stage favoured high NH_4^+-N and NO_3-N in all the three treatment. Subsequently higher NO_3-N was observed in RG soil during the flowering stage whereas lowest NO_3-N was obtained in SG at the PHV stage. MBC in RG soil ranged from 308.3 µg g^{-1} to 371.6 µg g^{-1} during PC, FS and PHV, 268.6 µg g^{-1} to 298 µg g^{-1} in SG treatment and 310.3 µg g^{-1} to 357.5 µg g^{-1} during PC, FS and PHV of Control treatment (Table 4.6). Higher slope showed less MBC than lower soil across the land uses. MBC was lowest during pre-cultivation across all the three treatment. The values varied significantly ($p<0.05$) between the seasons and the highest MBC was shown during flowering stage in all RG, SG and CTRL soils. RG and CTRL showed the maximum values compared to SG during all the seasons. SG showed the lowest MBC during the PC stage. In general, the microbial properties (e.g. MBC) in RG and CTRL were considerably higher for all the season (PC, FS and PHV) relative to control and significant difference in microbial properties were marked between the sampling seasons i.e. PC, FS and PHV.

Table 4.6 Effect of different treatments ((Rubber+Ginger=RG, Sole Ginger=SG, and Control=CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post-Harvest-PHV) on soil biological properties (30% above slope)

Treatments with seasons		**Soil biological characteristics**		
		NH_4-N (mg $g^{-1)}$	**NO_3-N (mg $g^{-1)}$**	**MBC (μg $g^{-1)}$**
R+G	**PC**	10.48±0.19	4.44±0.21	308.3±18
	FS	11.72±0.17	6.19±0.11	371.6±09
	PHV	7.1±0.37	2.35±0.17	366.8±09
SG	**PC**	2.16±0.75	2.12±0.72	268.6±15
	FS	5.49±0.16	2.69±0.11	294±10
	PHV	1.63±0.56	1.55±0.13	298±13
CONTROL	**PC**	7.3±0.39	4.45±0.52	310.3±11
	FS	10.59±0.14	5.53±0.39	346.6±21
	PHV	5.97±0.09	4.88±0.43	357.5±12
$LSD_{0.05}$				
T=		0.321	0.656	18.83
S=		0.321	0.656	23.06
T x S=		0.555	1.135	32.62

Note: T= Treatment; S= stages/season; T x S= Treatment x stages/season $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

4.2. Soil microbial population

4.2.1. *Changes in soil microbial population (fungi, bacteria and actinomycetes) across different treatment and sampling season*

The number of colonies counted in fungal population ranged from 50.4 CFU 10^3g^{-1} to 62.7 CFU 10^3g^{-1} in RG; 33.7 CFU 10^3g^{-1} to 52.4CFU 10^3g^{-1} in SG and 57.3CFU 10^3g^{-1} to 69.1CFU 10^3g^{-1} in CTRL treatment in all the three sampling season (Fig 4.1). Further the number of bacterial colonies counted in RG was 118.8 CFU 10^6g^{-1} to 142.4 10^6g^{-1} followed by 66.8 10^6g^{-1} to 104.7 10^6g^{-1} in SG and 135.4$10^6g^{-1}$ to 182.3$10^6g^{-1}$ in CTRL treatment during PC, FS and PHV respectively (Fig 4.2). Comparing the sampling season, the number of microbial populations were significantly increased in FS compared to PHV. Furthermore, the actinomycetes population was found highest in the CTRL plot (65.1 10^4g^{-1} to 75.7 10^6g^{-1}) followed by RG (58.4 10^4g^{-1} to 72.0 10^4g^{-1}) and the least in SG treatment (47.2 10^4g^{-1} to 59.6 10^4g^{-1}) (Fig 4.3). In addition, the number of colonies formed by bacterial population considerably increased compared to fungal population. Similar to the trend of fungi and bacteria population, actinomycetes also followed a decreasing trend during the PHV sampling season. As a general trend, fungi, bacteria and actinomycetes were observed to occur lowest during the PHV stage and highest during the FS of each treatment.

Figure 4.1 **Effect of different treatments ((Rubber+Ginger-RG, Sole Ginger-SG, and Control-CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post Harvest-PHV) on soil fungi population**

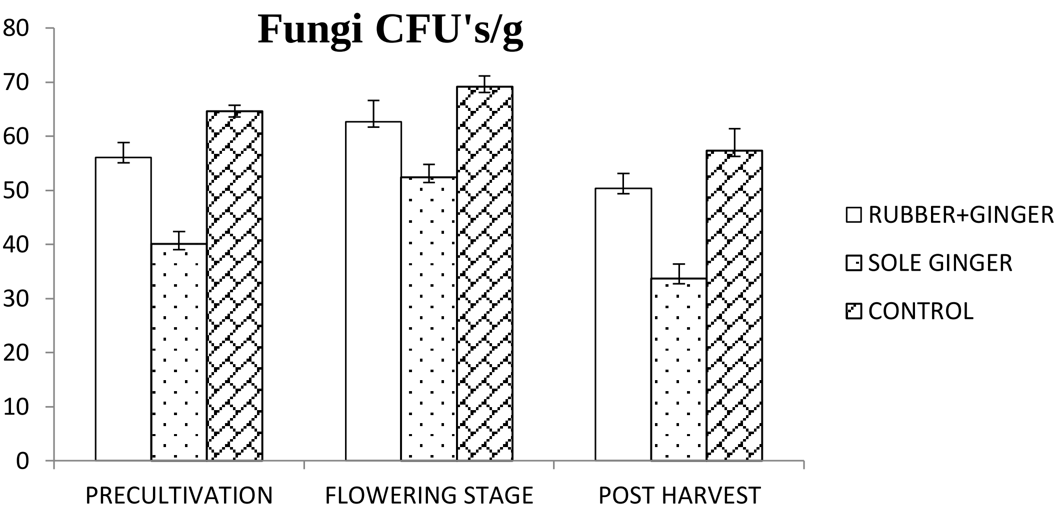


Figure 4.2 **Effect of different treatments ((Rubber+Ginger-RG, Sole Ginger-SG, and Control-CTRL) and different stages/seasons (Pre Cultivation-PC, Flowering Stage-FS, Post Harvest-PHV) on soil bacterial population**

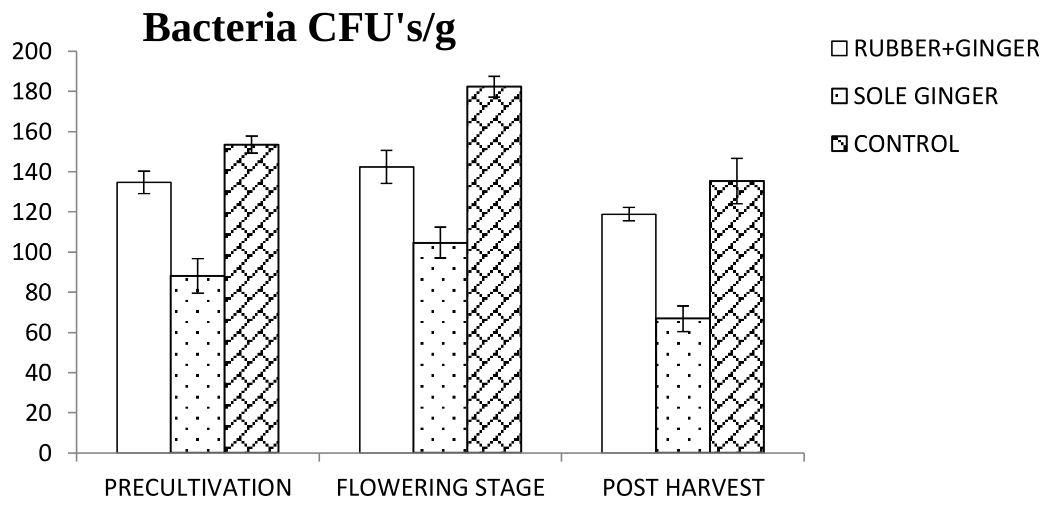
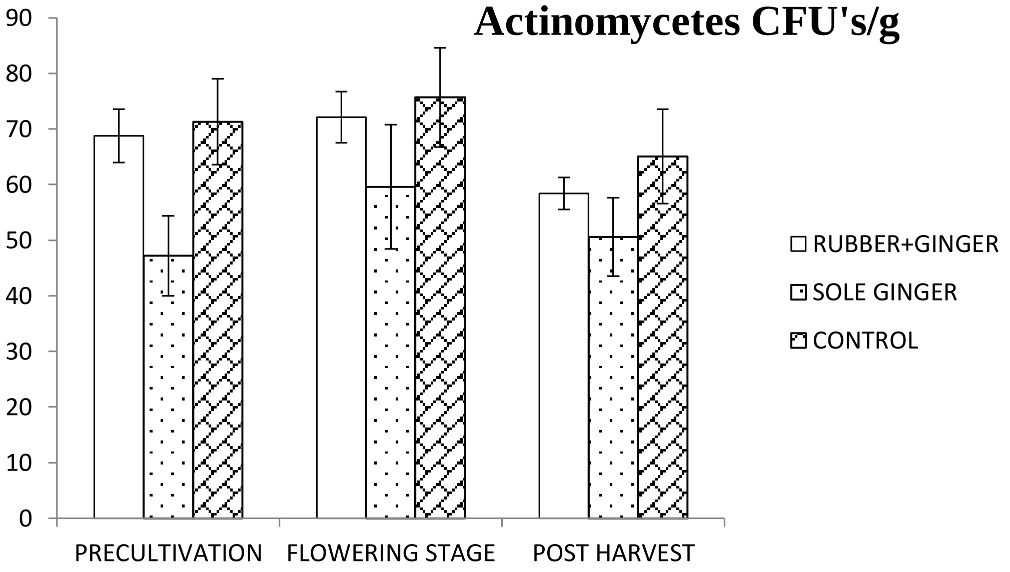


Figure 4.3 Effect of different treatments [Rubber+Ginger (RG), Sole Ginger (SG), and Control (CTRL)] and different stages/seasons (Pre-Cultivation-PC Flowering Stage-FS, Post Harvest-PHV) on soil actinomycetes population



4.3. Correlation between soil physical, soil bio-chemical parameters and microbial population at different sampling season (PC, FS and PHV)

Pearsons correlation test revealed significant correlations between various soil parameters at different sampling season (PC, FS and PHV) as shown in Table 4.7, 4.8 and 4.9. At the pre-cultivation (PC), SOC showed strong positive correlation ($p<0.01$) with pH, TN, MBC, Actinomycetes and fungi and also positively correlated ($p<0.05$) with NO_3-N. Soil moisture content showed strong positive correlation ($p<0.01$) with NO_3-N, actinomycetes and fungi and also positively correlated ($p<0.05$) with pH and MBC. Strong positive correlations ($p<0.01$) between MBC and the soil microbial population was also reported (Table 4.7). Exchangeable potassium was also found to be positive correlated ($p<0.05$) with NO_3-N and MBC. Available phosphorus also show positive correlation ($p<0.05$) with NH_4-N.

