ECOLOGICAL IMPACT OF OIL PALM (*Elaeis guineensis* Jacq.) PLANTATION IN KOLASIB DISTRICT, MIZORAM

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

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CERTIFICATE

This is to certify that this study **"Ecological impact of oil palm (*Elaeis guineensis* Jacq.) plantation in Kolasib district, Mizoram."** submitted by Lalawmpuia (MZU/Ph.D./1282 of 06.09.2018) in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Botany is a record of bonafide work carried out by him under my supervision and guidance.

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DECLARATION

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JULY, 2024

I **LALAWMPUIA**, 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 Botany.

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TABLE OF CONTENTS

	Supervisor's certificate	i
	Declaration certificate	ii
	Acknowledgement	iii
	Table of contents	iv-v
	List of Tables	vi-x
	List of Figures	xi-xiv
	Abbreviations	xv-xvi
Chapter 1	**Introduction**	**1-19**
Chapter 2	**Review of Literature**	**20-43**

2.1. Oil palm plantation

2.2. Soil Physicochemical Properties

2.3. Soil Microbial Biomass Carbon and Soil Enzymes

2.4. Natural Habitats and Species diversity

2.5. Socio economic impact

Chapter 3	**Materials and Methods**	**44-59**

3.1. Study site and soil sampling

3.2 Soil physico-chemical properties

3.3. Soil enzyme activities and microbial biomass carbon

3.4. Species diversity

3.5. Socio-economic impact

Chapter 4	**Soil Physico-chemical property**	**60-98**

4.1. Introduction

4.2. Result

3.5. Discussion

Chapter 5 **Soil enzyme activity and microbial biomass carbon** **99-120**

5.1. Introduction

5.2. Result

5.3. Discussion

Chapter 6 **Principal Component Analysis of soil physico-chemical properties, enzyme activities and soil microbial biomass carbon** **121-132**

6.1. Introduction

6.2. Result

6.3. Conclusion

Chapter 7 **Plant species diversity under oil palm plantation** **133-143**

7.1. Introduction

7.2. Methodology

7.3. Data analysis

7.4. Result

7.5. Discussion

Chapter 8 **Socio economic impact of oil palm plantation** **144-152**

8.1. Introduction

8.2. Methodology

8.3. Result

8.4. Discussion

Chapter 9 Summary and conclusion 153-156

References 157-174

Photo plate 175

Bio-data 176

List of seminars and workshops 177

Particulars of the candidate 178

LIST OF TABLES

Table 4.1: One-way ANOVA of pH level in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Table 4.2: One-way ANOVA of pH level in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Table 4.3: One-way analysis of variance (ANOVA) of Soil Moisture Content in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Table 4.4: One-way analysis of variance (ANOVA) of Soil Moisture Content in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Table 4.5: One-way analysis of variance (ANOVA) of Soil Bulk Density in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Table 4.6: One-way analysis of variance (ANOVA) of Soil Bulk Density in different soil samples such as 3 years (3y), 5 years(5y), 10 years (10y) and 15 years(15y) from plot 2 and undisturbed forest (UD).

Table 4.7: One-way ANOVA of Soil Water Holding Capacity in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Table 4.8: One-way ANOVA of Soil Water Holding Capacity in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Table 4.9: One-way ANOVA on the level of Soil Organic Carbon (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Table 4.10: One-way ANOVA on the level of Soil Organic Carbon (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Table 4.11: One-way ANOVA on the level of Soil Total Nitrogen (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Table 4.12: One-way analysis of variance ANOVA on the level of Soil Total Nitrogen (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Table 4.13: One-way ANOVA on the level of Soil Available Phosphorus (Kg ha^{-1}) in different soil samples such as 3 years , 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Table 4.14: One-way ANOVA on the level of Soil Available Phosphorus (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Table 4.15: One-way ANOVA on the level of Soil exchangeable Potassium (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Table 4.16: One-way ANOVA on the level of Soil exchangeable Potassium (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Table 5.1: One-way ANOVA of Soil Dehydrogenase Activity (µgTPF ml^{-1} 24 hrs^{-1}) in different soil samples of plantation ages such as 3 years, 5

years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Table 5.2: One-way ANOVA of Soil Dehydrogenase Activity (μgTPF ml^{-1} 24 hrs^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 and from undisturbed forest (UD).