At the flowering stage (FS), soil moisture content showed strong negative correlation ($p<0.01$) with soil pH and positively correlated ($p<0.05$) with SOC. SOC is negatively correlated ($p<0.05$) with TN, P_{avail} and K (Table 4.8). MBC is negatively correlated ($p<0.05$) with soil moisture content and show strong positive correlation ($p<0.01$) with NH_4-N and potassium. Nitrate nitrogen showed negative correlation ($p<0.05$) between soil pH and phosphorus. Actinomycetes and fungi showed negative correlation ($p<0.05$) SOC and positively correlated ($p<0.05$) with TN. Potassium was found to be strongly correlated ($p<0.01$) with ammonium nitrogen and MBC. NH_4-N showed strong positive correlation ($p<0.01$) between MBC and bacteria. Fungi population was found to be strongly correlated ($p<0.01$) with soil pH and phosphorus and negatively correlated ($p<0.05$) with MC and SOC. Strong positive correlation ($p<0.01$) of bacteria with ammonium nitrogen and MBC was also observed (Table 4.8).

A correlation analysis was carried out for the post-harvest (PHV) stage of the different treatment by taking average values of the various soil parameters from three different treatments where significant correlations were observed between different soil parameters. Significant strong positive correlations of SOC with TN and pH ($p<0.01$) and negative correlation with SMC ($p<0.05$) were observed. Total nitrogen was found to be positively correlated ($p<0.05$) with actinomycetes and fungi (Table 4.9). Strong negative correlation ($p<0.01$) of P_{avail} with K and bacteria and also negatively correlated ($p<0.05$) with MBC and actinomycetes were observed. Nitrate nitrogen was found to be negatively correlated ($p<0.01$) strongly with soil moisture content and ammonium nitrogen (Table 4.9). NH_4-N were positively and negatively correlated strongly ($p<0.01$) with soil moisture content and NO_3-N respectively. Positive correlation ($p<0.05$) of MBC with pH, K, actinomycetes and fungi and also negative correlation with phosphorus was also observed. Bacteria showed strong positive correlation ($p<0.01$) with potassium, also strongly correlated negatively with phosphorus and positive correlation with NH_4-N were observed. Fungi and actinomycetes showed strong positive correlation with each other.

Table 4.7 Correlation coefficients (R) between pH, moisture content (MC), Soil organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P_{avail}), Exchangeable Potassium (K_{exch}), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during pre-cultivation stage (PC)

PRE CULTIVATION	pH	MC	SOC	TN	Avail P	K	NO3-N	NH4-N	MBC	ACTINO	FUNGI	BACTERIA
pH	1											
MC	**0.735***	1										
SOC	**0.899****	**0.671***	1									
TN	**0.901****	0.646^{NS}	**0.815****	1								
Avail P	-0.281^{NS}	-0.232^{NS}	-0.242^{NS}	-0.290^{NS}	1							
K	0.322^{NS}	**0.697***	0.580^{NS}	0.304^{NS}	-0.160^{NS}	1						
NO3-N	**0.703***	**0.941****	**0.720***	**0.693***	-0.418^{NS}	**0.794***	1					
NH4-N	-0.043^{NS}	0.186^{NS}	0.191^{NS}	-0.186^{NS}	**0.687***	0.512^{NS}	0.094^{NS}	1				
MBC	**0.722***	**0.684***	**0.844****	0.598^{NS}	0.141^{NS}	**0.667***	0.627^{NS}	0.576^{NS}	1			
ACTINO	**0.892****	**0.808****	**0.958****	**0.847****	-0.281^{NS}	0.662^{NS}	**0.844****	0.149^{NS}	**0.843****	1		
FUNGI	**0.942****	**0.811****	**0.944****	**0.913****	-0.309^{NS}	0.571^{NS}	**0.838****	0.054^{NS}	**0.809****	**0.985****	1	
BACTERIA	0.433^{NS}	0.592^{NS}	0.656^{NS}	0.273^{NS}	0.292^{NS}	**0.789***	0.557^{NS}	**0.840****	**0.881****	0.643^{NS}	0.560^{NS}	1

*Correlation is significant at 0.05 level; ** Correlation is significant at 0.01 level

Table 4.8 Correlation coefficients (R) between pH, moisture content (MC), Soil organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P$_{avail}$), Exchangeable Potassium (K$_{exch}$), Nitrate Nitrogen (NO$_3$-N), Ammonium Nitrogen (NH$_4$-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during Flowering stage (FS)

FLOWERING STAGE	pH	MC	SOC	TN	Avail P	K	NO3-N	NH4-N	MBC	ACTINO	FUNGI	BACTERIA
pH	1	**-0.958****	**-0.726***	**0.688***	**0.934****	0.569^{NS}	**-0.778***	0.293^{NS}	0.575^{NS}	**0.896****	**0.960****	0.168^{NS}
MC		1	**0.753***	-0.638^{NS}	**-0.897****	-0.663^{NS}	**0.718***	-0.435^{NS}	**-0.696***	**-0.924****	**-0.961****	-0.300^{NS}
SOC			1	**-0.769***	**-0.745***	**-0.785***	0.234^{NS}	-0.423^{NS}	-0.616^{NS}	**-0.763***	**-0.737***	-0.308^{NS}
TN				1	**0.836****	0.520^{NS}	-0.238^{NS}	0.094^{NS}	0.485^{NS}	**0.777***	**0.769***	0.030^{NS}
Avail P					1	0.556^{NS}	**-0.677***	0.271^{NS}	**0.677***	**0.958****	**0.980****	0.185^{NS}
K						1	-0.198^{NS}	**0.853****	**0.812****	**0.718***	0.615^{NS}	**0.748***
NO3-N							1	-0.216^{NS}	-0.454^{NS}	-0.659^{NS}	-0.728*	-0.203^{NS}
NH4-N								1	**0.825****	0.512^{NS}	0.364^{NS}	**0.966****
MBC									1	**0.843****	**0.722***	**0.804****
ACTINO										1	**0.975****	0.436^{NS}
FUNGI											1	0.262^{NS}
BACTERIA												1

*Correlation is significant at 0.05 level; ** Correlation is significant at 0.01 level

Table 4.9 Correlation coefficients (R) between pH, moisture content (MC), Soil organic carbon (SOC), total nitrogen (TN), Available Phosphorus (P_{avail}), Exchangeable Potassium (K_{exch}), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), Soil microbial biomass carbon (MBC), Fungi, Bacteria and Actinomycetes (Actino) during Post-harvest (PHV)

POST-HARVEST	pH	MC	SOC	TN	Avail P	K	NO3-N	NH4-N	MBC	ACTINO	FUNGI	BACTERIA
pH	1											
MC	**-0.733***	1										
SOC	**0.888****	-0.637^{NS}	1									
TN	**0.716***	-0.600^{NS}	**0.844****	1								
Avail P	-0.393^{NS}	-0.213^{NS}	-0.334^{NS}	-0.327^{NS}	1							
K	0.356^{NS}	0.239^{NS}	0.452^{NS}	0.274^{NS}	**-0.830****	1						
NO3-N	0.607^{NS}	**-0.896****	0.599^{NS}	0.505^{NS}	0.443^{NS}	-0.322^{NS}	1					
NH4-N	-0.557^{NS}	**0.928****	-0.520^{NS}	-0.447^{NS}	-0.483^{NS}	0.434^{NS}	**-0.973****	1				
MBC	**0.752***	-0.205^{NS}	0.581^{NS}	0.352^{NS}	**-0.754***	**0.700***	-0.020^{NS}	0.075^{NS}	1			
ACTINO	**0.853****	-0.441^{NS}	**0.872****	**0.735***	**-0.693***	**0.696***	0.277^{NS}	-0.231^{NS}	**0.770***	1		
FUNGI	**0.935****	-0.608^{NS}	**0.908****	**0.743***	-0.544^{NS}	0.585^{NS}	0.464^{NS}	-0.409^{NS}	**0.768***	**0.968****	1	
BACTERIA	0.145^{NS}	0.492^{NS}	0.189^{NS}	0.151^{NS}	**-0.919****	**0.886****	-0.645^{NS}	**0.714***	0.646^{NS}	0.511^{NS}	0.340^{NS}	1

*Correlation is significant at 0.05 level; ** Correlation is significant at 0.01 level

4.4 Growth and yield parameters of ginger

4.4.1 *Growth attributes of ginger between as intercrop in rubber plantation and as sole crop at different stage of growth*

The plant height of ginger was significantly influenced by the effect of different agroforestry production systems. The tallest plants (73.7cm) were recorded under intercrop rubber plantation (RG) at 24 weeks after planting (WAP). On the contrary, significantly, the shortest plants (24.16 cm) were observed under sole ginger (SG) at 4WAP. The progressive plant height growth from 8WAP to 20WAP showed that the tallest plants found during 20 WAP in both RG and SG was 72.01 cm and 68.07 cm respectively. With respect to weeks after planting of ginger, the height of the plant ranged from 28.57 cm to 73.7 cm in RG treatment and 24.16 cm to 68.9 cm in sole ginger treatment. The pattern of plant height observed in both RG and SG treatment was as 24WAP>20WAP>16WAP>12WAP>8WAP>4WAP. Number of tiller during the study period was significantly influenced by different intercrop system. In RG intercrop treatment the number of tillers ranged from 1.27 to 24.1 and 1.94 to 22 in sole ginger (SG) treatment. The lowest number of tiller per plant was observed during 4WAP (1.27) of RG treatment. Higher number of tiller per plant was observed at 24WAP between ginger intercrop in rubber plantation. Significantly higher plant height and number of tiller per plant were recorded at rubber ginger intercropping (73.7cm and 24.1 respectively) as compared to sole cropping (68.9 cm and 22 respectively) as indicated in Table 5.0. Number of tiller per plant does not show any specific pattern. Like the plant height, the sole ginger also had low number of tiller as compared to rubber ginger intercrop.