Table 5.3: One-way ANOVA on the level of Acid Phosphatase Activity(μg p-NP ml^{-1} hr^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Table 5.4: One-way ANOVA on the level of Acid Phosphatase Activity(μg p-NP ml^{-1} hr^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Table 5.5: One-way ANOVA on the level of Urease Activity (μg NH_3 g dry soil-^{1} 2hr-^{1})in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Table 5.6: One-way ANOVA on the level of Urease Activity (μg NH_3 g dry soil-^{1} 2hr-^{1})in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Table 5.7: One-way ANOVA on the level of Microbial Biomass Carbon C_{mic} (mg kg^{-1})in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Table 5.8: One-way ANOVA on the level of Microbial Biomass Carbon C_{mic} (mg kg^{-1})in different soil samples of plantation ages such as 3 years, 5

years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Table 6.1: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physicochemical properties across oil palm age.

Table 6.2: Variable correlations with principal component analysis (PCA) components for soil physicochemical properties across oil palm age.

Table 6.3: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physicochemical properties during study months of oil palm.

Table 6.4: Variable correlations with principal component analysis (PCA) components for soil physicochemical properties during study months of oil palm.

Table 6.5: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physicochemical properties within study plots of oil palm.

Table 6.6: Variable correlations with principal component analysis (PCA) components for soil physicochemical properties within study plots of oil palm.

Table 7.1: Distribution of species within oil palm plantation site.

Table 7.2: Diversity indices of plant species within oil palm plantation site.

LIST OF FIGURES

Figure 3.1. Map of North East India showing Mizoram.

Figure 3.2. Map of the study site at Buhchangphai, Kolasib District, Mizoram.

Figure 3.3. Soil sample collection site of Plot 1 (P1) and Plot 2 (P1).

Figure 3.4. Sample collection and analysis during the study period.

Figure 4.1. Soil pH in different oil palm plantation ages and undisturbed (UD) forest in 2019.

Figure 4.2. Soil pH in different oil palm plantation ages and undisturbed (UD) forest in 2020.

Figure 4.3. Soil pH in different oil palm plantation ages and undisturbed (UD) forest in 2021.

Figure 4.4. Soil Moisture Content of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019.

Figure 4.5. Soil Moisture Content of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020.

Figure 4.6. Soil Moisture Content of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021.

Figure 4.7. Soil Bulk Density of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019.

Figure 4.8. Soil Bulk Density of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020.

Figure 4.9. Soil Bulk Density of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021.

Figure 4.10. Soil Water Holding Capacity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019.

Figure 4.11. Soil Water Holding Capacity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020.

Figure 4.12. Soil Water Holding Capacity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021.

Figure 4.13. Soil Organic Carbon (%) of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019.

Figure 4.14. Soil Organic Carbon (%) of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020.

Figure 4.15. Soil Organic Carbon (%) of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021.

Figure 4.16. Soil Total Nitrogen (%) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019.

Figure 4.17. Soil Total Nitrogen (%) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020.

Figure 4.18. Soil Total Nitrogen (%) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021.

Figure 4.19. Soil available Phosphorus Kg ha-1 of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019.

Figure 4.20. Soil available Phosphorus Kg ha-1 of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020.

Figure 4.21. Soil available Phosphorus Kg ha-1 of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021.

Figure 4.22. Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019.

Figure 4.23. Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020.

Figure 4.24. Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021.

Figure 5.1. Soil Dehydrogenase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019.

Figure 5.2. Soil Dehydrogenase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020.

Figure 5.3. Soil Dehydrogenase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021.

Figure 5.4. Soil Apase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2019.

Figure 5.5. Soil Apase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2020.

Figure 5.6. Soil Apase Activity of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2021.

Figure 5.7. Soil urease Activity of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019.

Figure 5.8. Soil urease Activity of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020.

Figure 5.9. Soil urease Activity of different ages of plantation (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021.

Figure 5.10. Microbial Biomass Carbon (C_{mic}) in soil of different plantation ages and undisturbed (UD) forest in 2019.

Figure 5.11. Microbial Biomass Carbon (C_{mic}) in soil of different plantation ages and undisturbed (UD) forest in 2020.

Figure 5.12. Microbial Biomass Carbon (C_{mic}) in soil of different plantation ages and undisturbed (UD) forest in 2021.

Figure 6.1a. Principal component analysis (PCA) for soil physicochemical properties across oil palm ages. Contribution of each principal component to total variance.

Figure 6.1b. Principal component analysis (PCA) for soil physicochemical properties across oil palm ages**.** Biplot of individuals and variables (PC1 & PC2).

Figure 6.1c. Principal component analysis (PCA) for soil physicochemical properties across oil palm ages**.** Principal components and their relation with variables.

Figure 6.2a. Principal component analysis (PCA) for soil physicochemical properties across study months of oil palm. Contribution of each principal component to total variance.

Figure 6.2b. Principal component analysis (PCA) for soil physicochemical properties across study months of oil palm. Biplot of individuals and variables (PC1 & PC2).

Figure 6.2c. Principal component analysis (PCA) for soil physicochemical properties across study months of oil palm. Principal components and their relation with variables.

Figure 6.3a. Principal component analysis (PCA) for soil physicochemical properties within study plots of oil palm. Contribution of each principal component to total variance.

Figure 6.3b. Principal component analysis (PCA) for soil physicochemical properties within study plots of oil palm. Biplot of individuals and variables (PC1 & PC2).

Figure 6.3c. Principal component analysis (PCA) for soil physicochemical properties within study plots of oil palm. Principal components and their relation with variables.

Figure 6.4. Correlation heat map of different soil properties in oil palm plantation during the study period.

Figure 7.1. Family distribution and number of species under oil palm plantation.

Figure 7.2. Total number of individual species for each family.

Figure 8.1. Age distribution of oil palm farmers.

Figure 8.2. Gender distribution of oil palm farmers.

Figure 8.3. Educational status of oil palm farmers.

Figure 8.4. Main source of income among farmers.

Figure 8.5. Year of starting of oil palm plantation.

Figure 8.6. Reason for choosing OPP by farmers.

Figure 8.7. Satisfactory level of farmers on OPP.

Figure 8.8. Annual income of farmers from OPP.

Figure 8.9. Previous cultivation practice among farmers.

Figure 8.10. Type of land before oil palm cultivation.

ABBREVIATIONS

µl	Microlitre
ANOVA	Analysis of variance
AOAC	Association of official analytical collaboration
Apase	Acis phosphatase
BD	Bulk density
C	Carbon
cm	Centimetre
C_{mic}	Microbial biomass carbon
DHA	Dehydrogenase
FFB	Fresh fruit bunch
Fig	Figure
g	gram
ha	hectare
HCl	Hydrochloric acid
hrs	hours
K	Potassium
KCl	Potassium chloride
Kg	Kilogram
L	Litre
Ltd	Limited
M	Molar
mg	milligram

ml	mililiter
mm	milimeter
N	Nitrogen
NH_3	Ammonia
nm	Nanometre
NMOOP	National Mission on Oilseeds and Oil Palm
OPP	Oil palm plantation
OPF	Oil Palm Farmer
P	Phosphorus
P1	Plot 1
P2	Plot 2
p-NPP	p-nitrophenyl phosphate
ppm	parts per million
SMC	Soil moisture content
$SnCl_2$	Stannous chloride
SOC	Soil organic carbon
SOM	Soil organic matter
TN	Total nitrogen
UD	Undisturbed Forest
v/v	volume by volume
w/v	weight by volume
WHC	Water holding capacity