4.4.2 *Yield attributes of ginger between as intercrop in rubber plantation and as sole crop at different stage of growth*

Yield attributes of ginger such as number of primary fingers and length of finger of ginger were higher in rubber shade (2.83 and 12.9 cm respectively) compared to sole cropping (2.66 and 7.52 cm respectively). The number of primary, secondary and tertiary fingers of the harvested ginger rhizome in RG treatment ranged from 2.83 to 7.25 and in SG treatment the number of fingers ranged from

2.66 to 5.75. The number of primary finger in RG and SG treatment were 2.83 and 2.66 respectively. The number of secondary finger was higher in SG as compared to RG treatment with values 5.58 and 5.75. However, an increase in the tertiary fingers of RG treatment (7.25) as compared to sole ginger (5.41). The size of the ginger finger was estimated on the basis of its length and diameter of the rhizome. Both the length and diameter of the ginger rhizome ranges 12.90cm and 7.64cm respectively in the rubber ginger intercropped plot. In sole ginger plot, the length and diameter of the ginger size was recorded as 11.93 cm and 7.52 cm respectively (Table 5.1). The size of the ginger rhizome on the basis of length and diameter was recorded higher in RG treatment as compared to sole cropping of ginger. Subsequently, the fresh rhizome yield of ginger was found to be higher in rubber ginger intercrop plantation (2.2 t/ha) and in sole cropping of ginger the fresh rhizome yield was found to be 2 t/ha. Higher yield of ginger rubber intercropping may be attributed to increase crop duration and shade loving nature of crop.

Figure 4.4. Tiller frequency of ginger between sole ginger and rubber+ginger at different stage of growth

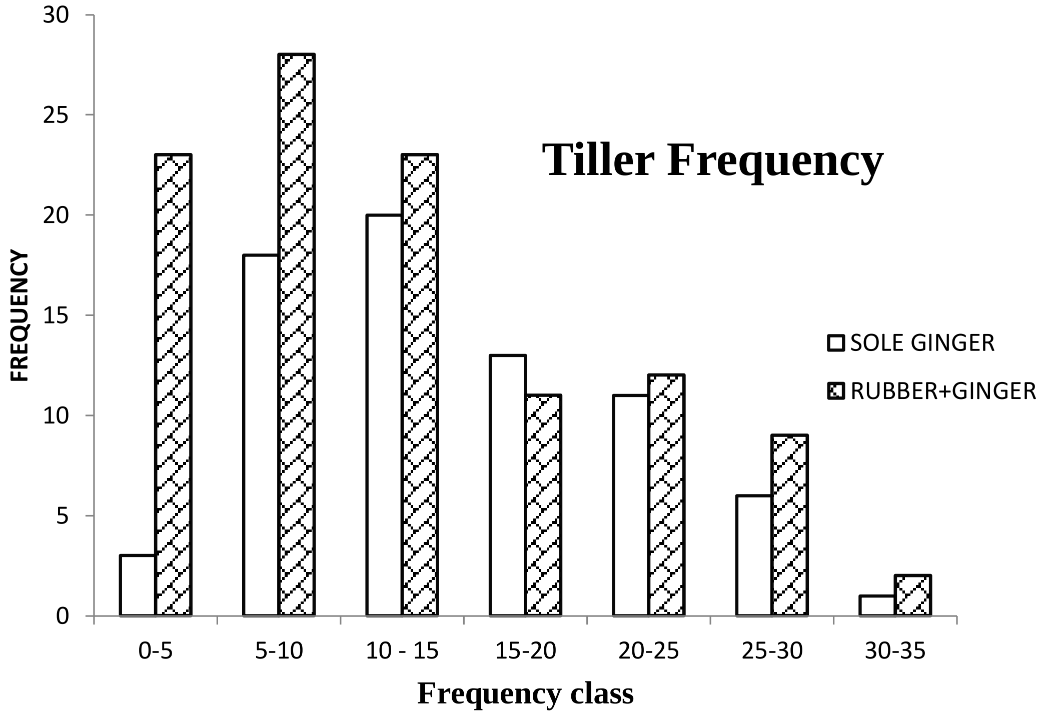


Table 5.0 Growth attributes of ginger (plant height and number of tillers) between as intercrop in rubber plantation and as sole crop at different stage of growth

Treatment/ Parameters		Weeks after planting						**t- value**
		4 WAP	8WAP	12WAP	16WAP	20WAP	24WAP	
PLANT HEIGHT	R+G	28.57±1.37	45.33±2.69	55.58±2.11	64.05±2.62	72.01±1.37	73. 7±1.29	**5.70**
	SG	24.16±1.27	40.24±1.68	48.38±2.67	55.63±2.16	68.07±2.78	68.9±1.82	
NO. OF TILLERS	R+G	1.27±0.14	7.38±1.40	9.27±0.54	13.11±0.48	19.72±3.45	24.11±1.22	**1.56**
	SG	1.94±0.69	7.83±0.83	8.44±0.72	11.05±1.31	19.05±0.52	22±2.5	

Table 5.1 Yield attributes of ginger (number of fingers, finger size and ginger yield) between as intercrop in rubber plantation and as sole crop at different stage of growth

Treatments	No. of Fingers			Finger Size		Fresh rhizome yield (ton/ha)
	Primary Fingers	Secondary Fingers	Tertiary Fingers	Length	Diameter	
R+G	2.83±0.08	5.75±0.38	7.25±0.25	12.90±0.22	7.64±0.25	2.2
SG	2.66±0.08	5.58±1.17	5.41±0.30	11.93±0.074	7.52±0.08	2
t-value	**4.30**			**6.31**		

CHAPTER 5

DISCUSSION

5.1. Effect of different treatment and sampling season on soil physico-chemical properties

The physical properties of the soils studied were found to be significantly different between the treatment ($p<0.05$), as shown in Table 1. Bulk density (BD) values ranged from 1.08g/cm^3-1.36g/cm^3 with maximum density in intercropped ginger (RG) followed by SG>Control. Due to extensive root growth and dense root distribution, the control site may have the lowest bulk density when compared to other land uses. The loss of soil organic matter (SOM) caused by the conversion of natural forests to plantations is thought to have resulted in increased bulk density in plantation soils. In Indonesia, higher bulk densities were previously recorded under intense rubber plantation (Allen *et al*., and Guillaume *et al*., 2015). The difference in soil particle size distribution and the disruption of soil particles caused by erosion may be responsible for the change in soil bulk density across slope gradients. Less than 1.61 g cm^{-3} of bulk density was detected in the examined soils, which is typical and appropriate for sandy clay and sandy clay loam soils (Amusan *et al*., 2001). This suggests that the studied area's soils are not compacted. The relative high bulk densities observed under these systems could be attributed to the corresponding low organic matter contents (Masebo *et al*., 2014). According to Jiregna *et al*. (2005), bulk density is highly influenced by tree based systems and management practices that enhance the accumulation of organic matter to modify soil properties such as bulk density. This could have possibly resulted from the swelling and sealing of the soil surface as a result of intense rains coupled with the effect of tillage operations. The results show that cropping systems had no significant effect on bulk density. This could be attributed to the immature rubber trees at the time of this study. Several studies have reported the effect of matured trees on reduction in soil bulk density (Seobi *et al*., 2005). The relative high soil bulk density observed under some of the treatments indicates the occurrence of soil compaction, which directly implies decreased soil porosity and reduced permeability (Agboola, 1994). According to

Hajabbasi *et al*. (1997) high bulk density could reduce the soil quality. Since, the rubber trees in the study are young, their impact on deeper soil horizons are yet to be expressed. Therefore, it is expected that, as the trees mature and their roots occupy greater soil volume, there will be drastic alterations in the soil pore structure in both shallow and deeper horizons.

High SMC values were observed under RG and CTRL as compared to SG treatments. This could be strributed to litter fall (Masebo *et al*., 2014), and the dense canopy cover highly contributed by the foliage of rubber leaves, which provided good ground surface cover, resulting in reduced evapotranspiration rate, and runoff as evidenced by the high hydraulic properties (i.e., cumulative infiltration amount, sorptivity, infiltration rates and steady state infiltrability). The high water penetration rate in the soil observed under the RG treatment are clear indications that the rubber in agroforestry systems have considerable effects on both bio-physical and chemical processes that affect soil health (Nair, 1993). These observations support earlier assertions on the effects of intercropping on soil, which include reduction of runoff and/or erosion, basically through the improvement of soil physical properties such as structure, porosity, and moisture retention as a result of extensive root system and the canopy cover (Pattanayak and Mercer, 1996).