Chapter 1

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is currently the most economical, multifaceted but also contentious agricultural crop worldwide. *Elaeis guineensis* belongs to Asteraceae family and is commonly known as oil palm. It is occasionally referred to as the African oil palm or mascaw-fat. The species is native to tropical Africa, with its native range extending from Guinea to Angola (Corley & Tinker, 2003) Certain component parts of the plants have been utilised since at least 3000BC. The genus *Elaeis* is derived from the Greek word Elaion, which means oil (Hartley, 1988). The species name *guineensis* is derived from the name of its original geographical region, Guinea coast (Hartley 1988). The classification of oil palm is as follows:

Kingdom	: Plantae
Division	: Tracheophyta
Class	: Magniolopsida
Order	: Arecales
Family	: Arecaceae
Genus	: *Elaeis*
Species	: *guineensis*

Elaeis guineensis is a monocotyledonous plant. It is a single-stem structure that allows many fronds to emerge from the main trunk. Its stem bears a perfect cylindrical structure. A mature plant can reach a maximum height of approximately 20 m. The oil palm begins fruit production approximately three years after plantation and continues to do so until around 28 to 30 years, at which point it reaches its limits. Additionally, the stem grows excessively long, posing challenges in harvesting. Nevertheless, it has the ability to produce fruit for a maximum of 30 years. After 30 years, the tree is cut down to make way for a new plantation. The vascular stem generates approximately 30 to 40 pinnate fronds during the initial 10 years of the plant's growth and subsequently maintains a production rate of around 20 to 25 fronds as it matures. The frond typically reaches a height of 7 m; however, in certain case it may reach as high as 7.5 to 9 m. Each frond has an estimated number of leaflets, ranging from 250 to 400. The fronds are periodically removed in order to harvest the fruits.

A fully grown palm alternates between male and female inflorescence production during its life cycle as it is a monoecious plant. Insects and wind are the primary agents responsible for pollination (Pursglove, 1972). The *Elaeidobius* species function as popular pollinators (Syed, 1980). The oil palm tree starts producing Fresh Fruit Bunch (FFB) after three years on the axil of the frond base. A mature fruit bunch consists of hundreds to a few thousand fruits. The ripe fruit exhibits a reddish hue and possesses sizes comparable to that of a big plum. The weight of FFB exhibits significant variation, ranging from 5 to 50 kg, depending on factors such as the age of the crop, genetic characteristics, and environmental circumstances. A tree in good health yields harvestable FFB on a biweekly basis. Each fruit comprises around 50%

oil, and both the fleshy pulp (mesocarp) and the kernel (endocarp) have the potential to produce oil. However, only the pulp primarily extracts edible oils.

Oil palm cultivation have been established in multiple countries, primarily for economic reasons as well as for decorative purposes. The adaptability of oil palm to survive in harsh environmental conditions accounts for its extensive dispersion. The plant grows in regions with high water content, shallow lateritic or stony soils, sandy soils, and peatlands, as well as in regions with low annual rainfall of less than 800 mm, varying terrain from steep to mild slopes, and elevations of up to 1300 m above sea level. However, in order to cultivate cost-effective fruits that yield high-quality oil, it is essential to create optimal conditions for their cultivation. Tropical lowland regions below 500 m altitude, located between 10° N and 10° S, provide a suitable conditions for oil palm cultivation. These areas should get a minimum annual rainfall of 2000 to 2500 mm, with consistent rainfall throughout the year and no more than 3 consecutive dry months. The temperature fluctuates between 20°C and 35°C, while the soil composition varies from sandy clay loam to sandy clay texture. The soil is well-drained, and the areas range from plain to a slope of 4° (Goh et al., 2017).

In India, planting is mainly done between the months of June and December, with a preference for the monsoon season. Seedlings that are 12-16 months old are recommended for planting in the field. A triangular planting pattern is used on one hectare of land, with a spacing of 9 metres between each plant. A total of 143 plants are planted in this area. The act of planting involves creating a hole with dimensions of 60cm x 60cm x 60cm (length x width x height). To ensure the oil palm's productivity, sustainability, and high yield, it is essential to provide the palm tree with sufficient soil nutrients to maximise the production of FFB. It is imperative to monitor the output of FFB and the health of oil palm trees because of their significant land occupancy. Weeding is carried out frequently on the ground surrounding the tree. Agrochemicals, pesticides and herbicides are frequently being introduced in oil palm field. (https://vikaspedia.in/agriculture/crop-production/package-of-practices/oilseeds/oil-palm-cultivation-practices).