According to Achalu *et al*., (2012), organic matter improves soil aggregation, which reduces bulk density. The high bulk density, low clay content, and low organic matter content may be responsible for the lowest total porosity seen in slope gradients with strongly steep slopes. On the other hand, the moderately sloped area with the highest clay concentration had the highest total porosity, indicating that clay content had a beneficial impact on total porosity. All slope gradients had very high percent total porosity values, according to FAO's (2006b) rating of total porosity (greater than 40%). This suggests that the soils in the study area are physically fertile. All of the treatments had sandy loam soil texture, with sand, silt, and clay values ranging from 59.8% to 67.1%, 23.9% to 28.7%, and 12.3% to 19.8%, respectively. In different Mizoram land use systems, the percentages of sand, silt, and clay were 62–72 percent, 17–21 percent, and 11–17 percent, respectively

(Manpoong and Tripathi, 2019). Since these soils have a potentially well-balanced capacity to hold water, develop a stable structure, and offer enough aeration, most field crops might grow well in such soils with sandy clay and sandy clay loam textural class. Looking at the data on particle size distribution, it was found that clay content exhibited an ascending tendency as slope gradient decreased, whereas sand content exhibited a descending trend. This is most likely because clay particles are more easily removed by erosion on the upper slope gradient, whereas deposition of these particles takes place on the lower slope gradient. Mohammed *et al*., (2005) reported a similar finding, stating that finer soil materials deposition occur at the lower slope position, where they are arriving from the top position.

The pH of the soil differed significantly between treatments (T) and seasons (S) ($p<0.05$), but not between their interactions (Table 4.2). Soil pH was acidic in all the treatments ranging from 4.9 to 5.05 in PC, 5.07 to 5.23 in FS and 5.09 to 5.36 in PHV. Higher soil pH in the surface layer of SG and Control as compared to RG is well attributed to the release of cations as a result of the traditional slash and burn technique in the SG land use system. Burning enhances the release of nutrients in the soil and thus increasing the soil pH (Moraes *et al*., 1996). The higher values of pH in the cultivated lands may also result from the conversion of natural forest into cultivation, which leads to an increment in pH at the surface soil layers (Lumbanraja *et al*., 1998). The present values of pH are in accordance with other findings from the study area, indicating strongly acidic natures of reaction in these soils (Grogan *et al*., 2012; Tripathi *et al*., 2017; Lungmuana *et al*., 2017). The loss of basic cations from runoff and erosion may be the cause of the lowest pH in soils with steep slope gradients. In turn, this lowers soil pH and boosts H+ ion activity in the soil solution. According to a 2013 study by Nega and Heluf, loss of base-forming cations through leaching and runoff caused by rapid erosion causes a decrease in soil pH and an increase in soil acidity. However, the build-up of bases that were thought to have been lost from the highly sloping gradients could be the cause of the rise in soil pH at the moderately sloping gradient. Similar to this, the highest basic cation concentration and pH were found towards the bottom of the slope, according to Garcia *et al*., (1990) and Hendershot *et al*., (1992). Similarly, the moisture content was also higher in RG soils. Comparing the individual agroforestry systems, the soil pH in the different slopes did not differ from the initial values in both study sites. The differences in pH observed at different soil slopes at both sites could be as a result of leaching and lack of mixing of the soil profile, and variations in the soil fractions and SOC contents at different depths (Tuffour et al., 2013). The relatively low pH observed under the sole ginger vegetation could be attributed to the low SOC compared to the rubber-ginger systems (Juo and Manu, 1996). On the other hand, the increased accumulation of aboveground biomass and associated cation uptake in the agroforestry systems could also explain the low pH in the soils, which could probably be due to the tree root abundance in the soils resulting in high uptake of cations (Tornquist et al., 1999).

High organic matter content and dense vegetation in the Control site probably conserve the soil moisture. Forest conversion to plantations has been documented to result in low moisture availability due to losses in top soil and vegetation in Indonesia, Peru, and Southern Cameroon (Van Straaten *et al*., 2015; Guillaume *et al*., 2016). In the current investigation, changes in soil properties between PC, FS and PHV were tested. It shows that the soil properties were significantly influence by seasonal variation where FS has higher biochemical and microbial properties compared to PHV. Earlier studies highlight increase soil chemical and microbial properties during FS relative to PHV (Hauchhum and Tripathi, 2017b). Seasonally, the TN, SOC, MBC and MBN show peaked amount during FS and significantly low during PHV. The high amount of MBC and MBN during FS may be the result of increased SMC content and relative humidity which is ideal for microbial activity. Earlier studies reported a close relationship between SMC and microbial biomass (Devi and Yadava, 2006). Lower amount of microbial biomass during PHV may be due to low SMC that suppressed the activity of soil microbes. In addition, higher mobilization of soil nutrients by microbes during the composition of organic matter results in increase microbial biomass during FS relative to PHV.

Different treatments (T), seasons (S), and their interactions (TxS) all had a significant impact on soil organic carbon ($p<0.05$). The highest value during the flowering stage (FS) was reported from CTRL followed by RG and the least in SG with values of 2.79%, 2.69% and 2.63%, respectively. However, during PHV Soil Organic Carbon is highest in Control treatments (2.61%).The high SOC in the Control site can be attributed to a large quantity of litter decomposition and soil nitrogen availability. Higher organic matter and nutrient inputs through litter fall have been reported to have a favourable impact on soil organic matter (Hattori *et al.*, 2005; Chen *et al*., 2010). In tropical ecosystems, SOC availability is a good indicator of soil nutrient supply (Chase and Singh, 2014). The variation of the soil organic carbon of the two slopes could be contributed by the effect of slope gradient on the soil moisture storage capacity and biomass production. In the moderately sloping area, the soil moisture storage is better and resulting in better biomass production. Furthermore, the expected impeded drainage could also slow down the OM decomposition process. However, in the strongly sloping steep areas, there could be high drainage, low moisture storage and less biomass production thereby decreases soil OM content. This result is in agreement with the work of Abebe and Endalkachew (2012) in Nitisol of Southwestern Ethiopia. The significant low level of soil organic carbon in the study area may be caused by the limited application of organic fertilizers to maintain and/or enhance soil organic matter.

From the study, the intercropping systems (RG) generally resulted in increased N and SOC contents than the sole cropping systems (SG). These findings are in agreement with Barua and Haque (2013), who reported that the SOC content and storage under intercropping systems is significantly higher than those in the sole cultivation land. The general increase in N contents in the intercropping systems compared to the monocultural systems are evidence of enhanced N cycling as reported by Kumar (2006) and Mbow *et al*. 2014. Similarly, Richard *et al*. (2013) reported higher N mineralization potential in tree-based intercropping systems compared to other conventional agricultural systems. This implies that the rubber trees in the various intercropping systems used in this study served as effective traps for atmospheric dust, and also acted as central points for attracting soil micro and macro fauna, for enhanced organic matter decomposition Seneviratne *et al*. (2015). Thus, in this study, intercropping rubber with ginger, therefore, enhanced soil nutrient pools such as P, total N and SOC (Rivest *et al*., 2013). According to the rating system established by Tekalign (1991), organic matter content of all the slope gradients were categorized under low and below the critical level (3.4%). The significant low level of soil OM in the research region may be caused by the seldom use of organic amendments for the upkeep and/or enhancement of soil organic matter. The value of TN was found highest during the FS Stage of the Control site (0.34%) followed by SG (0.28%)>RG (0.27%). Total Nitrogen was significantly affected by different treatments (T) and seasons (S) but does not show significant affect between their interactions (TxS). Available forms of nitrogen play an important role in N transformation. The reason for rapid loss of the total N from the rubber plantation may be due to heavy rainfall occurred in the sites causing nutrient runoff from the hill slopes. The adventitious root system, use of machinery during the harvesting period and cultural operations involved in ginger cultivation could further deteriorate the soil physical conditions restricting the root growth. On the other hand, since land use management techniques are so important for nutrient conservation, a lower concentration of SOC and TN in the cultivated land uses may be linked to their impact (Ovung *et al*., 2021). A downhill movement with runoff water from higher slope gradients and accumulation there at the lower slope gradient may be the cause of the total N results showing an increasing trend from steep slope to moderately sloping gradient. The result also shows how much OM contributed to the high total N. According to Tekalign's (1991) evaluation, the total nitrogen of all the slope gradients in the current study region was in the range of medium. This indicates that, due to the low level of soil organic matter content and the limited use of nitrogen-containing inputs such commercial fertiliser, plant wastes, and animal manure, nitrogen is found to be the limiting plant nutrient in the research area. Microbial activity is reduced as a result of routine weeding and leaf litter removal from the surface vegetation. These management techniques typically leave the soil exposed and vulnerable to erosion by soil and water by removing soil cover and reducing organic matter inputs (Foley *et al*., 2005; Giller *et al*., 1997; Mills and Fey, 2004).The uptake of N by crops, one of the elements that are absorbed by plants the quickest, can be a significant impact in the loss of TN in cultivated soils like SG (Salcedo, 2008). According to several studies, the conversion of natural forests to cultivated lands, including plantations, has resulted in a rapid loss of soil carbon and nitrogen as well as changes to the microbial population (Murty *et al*., 2002; Saggar *et al*., 2001, Xiangmin *et al*., 2014).

P_{avail} concentrations in soil were significantly affected by different season (S) and their interactions (TxS) ($p<0.05$). The highest value was recorded at the Control site during the flowering stage (FS) (16.77 mg g^{-1}) and the least in SG (5.88mg g^{-1}). The higher P_{avail} content in the Control site could be attributable to the quick recycling of nutrients through litter breakdown and mineralization. Less use of FYM, no addition of chemical fertilizers, higher leaching loss from litter residues may also have resulted in low P content in the soils of rubber plantation (Chauhan *et al.,* 2010; Chase and Singh. 2012). In addition, SOM influences P_{avail} through anion replacement of H2PO4 from adsorption sites and the formation of organophosphate complexes which are readily taken up by plants as reported in different studies (Nega and Heluf 2013; Yihenew and Getachew 2013; Tripathi *et al*., 2012). According to Sarkar *et al*., (2010), the amount of soil increased when litter was added to the soil surface. While decreasing SOM content, which largely contributes to the P pool in the soils of the study area, may also be the cause of the decline in soil P_{avail} with rising soil depths. Higher P_{avail} content during PC and FS in RG and SG is probably due to the presence of higher number of Pseudomonas (phosphorous solubilizing bacteria). The fluctuation in P_{avail} content throughout the slope gradients is parallel to that of SOC content, as can be observed in Table 4.5. This demonstrates how soil organic matter may contribute to making more phosphorus available in the soil system. Accordingly, Fisseha *et al*., (2014) discovered low levels of P_{avail} in soils with low levels of organic matter. Nega and Heluf (2013), however, came to the conclusion that the P_{avail} content of tropical soils did not always decline with a reduction in organic matter. The high availability of P in the soils may be greatly influenced by the preferred pH ranges of soils (5.7–6.8) and mineral weathering. According to Cottenie (1980), our values for P_{avail} fall within the low to medium range in terms of the various land use systems and slope gradient. Exchangeable K showed no significant affect between the Season (S) and their interaction (TxS), while it varied significantly between treatments (T) ($p<0.05$). The greater exchangeable K values in both RG and CTRL could be attributed to the establishment and presence of herbaceous vegetation and canopy cover that shielded the soil from direct rainfall and reduced nutrient loss through runoff and erosion. The observation regarding K indicates that it was taken up due to higher plant root density (Bowden 1985) and may have accumulated in the plant biomass.

5.2. Effect of different treatment and sampling season on soil biochemical properties

In the present finding, the physico-chemical and microbial properties in different treatment were enhanced significantly with different sampling season. Yang *et al.*, (2010) reported that an increase of soil microbial biomass results in immobilization of nutrients, whereas decrease in microbial biomass results in mineralization of nutrients. During the cold and dry winter i.e. PHV, a slow rate of decomposition, attributable to low microbial activity, might have resulted in greater immobilization of inorganic N by microorganisms resulting in reduced N-min (Maithani *et al*., 1996). From our findings, high value of NH_4-N was reported during the flowering stage of each treatment. High NH_4-N during FS in RG, SG and CTRL suggested that the uptake of NH_4-N was reduced during mid-monsoon likewise the uptake of NO_3-N was reduced during PHV. Greater availability of NH4-N during FS also depicts the higher rate of ammonification and similarly lower availability of NO_3-N during PHV suggested higher nitrification rate in the soils. These both processes were enhanced by higher soil moisture content in the study. Increased vegetation cover and plant richness in RG and CTRL could have retained the available nutrient (e.g. N and P) which was an important factor for increase in NH_4-N and NO_3-N with sampling season. Enhanced nitrification and N-min in older fallow than young fallow may be attributable to increased organic matter decomposition and greater microbial activity (Singh *et al.*, 2001). Greater concentration of ammonium than nitrate may be the result of potential loss of nitrate through leaching in sloping agriculture field where surface runoff is high.

Furthermore, the acidic nature of the soil also might have inhibited the activity of autotroph nitrifiers in the soil to some extent that reduced the rate of nitrification (Chao *et al*., 1993).

On contrary to increase NH_4-N and N-min in RG, the concentration of NO_3-N significantly decrease in SG compared to RG and CTRL indicating the uptake of NO_3-N by the plant roots and microbes in rhizosphere exceeded the nitrification rate. Since, the study site soil is N-limited, and thus it is suggested that the microbial growth is N-limited rather than C-limitation, and that rhizosphere C-flux may reduce the N-availability if nutrient – limited rhizosphere microbes immobilize N (Cheng *et al*., 1996; Phillips and Fahey, 2006). On the other hand, Wang *et al*., (2001) observed great depletion of NH_4 and NO_3 in rhizosphere of Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) seedlings. Erhenfield *et al*., (1997) found that NH_4 and NO_3 were not influence by live plant roots in mineral soil. Soil microbial biomass carbon was also influenced by SOC in the present study.

The comparatively high MBC values in RG and CTRL may be because of the abundance of diverse vegetation and vegetation cover which contributed to high amount of substrate for the activities of microorganisms. Several researchers have reported a close linkage between plant richness and microbial biomass (Broughton *et al*., 2000; Spechn *et al*., 2000; Bardget *et al*., 1999). Reports have shown that higher soil carbon enhance the growth of soil microbes and accumulation of microbial biomass in soil (Tripathi *et al*., 2008; Chen *et al*., 2005). The minimum MBC recorded in SG soils may be attributed to lack of surface vegetation cover. Reduced quality and quantity of organic matter in the soil have resulted in loss of microbial activity (Degens *et al*., 2000). Influence of quantity and quality of organic matter inputs on soil microbial biomass and activities by different vegetation has been well documented (Jin *et al*., 2010; Xu *et al*., 2008).The higher microbial biomass during mid-monsoon in the present study may be due to high immobilization rate during the soil organic matter decomposition. Several workers reported a close relation of soil moisture with microbial biomass, which often favours the growth of microbes and fungi during this season (Yang *et al*., 2010). The observed differences in C_{mic} under the different cropping systems in both sites could be attributed to variable microclimates resulting from the differences in vegetation cover and actively growing vegetation (Bautista and Castillo, 2005) especially in the systems involving ginger. Accordingly, Djagbletey (2017) reported that larger pool of C_{mic} under vegetation could create and enhance soil physical structure with a concomitant effect on carbon sequestration. However, the buildup of C_{mic} in the PPPR systems could subsequently result in increased fluxes of trace gases from microbial processes (Lloyd, 1995; Liao and Boutton, 2008).

5.3. Changes in soil microbial population across different treatment and sampling season

Comparing the sampling season, the number of microbial populations were significantly increased in FS compared to PHV. Furthermore, the actinomycetes population was found highest in the CTRL plot (65.1 $10^4 g^{-1}$ to 75.7 $10^6 g^{-1}$) followed by RG (58.4 $10^4 g^{-1}$ to 72.0 $10^4 g^{-1}$) and the least in SG treatment (47.2 $10^4 g^{-1}$ to 59.6 $10^4 g^{-1}$) (Fig 3). In addition, the number of colonies formed by bacterial population considerably increased compared to fungal population. Similar to the trend of fungi and bacteria population, actinomycetes also followed a decreasing trend during the PHV sampling season. The decline in organic matter, which serves as a source of carbon for the microbes' metabolism, may be responsible for the population decline of fungus, bacteria, and actinomycetes with rising slopes (Bhattarai et al., 2015). Additionally, ideal environmental factors like soil temperature and aeration in the topsoil encourage population increase, while the opposite is true in the deeper soil depths (Bhattarai et al., 2015). Higher populations of bacteria and fungi were found in RG and CTRL, respectively. This suggests that the continued presence of vegetation in these land uses increased the concentration of carbon sources in the soil through higher organic matter accumulation, which in turn supported a higher microbial population (Ndour, 2008). Positive link between soil pH and soil microbial population suggests that the lower pH in the soils of RG and CTRL may also be responsible for the increased population in these land uses (Ibekwe et al., 2012).

Contrarily, as in the case of the SG land use system, agricultural management methods can have a considerable impact on microbial population and activity (Wakelin et al., 2008; Rasche et al., 2006; Ferreira et al., 2000). The present findings, which show that RG soil has the highest microbial counts at the surface, followed by CTRL, and SG soil have the lowest counts, are consistent with earlier results that showed a significant relationship between soil depth and microbial population counts (Wani et al., 2018; Bello et al., 2013; Asadu et al., 2015; Silva et al., 2013). As a general trend, fungi, bacteria and actinomycetes were observed to occur lowest during the PHV stage and highest during the FS of each treatment.

Higher bacterial population than fungal population in the present study revealed that the rhizosphere of the plant studied favours the growth of bacteria which is similar to earlier reports (Tamilarasi *et al*., 2006; Karthikeyan *et al*., 2008). Broeckling *et al*., (2008) reported that population richness of microbes in particular rhizosphere of plant species is the result of influence of root exudates released by plant roots. It shows that plant exudates play an important role in the microbial activity that gradually increase the microbial population in FS compared to PHV. The seasonal changes in microbial population in different treatment could be due climate and soil variables that affect the growth of microbes. The presence of more fungus in RG and CTRL suggests that the population of ectomycorrhizal fungi, which is present in most tree species, may have increased due to the dominance of trees and other vegetation. According to Asadu et al., (2015) the presence of trees and vegetation cover also decreased the effect of rain on the soil and produced ideal microclimatic conditions for increased fungal development and multiplication. In addition, higher fungal and bacterial populations during FS may be the result of increase SMC and exudation of plant roots in the rhizosphere zone (Rigobelo and Nahas, 2004).

From the result of analysis of correlation coefficient, it indicates that variation in microbial population is greatly influence by seasons where fungal and bacterial population positively significantly correlated with SMC in FS but not in PHV. Seasonal influence on rhizosphere microbes had also been reported by Collado *et al*., (1999) and Gao *et al*., (2005). The most logical explanation is that moisture is the primary environmental component in an area that is relatively dry, therefore more moisture at sites which have high canopy cover may improve nutrient cycling and increase microbial community activity. The higher temperatures at sites with more exposure to sunlight will result in more microbial activity and improved soil nutritional quality. Temperature sensitivity can be a big issue for soil bacteria. Sites with a sunny aspect receive more solar radiation and experience temperatures that are better suited for microbial growth in cold environments like plateaus.