Elaeis guineensis is widely recognised as the predominant vegetable crop, constituting 38% of the global vegetable oil market (Spink and Rosi, 2014). The plant is usually referred to as oil palm due to its role as the primary provider of palm oil. Palm oil, also known as Palmolein, is widely regarded as one of the most cost-effective oils available today due to its capacity to be processed into a diverse range of goods. The crop is highly productive and incredibly versatile since it can be processed into biofuel, lubricant, and cooking oil and used as an ingredient in food and cosmetic industries (Nair, 2010). Palm oil, traded as vegetable oil, has gained significant popularity since the 1990s. Global oil manufacturing companies are searching for alternative oils that have the potential to replace unhealthy hydrogenated fats. Like most natural seed oils, palm oil contains less than one percent trans fat, so it can play an important role in a healthier diet. Palm oil possesses a superior shelf life in comparison to other vegetable oils. Additionally, unlike several counterparts, it solidifies at room temperature, rendering it an optimal raw material suitable for a diverse range of food applications. Due to its exceptional thermal stability, palm oil is highly suitable for cooking and frying purposes. Palm oil's elevated melting point renders it a cost-efficient alternative to animal fats in a wide range of products, including spreads and baked goods (Murphy et al., 2012). Additionally, it contributes to the production of several chemical compounds, such as sodium lauryl sulphate. This particular component is used as a foaming ingredient in common household cleaning products like soap and toothpaste. Consequently, it has made a significant impact on the market and may be found in a wide range of products available in stores, including animal feeds, chocolate, cookies, chips, lipstick, cream, and the pharmaceutical industry. Both kinds of oil, derived from the pulp and kernel, are used as ingredients in almost half of the fundamental items sold in a normal store. Approximately three billion individuals rely on palm oil as a basic ingredient in their diet, and it serves as a common cooking oil in African and Asian processing. Owing to the substantial surge in the global population, there exists a significant need for resources, particularly palm oil, which is highly probable to continue experiencing a substantial increase. Between 2000 and 2019, the worldwide output of vegetable oils increased by 125 percent, reaching 208 million metric tonnes in 2019. Among these, palm oil experienced the most substantial growth, 246%, or 52 million metric tonnes, in production (FAO, 2022). According to estimates from multiple industry sources, it is predicted that the global demand for palm oil by 2050 could range from 93 to 156 million metric tonnes (Frost and Sullivan, 2017; Harris et al., 2013; Pirker et al., 2016).

Oil palm is considered as highly lucrative crop, producing four to six tonnes of crude palm oil per hectare, in comparison to other oil producing seed plants which yield less than one tonne per hectare. Palm oil is not only one of the most affordable vegetable oils globally, but it is also very efficient compared to other oil-producing crops from a farmer's perspective. It is predicted that a single hectare of land may yield 4.17 metric tonnes of palm oil annually. Oil palm farming requires substantially less land clearance compared to other crops such as sunflower, as oil palms may produce the same quantity of vegetable oil using only a quarter or a fifth of the land required by sunflower crops.

The practice of oil palm cultivation originally emerged as an informal practice primarily limited to the coastal zone of West and Central Africa (Corley and Tinker, 2015). European merchants dealing in the West African region began sporadically acquiring palm oil for use in Europe in the seventeenth century, marking the first known use of palm oil outside of the African belt. Because palm oil was both abundant and inexpensive, and because it yielded greater profits from slave-trade, the trading of palm oil remained limited to regions outside of Africa. Indonesia and Malaysia began to cultivate oil palm in the 1910s, and it slowly spread to other tropical regions (Sati and Vangchhia, 2017). In Asia, cultivation did not initially commence as a large-scale commercial endeavour. Rather, British Malaya introduced it to Southeast Asia primarily for its aesthetic value as an ornamental tree. In 1917, Malaysia built the first crop-cultivating plantation. From the past two decades, oil palm plantations have expanded dramatically, especially in Southeast Asia (Koh, 2011). Currently, Indonesia and Malaysia are the primary producers of palm oil, accounting for over 80% of global production. Between 2006 and 2010, the area under oil palm cultivation in Indonesia increased by 2.37 million ha, bringing the total productive area of plantation estates to 5.9 million ha (Slette and Wiyono, 2011).