Additionally, soil moisture regulates microbial activity and survival (Drenovsky *et al*., 2004; Borken and Matzner, 2009). In general, fungi can tolerate higher soil moisture content than bacteria can. Using their hyphal system, fungi can create airgaps in wet soil, whereas excessive soil moisture content can slow down bacterial movement. Fungi are therefore more likely to survive at locations with a shady aspect (Wilson and Griffin, 1975; Wilkinson *et al*., 2002).

Since fungi are easily impacted by changes in soil as well as environmental factors, the management techniques that created disturbances to the soil structure may be responsible for the low fungal count in SG (Sui et al., 2012). Our current findings are in agreement with those reported by Bello et al. (2013), Asadu et al. (2015), and Wani et al. (2018), who found that natural forest soils, both in the surface and sub-surface layers, had the greatest counts of fungi. Similar to their findings, Okonkwo (2010) and Kumar et al. (2017) observed that natural forests have higher counts of bacteria and actinomycetes at the surface and sub-surface layers than cultivated lands. Our findings on bacteria and actinomycetes support their findings. It is hypothesised that continuous farming disturbs soil structure and processes, which over time depletes organic matter and decreases the number of microbial communities.

5.4. Growth and yield attributes of ginger

The results presented in various respective tables showed that at the harvesting stage, ginger recorded significant variability in various morphological observations under different agroforestry systems among both the treatment when compared to sole cropping. The results with respect to the plant height of ginger plants (Table 5.0) reveal that plant height of ginger crop was significantly increased in those treatments where ginger was intercropped with rubber rather than sole cropping. This might be due to tree-crop association providing better micro-site conditions than sole crop. It might also be due to less light intensity as ginger is a shade loving plants under intercropping as compared to open condition. These findings is in conformity with the findings of Parihar *et al.*, (2015) in turmeric under agri-silvi-horti system, Chaudhary *et al.*, (1998) in ginger under mango orchard, Alam *et al.*, (2014) under different regimes of shade in turmeric, Paajapati *et al.*, (2007) in ginger, Vanlalhluna and Sahoo (2010) under ginger, turmeric maize, Saroj *et al.*, (2003) in groundnut, wheat, cluster, bean, mustard and Singh *et al.*, (1997) in turmeric. Higher plant height and number of tillers per clump in ginger grown as intercrop in rubber plantation is attributed to low light intensity and shade loving nature of ginger. Plant under diffuse light generally grow taller and produce more of foliage as observed in the present study. Similar results were also reported by earlier workers in ginger when grown as intercrop in popular (Jaswal *et al.*, 1993) and in arecanut (Thangaraj *et al.*, 1983). The increased in the length and diameter of the rhizome yield in RG treatment may be due to the micro-site improvement in rubber based agroforestry systems and partial shade loving nature of the ginger intercrop. It might also be due to the compatibility of light shade of rubber for ginger intercrop. The higher yield of ginger in RG plot might attribute to tree-crop association providing better micro-site conditions than pure crop. Higher yield of ginger rubber intercropping may be attributed to longer crop duration.

CHAPTER 6

SUMMARY AND CONCLUSION

A field experiment were conducted at Kawnpui, Kolasib District, Mizoram during 2016-2018 to study the soil properties and growth parameters of intercropping of rubber (*Hevea brasiliensis*) under ginger based agroforestry systems. The experiments were replicated three times in a randomized block design. The salient findings of the study during the course of investigation are described in this chapter.

- The soil texture of all the study sites was sandy loam where the clay percent was highest in CTRL soils. Porosity was higher in sole ginger followed by CTRL and RG. Bulk density were significantly different ($p<0.05$) across the different treatments.
- The soil moisture content ranged from 12.19% (PHV, SG treatment) to 27.37% (FS, RG treatment). The values were found to be high during the monsoon season and low during post monsoon season in all the treatment.
- The pH ranged from 4.05 (CTRL, PC stage) to 5.36 (RG, PHV stage). The values were found to be lower during PC stage and high during PHV stage.
- Soil organic carbon was found to be lower during post monsoon or PHV stage and higher during the monsoon or FS.
- The total nitrogen values was found to be lowest during PHV of SG treatment (0.15%) and highest during FS of Control treatment (0.34%).
- The control treatment show consistent high P_{avail} concentration during the three sampling season ranging from 13.87 mg g^{-1} to 16.77 mg g^{-1}. In RG treatment, the P_{avail} concentration ranged from 7.47 mg g^{-1} to 12.98mg g^{-1}; 5.88 mg g^{-1} to 13.26mg g^{-1} and 13.87 mg g^{-1} to 16.77 mg g^{-1} in SG treatment.

- Exchangeable K showed no significant effect between the Season (S) and their interaction (TxS), while it varied significantly between treatments (T) ($p<0.05$).

- NH_4^+-N concentration varied from 7.26 mg g^{-1} to 13.98 mg g^{-1} in RG treatment followed by 5.81 mg g^{-1} to 10.07 mg g^{-1} in Control treatment and the least in SG treatment ranging from 2.31 mg g^{-1} to 5.46 mg g^{-1} during the three sampling season.

- The values of NO_3-N in RG treatment ranged from 2.69 mg g^{-1} to 6.43 mg g^{-1} during PC, FS and PHV.

- Different treatment (T), Season (S) and their interaction (TxS) significantly ($p<0.05$) influenced soil microbial biomass carbon in all the study sites. . During PHV season, MBC showed a decreasing trend in all the three treatment while the highest concentration of MBC was observed during the flowering stage of the sampling season.

- The number of colonies counted in fungal population ranged from 50.4 CFU 10^3g^{-1} to 62.7 CFU 10^3g^{-1} in RG; 33.7 CFU 10^3g^{-1} to 52.4CFU 10^3g^{-1} in SG and 57.3CFU 10^3g^{-1} to 69.1CFU 10^3g^{-1} in CTRL treatment in all the three sampling season.

- The number of bacterial colonies counted in RG was 118.8 CFU 10^6g^{-1} to 142.4 10^6g^{-1} followed by 66.8 10^6g^{-1} to 104.7 10^6g^{-1} in SG and 135.410^6g^{-1} to 182.310^6g^{-1} in CTRL treatment during PC, FS and PHV respectively.

- The actinomycetes population was found highest in the CTRL plot (65.1 10^4g^{-1} to 75.7 10^6g^{-1}) followed by RG (58.4 10^4g^{-1} to 72.0 10^4g^{-1}) and the least in SG treatment (47.2 10^4g^{-1} to 59.6 10^4g^{-1}).

- The tallest plants (73.7cm) were recorded under intercrop rubber plantation (RG) at 24 weeks after planting (WAP) and the shortest plants (24.16 cm) were observed under sole ginger (SG) at 4WAP. The pattern of plant height observed in both RG and SG treatment was as 24WAP>20WAP>16WAP>12WAP>8WAP>4WAP.

- In RG intercrop treatment the number of tillers ranged from 1.27 to 24.1 and 1.94 to 22 in sole ginger (SG) treatment. The lowest number of tiller per plant was observed during 4WAP (1.27) of RG treatment.
- Yield attributes of ginger such as number of primary fingers and length of finger of ginger were higher in rubber shade (2.83 and 12.9 cm respectively) compared to sole cropping (2.66 and 7.52 cm respectively).
- The number of primary, secondary and tertiary fingers of the harvested ginger rhizome in RG treatment ranged from 2.83 to 7.25 and in SG treatment the number of fingers ranged from 2.66 to 5.75.
- The number of primary finger in RG and SG treatment were 2.83 and 2.66 respectively. The number of secondary finger was higher in SG as compared to RG treatment with values 5.58 and 5.75.
- The length and diameter of the ginger rhizome ranges 12.90cm and 7.64cm respectively in the rubber ginger intercropped plot. In sole ginger plot, the length and diameter of the ginger size was recorded as 11.93 cm and 7.52 cm respectively.

The overall findings show that there was a seasonal fluctuation in the values of various physico-chemical characteristics in the soil. All the soil values lie within the permissible limit as given by different scientific researcher. Most of those studies have been confined to the sole cropping systems of rubber; however, according to the present study, intercropping ginger with rubber undoubtedly improves the growth rate of ginger. Not only the fact that the improved growth of ginger in the rubber/ginger system is a good sign which invites more farmers to practice the same, on-farm conditions provide additional confidence to them. The above analysis shows that intercropping in rubber plantation is not so popular in Mizoram. In immature rubber plantation growers can cultivate various crops/fruits like banana, pineapple, tea, ginger, turmeric, agar etc. The rubber-food crops intercropping help farmers to produce food and generate income. Therefore, it is a veritable tool to rural poverty reduction, and employment generation, if properly adopted by farmers. Therefore, intercropping in rubber plantation shows a new way for earning additional income from rubber plantation and it also helps solving nutrition problem among tribal people. In certain cases, intercropping can be extended into the fourth or fifth year if the intercrops are shade tolerant. The current research supports the notion that the sole ginger soil under cultivation is subject to a number of disturbances as a result of the management practises that have been implemented, as well as the regular growth and harvesting of crops that add less organic matter to the soil and thus contribute to its depletion. Additionally, compared to sole ginger soil, the soil from control and rubber plantations had greater values for soil porosity, moisture content, soil organic carbon and matter levels, total nitrogen, available phosphorus, and available potassium. High SMC values under RG treatment is clear evidence that agroforestry systems could be more effective in the conservation of soil moisture through supply of litter to cover soil surface and the effects of the canopy cover.

The present study concluded that the clearing of native forests for cultivation led to negative feedbacks on soil. From our result, the effect of jhum land and/or monoculture clearly indicates the decline of soil fertility. To regain the soil fertility, at least lengthening of the fallow period should be considered or either the fertility of the soil should be enhanced with suitable and appropriate fertilizers to keep the productivity of the land. Thus, a diversified land use system i.e. agroforestry will increase the soil fertility status, increased crop yield and forest wealth; improve the biodiversity and environment degradation. However, careful consideration should be given in selecting the right combination of soil-enriching nitrogen-fixing tree species, as well as remunerative pulses/legumes with adequate surface-covering capability, to ensure long-term land productivity. Therefore, it can be concluded that for reclamation and restoration of soil health in degraded jhum lands, especially in Northeastern Hilly Regions of India, adoption of agroforestry system can be a viable option, provided selection of proper combination of crops and trees are done which should be soil enriching and complimentary to each other. Agroforestry system also helps in providing an alternate livelihood strategy to many people.

Our results indicate that native forest conversion for cropping and other management techniques in small-scale agro-ecosystems causes soil quality to deteriorate and inhibits sustainability. The findings showed SOM have a significant impact on a variety of soil characteristics, particularly soil aggregation, which is one of the most significant soil features and is responsible for maintaining soil fertility in general as well as the conservation of soil nutrients. The management of SOM targeted at repletion and retention is a crucial component in creating management strategies and choosing land use systems due to their significant significance and influence on soil health. Adopting appropriate agricultural techniques and methods that will improve soil qualities is crucial. Our understanding of the effects of the conversion of native forests to other land uses, such as cropping, and management practises on soil physico-chemical and biological properties would be improved by the study's findings and conclusions. Adoption of any agro-ecosystems in the current context of land use change should focus on suitable management strategies targeted at protecting and enhancing soil qualities in order to attain sustainability.

Many researchers have testified the impact of rubber plantations on soil health. Soil erosion is a global problem and rubber plantation can play a role in reinstating soil erosion. Due to the effects of rainfall, there is an increase in the breakdown of organic matter, release of nutrients, and failure of the surface soil's collective structure. Therefore, introduction of suitable intercrops which helps to minimize the effects of erosion in relation to the addition of nutrients in the soil should be carried out. Based on the study on the selected soil physicochemical properties showed that they are low for cultivated land; this implies that inputs either in the form of organic or inorganic fertilizer needs to be added adequately so that the cultivated land will continue to give better productivity. 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. A similar system could be introduced in the estate sector allowing poorly paid farmers to cultivate cash crops on immature rubber lands during their free time and raise the income, while the estate management to reduce the cost on immature upkeep.

With regard to the soil hydro-physical properties, greater improvements were observed under the rubber-ginger intercropping systems than the monocropping systems. Additionally, the study has revealed that rubber has the ability to improve soil physical and hydraulic parameters through surface cover by litter fall and canopy cover, and also root coverage in the soil. This study has revealed the potential of agroforestry under rubber to present an opportunity in increasing land productivity and improve soil fertility. In addition, agroforestry practices can increase the nutrient cycling, control of surface runoff and/or erosion, and C sequestration.

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PHOTO PLATES

Photo plate 1: Rubber + ginger plantation

Photo plate 2: Sole ginger cultivation

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DATE OF ADMISSION : 06.08.2014
APPROVAL OF RESEARCH PROPOSAL

1. DRC : 28.04.2015
2. BOS : 08.05.2015
3. SCHOOL BOARD : 19.05.2015

MZU REGISTRATION NO : 5758 of 2012

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EXTENSION (IF ANY) : No. 17-1/MZU (Acad)/20/22 (7th Dec 2021)

HEAD

Department of Forestry

ABSTRACT

CROP PRODUCTION AND SOIL PROPERTIES IN GINGER-BASED AGROFORESTRY SYSTEM IN MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DEPARTMENT OF FORESTRY
SCHOOL OF EARTH SCIENCE AND NATURAL RESOURCES MANAGEMENT
JUNE 2022

CROP PRODUCTION AND SOIL PROPERTIES IN GINGER-BASED AGROFORESTRY SYSTEM IN MIZORAM

BY

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Department of Forestry

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Submitted

In partial fulfillment of the requirement of the Degree of

Doctor of Philosophy in Forestry of Mizoram University, Aizawl.

Ginger (*Zingiber officinale* Rosc) a member of Zingiberaceae family, is a perennial herbaceous monocotyledon, typically grown as an annual, and is known to human generations as a medicinal and spice crop. Ginger is one in all the foremost important cash crops in Mizoram, and is usually grown in Jhum land. Because Mizoram's agro-climatic conditions are favourable for ginger cultivation, cultivars do not use manures, fertilizers or pesticides. Its cultivation as a harvest within the state is known to have started in late 1970s. Thingpui, Thingria and Thinglaidum are the three major varieties of ginger grown in Mizoram of which Thinglaidum is the most popular. However, this variety of ginger does not seem to have any implication in the price fetched and hence, most of the farmers are unaware of the quality of the variety they grow.

The planting season of ginger in Mizoram starts during the month of April-May that coincides with onset of monsoon. The first two weeks of April is the best time for planting ginger. The stored rhizome of ginger for planting should be sorted with large, shiny; disease-free, spots, marks, bud or eye injury should be selected for planting. The seed rhizome can be planted whole or broken into parts, with each cutting bearing 2-4 sprouts. Ginger is one of the most suitable vegetables for intercropping in agroforestry systems in pre humid- sub humid and semi humid-semiarid regions from lowlands (%00mt) to medium elevation (500-1000mt).

Extensive cultivation methods like heavy spading, earthing up, crop cultivation along with slope, slash and burn caused soil loss from the hill slope for cultivation of different crops. The hilly people cultivate ginger, turmeric, aroid and jhum rice along the slope land of the hill. They usually harvest the rhizome from soil by spade. Thus, soils become loose and soil erosion occurs in hilly areas that causes appreciable depletion in organic matter content resulting nutrient exhaustion in soil. This accelerates soil erosion and causes flash floods.

Agroforestry systems have enormous potential for improving the productivity and sustainability of agricultural lands or land resources, which have never been put into service due to so many factors, can be better used by adopting different agroforestry practices like inclusion of ginger cultivation in it for high remuneration and useful combination, if properly managed could increase the production potential sufficiently. Hence, such systems need to be made popular among farmers for sustainable livelihood.

Study site: The study was conducted at Kawnpui, Mizoram where ginger (*Zingiber officinale* Rosc.) and rubber (*Hevea brasiliensis)* are intercropped. Kawnpui is a village in Kolasib District of Mizoram. It is 10 km south of the district headquarters in Kolasib and 56 km north of the state capital in Aizawl. The study site is located between the latitudes of $24^{o}05'13''$ N and the longitudes of $92^{o}67'21''$ E. It is situated at an altitudinal range of 930 m (3050 ft) msl. The average temperature of the study area ranges from 11^{o}C to 34^{o}C. The annual rainfall varies from 2500 to 3000mm.

Soil sampling: Soil samples of three replicates at a depth of 0-15cm were collected at an interval of (i) Pre-cultivation (April/May); (ii) Flowering stage (Sept/Oct); and (iii) Post Harvest (Feb/Mar) within each treatment i.e., Rubber + Ginger (RG), Sole Ginger (SG) and Control (CTRL). Roots, stones, and other debris were removed, and the soil was hand sieved through a 2 mm mesh and divided into two parts. One component was air dried, while the other was stored in the deep freezer for later analysis.

Analysis of soil properties: Soil bulk density (BD) was determined by taking a known volume of soil and pressing a metal ring into it (intact core), then weighing it after drying. The hydrometer method was used to determine the texture of the soil. The textural classification of the United States Department of Agriculture (USDA) was used to determine the textural class of the soil. A pH analyzer was used to measure the pH of the soil in a soil-water suspension (1:2.5 soil-water ratios). The soil moisture content was determined using the gravimetric method (SMC). Soil organic carbon (SOC) and total nitrogen (TN) was determined by dry combustion in a CHNS/O Elemental Analyzer with auto sampler and TCD detector –Euro Vector, Model: EuroEA3000. For the analysis of soil exchangeable nutrients (P_{avail} and K) air dried soil samples were extracted in Mehlich-I solution (0.05 M HCl + 0.025 M

H_2SO_4) and analyzed using the inductively coupled plasma spectrometer (iCAP6300 series, Thermo scientific).

The physical properties of the soils studied were found to be significantly different between the treatment ($p<0.05$). Bulk density (BD) values ranged from 0.98g/cm^3-1.36g/cm^3 with maximum density in intercropped ginger (RG) followed by SG>Control. Due to extensive root growth and dense root distribution, the control site may have the lowest bulk density when compared to other land uses. The loss of soil organic matter (SOM) caused by the conversion of natural forests to plantations is thought to have resulted in increased bulk density in plantation soils. In Indonesia, higher bulk densities were previously recorded under intense rubber plantation. All of the treatments had sandy loam soil texture, with sand, silt, and clay values ranging from 59.8% to 60.5%, 21.2% to 29.6%, and 12.3% to 19.8%, respectively. In different Mizoram land use systems, the percentages of sand, silt, and clay were 62–72 percent, 17–21 percent, and 11–17 percent, respectively.

The pH of the soil differed significantly between treatments (T) and seasons (S) (p0.05), but not between their interactions. Soil pH was acidic in all the treatments ranging from 4.9 to 6.05 in PC, 5.16 to 6.07 in FS and 5.26 to 6.19 in PHV. Higher soil pH in the surface layer of SG and Control as compared to RG is well attributed to the release of cation as a result of the traditional slash and burn technique in the SG land use system. Burning enhances the release of nutrients in the soil and thus increasing the soil pH. The higher values of pH in the cultivated lands may also result from the conversion of natural forest into cultivation, which leads to an increment in pH at the surface soil layers. The present values of pH are in accordance with other findings from the study area, indicating strongly acidic natures of reaction in these soils. Similarly, the moisture content was also higher in Control soils. High organic matter content and dense vegetation in the Control site probably conserve the soil moisture. Forest conversion to plantations has been documented to result in low moisture availability due to losses in top soil and vegetation in Indonesia, Peru, and Southern Cameroon.

Different treatments (T), seasons (S), and their interactions (TxS) all had a significant impact on soil organic carbon ($p<0.05$). The highest value during the flowering stage (FS) was reported from SG followed by RG and the least in Control with values of 2.79%, 2.69% and 2.43%, respectively. However, during PHV Soil Organic Carbon is highest in Control treatments (2.27%). The high SOC in the Control site can be attributed to a large quantity of litter decomposition and soil nitrogen availability. Higher organic matter and nutrient inputs through litter fall have been reported to have a favourable impact on soil organic matter. In tropical ecosystems, SOC availability is a good indicator of soil nutrient supply.

The value of TN was found highest during the FS Stage of the Control site (0.34%) followed by SG (0.28%)>RG (0.27%). Total Nitrogen was significantly affected by different treatments (T) and stages (S) but does not show significant affect between their interactions (TxS). Available forms of nitrogen play an important role in N transformation. P_{avail} concentrations in soil were significantly affected by different stages (S) and their interactions (TxS) ($p<0.05$). The highest value was recorded at the Control site during the flowering stage (FS) (16.77 mg g^{-1}) and the least in R+G (7.47mg g^{-1}). The higher P_{avail} content in the Control site could be attributable to the quick recycling of nutrients through litter breakdown and mineralization. Less use of FYM, no addition of chemical fertilizers, higher leaching loss from litter residues may also have resulted in low P content in the soils of rubber plantation. In addition, SOM influences P_{avail} through anion replacement of H2PO4 from adsorption sites and the formation of organophosphate complexes which are readily taken up by plants as reported in different studies. Our values of P_{avail} falls within the range of low to medium among the various land use systems and soil depths as per the range of. Exchangeable K showed no significant affect between the Season (S) and their interaction (TxS), while it varied significantly between treatments (T) ($p<0.05$). The greater exchangeable K values in both RG and CTRL could be attributed to the establishment and presence of herbaceous vegetation and canopy cover that shielded the soil from direct rainfall and reduced nutrient loss through runoff and erosion.

NH_4^+-N concentration varied from 7.26 mg g^{-1} to 13.98 mg g^{-1} in RG treatment followed by 5.81 mg g^{-1} to 10.07 mg g^{-1} in Control treatment and the least in SG treatment ranging from 2.31 mg g^{-1} to 5.46 mg g^{-1} during the three sampling season. The values of NO_3-N in RG treatment ranged from 2.69 mg g^{-1} to 6.43 mg g^{-1} during PC, FS and PHV. Different treatment (T), Season (S) and their interaction (TxS) significantly ($p<0.05$) influenced soil microbial biomass carbon in all the study sites. . During PHV season, MBC showed a decreasing trend in all the three treatment while the highest concentration of MBC was observed during the flowering stage of the sampling season. The number of colonies counted in fungal population ranged from 50.4 CFU $10^3 g^{-1}$ to 62.7 CFU $10^3 g^{-1}$ in RG; 33.7 CFU $10^3 g^{-1}$ to 52.4CFU $10^3 g^{-1}$ in SG and 57.3CFU $10^3 g^{-1}$ to 69.1CFU $10^3 g^{-1}$ in CTRL treatment in all the three sampling season. The number of bacterial colonies counted in RG was 118.8 CFU $10^6 g^{-1}$ to 142.4 $10^6 g^{-1}$ followed by 66.8 $10^6 g^{-1}$ to 104.7 $10^6 g^{-1}$ in SG and 135.4$10^6 g^{-1}$ to 182.3$10^6 g^{-1}$ in CTRL treatment during PC, FS and PHV respectively. The actinomycetes population was found highest in the CTRL plot (65.1 $10^4 g^{-1}$ to 75.7 $10^6 g^{-1}$) followed by RG (58.4 $10^4 g^{-1}$ to 72.0 $10^4 g^{-1}$) and the least in SG treatment (47.2 $10^4 g^{-1}$ to 59.6 $10^4 g^{-1}$).

The tallest plants (73.7cm) were recorded under intercrop rubber plantation (RG) at 24 weeks after planting (WAP) and the shortest plants (24.16 cm) were observed under sole ginger (SG) at 4WAP. The pattern of plant height observed in both RG and SG treatment was as 24WAP>20WAP>16WAP>12WAP>8WAP>4WAP. In RG intercrop treatment the number of tillers ranged from 1.27 to 24.1 and 1.94 to 22 in sole ginger (SG) treatment. The lowest number of tiller per plant was observed during 4WAP (1.27) of RG treatment. Yield attributes of ginger such as number of primary fingers and length of finger of ginger were higher in rubber shade (2.83 and 12.9 cm respectively) compared to sole cropping (2.66 and 7.52 cm respectively). The number of primary, secondary and tertiary fingers of the harvested ginger rhizome in RG treatment ranged from 2.83 to 7.25 and in SG treatment the number of fingers ranged from 2.66 to 5.75. The number of primary finger in RG and SG treatment were 2.83 and 2.66 respectively. The number of secondary finger was higher in SG as compared to RG treatment with values 5.58 and 5.75. The length and diameter of the ginger rhizome ranges 12.90cm and 7.64cm respectively in the rubber ginger intercropped plot. In sole ginger plot, the length and diameter of the ginger size was recorded as 11.93 cm and 7.52 cm respectively.

Conclusion

The overall findings show that there was a seasonal fluctuation in the values of various physico-chemical characteristics in the soil. All the soil values lie within the permissible limit as given by different scientific researcher. Most of those studies have been confined to the sole cropping systems of rubber; however, according to the present study, intercropping ginger with rubber undoubtedly improves the growth rate of ginger. Not only the fact that the improved growth of ginger in the rubber/ginger system is a good sign which invites more farmers to practice the same, on-farm conditions provide additional confidence to them. The above analysis shows that intercropping in rubber plantation is not so popular in Mizoram. In immature rubber plantation growers can cultivate various crops/fruits like banana, pineapple, tea, ginger, turmeric, agar etc. The rubber-food crops intercropping help farmers to produce food and generate income. Therefore, it is a veritable tool to rural poverty reduction, and employment generation, if properly adopted by farmers. Therefore, intercropping in rubber plantation shows a new way for earning additional income from rubber plantation and it also helps solving nutrition problem among tribal people. In certain cases, intercropping can be extended into the fourth or fifth year if the intercrops are shade tolerant. The current research supports the notion that the sole ginger soil under cultivation is subject to a number of disturbances as a result of the management practices that have been implemented, as well as the regular growth and harvesting of crops that add less organic matter to the soil and thus contribute to its depletion. Additionally, compared to sole ginger soil, the soil from control and rubber plantations had greater values for soil porosity, moisture content, soil organic carbon and matter levels, total nitrogen, available phosphorus, and available potassium. High SMC values under RG treatment is clear evidence that agroforestry systems could be more effective in the conservation of soil moisture through supply of litter to cover soil surface and the effects of the canopy cover.

Many researchers have testified the impact of rubber plantations on soil health. Soil erosion is a global problem and rubber plantation can play a role in reinstating soil erosion. Due to the effects of rainfall, there is an increase in the breakdown of organic matter, release of nutrients, and failure of the surface soil's collective structure. Therefore, introduction of suitable intercrops which helps to minimize the effects of erosion in relation to the addition of nutrients in the soil should be carried out. Based on the study on the selected soil physicochemical properties showed that they are low for cultivated land; this implies that inputs either in the form of organic or inorganic fertilizer needs to be added adequately so that the cultivated land will continue to give better productivity. 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. A similar system could be introduced in the estate sector allowing poorly paid farmers to cultivate cash crops on immature rubber lands during their free time and raise the income, while the estate management to reduce the cost on immature upkeep.

The present study concluded that the clearing of native forests for cultivation led to negative feedbacks on soil. From our result, the effect of jhum land and/or monoculture clearly indicates the decline of soil fertility. To regain the soil fertility, at least lengthening of the fallow period should be considered or either the fertility of the soil should be enhanced with suitable and appropriate fertilizers to keep the productivity of the land. Thus, a diversified land use system i.e. agroforestry will increase the soil fertility status, increased crop yield and forest wealth; improve the biodiversity and environment degradation. However, careful consideration should be given in selecting the right combination of soil-enriching nitrogen-fixing tree species, as well as remunerative pulses/legumes with adequate surface-covering capability, to ensure long-term land productivity. Therefore, it can be concluded that for reclamation and restoration of soil health in degraded jhum lands, especially in Northeastern Hilly Regions of India, adoption of agroforestry system can be a viable option, provided selection of proper combination of crops and trees are done which should be soil enriching and complimentary to each other. Agroforestry system also helps in providing an alternate livelihood strategy to many people.

Our results indicate that native forest conversion for cropping and other management techniques in small-scale agro-ecosystems causes soil quality to deteriorate and inhibits sustainability. The findings showed that TOC and SOM have a significant impact on a variety of soil characteristics, particularly soil aggregation, which is one of the most significant soil features and is responsible for maintaining soil fertility in general as well as the conservation of soil nutrients. The management of TOC and SOM targeted at repletion and retention is a crucial component in creating management strategies and choosing land use systems due to their significant significance and influence on soil health. Adopting appropriate agricultural techniques and methods that will improve soil qualities is crucial. Our understanding of the effects of the conversion of native forests to other land uses, such as cropping, and management practices on soil physico-chemical and biological properties would be improved by the study's findings and conclusions. Adoption of any agroecosystems in the current context of land use change should focus on suitable management strategies targeted at protecting and enhancing soil qualities in order to attain sustainability.