The initial introduction of oil palm in India occurred at the National Royal Botanical Gardens in Kolkata in 1886. The first extensive oil palm planting project took place from 1971 to 1984 in Kerala, led by the Plantation Corporation of Kerala Ltd., which was later acquired by Oil Palm India Ltd. Since the fiscal year 1991–92, the Government of India has made numerous endeavours to enhance the output of oilseeds and oil palm. The Department of Agriculture, Cooperation, and Farmers Welfare in India has designated 19.33 lakh hectares for cultivation of oil palm across 19 states, with the North Eastern States contributing 2.18 lakh hectares in 2012. In thirteen Indian states, oil palm practices is being stretch to an area of approximately 3,000,000 hectares as of 2016-17(http://nmoop.gov.in/Circulars/2017-18). The 2020 report from the Reassessment Committee of ICAR-IIOPR indicated a total of 22 states in India with a potential area of 28 lakh hectares for oil palm growth.

The National Mission on Oilseeds and Oil Palm (NMOOP) aims to promote the growth of oil palm farming in India, with a specific focus on the northeastern region. The north eastern states have been categorised as having significant potential for oil palm cultivation. Oil palm farming were started in multiple states in the North East, including Assam, Mizoram, Tripura, and Nagaland, between 2004 and 2008. Mizoram ranks among the top five states in terms of oil palm output area in India. The forested area of the state comprises 18,748 square kilometres, or 88.93%, of its total geographical area (21,081 square kilometres), however it account an area of only 138 square kilometres of very dense forest (India State of Forest report, 2015).

In 1999–2000, the first documented OPP in Mizoram took place in Thingdawl, Kolasib District, and the Rotlang area of Lunglei District. This introduction yielded good outcomes and a very promising result (agriculturemizoram.nic.in.). The Mizoram Legislative Assembly enacted "The Mizoram Oil Palm Act, 2004" on December 2, 2004, wherein it signed an MoU with three companies: Godrej Agrovet Ltd., Ruchi Soya Industries Ltd., and 3F. Subsequently, the 3F firm ceased operations. Godrej

Agrovet, located in Kolasib district, is the sole firm now engaged in the purchase of oil palm fresh fruit bunches (FFB) from farmers in the districts of Kolasib, Mamit, Aizawl, and Serchhip. Cultivation of oil palm in the lowlands of Mizoram is anticipated to boost the income of local farmers and contribute to the economic advancement of the impoverished rural population (Lalzarliana, 2015).

The government and collaborating firms successfully entice numerous farmers to initiate OPP and persuade them to switch from other plantations to OPP. Nurseries were provided at no cost, and other subsidies were also given to farmers. Additionally, farmers received cultivation assistance of 4000 rupees annually during the gestation period as part of the MM-II (Oil Palm) aid programme under NMOOP.

According to records from Godrej Agrovet Ltd., there are approximately 500 oil palm farmers in Mizoram. Mizoram's northern region is characterised by several small rivers and a gently sloping topography, making it suitable for OPP. The climate and soil conditions in northern Mizoram, characterised by low elevation and gentle slopes, are highly suitable for oil palm cultivation (Reddy, 2004). Mizoram possesses a forest cover of 15,94,000 hectares. The potential area for cultivating oil palm in Mizoram has been determined to be 1,01,000 hectares, with 61,000 hectares recognised by the Dr. K.L. Chadha Committee and an additional 40,000 hectares which has also been identified by the Dr. P. Rathinam Committee (https://agriculturemizoram.nic.in/pages/Oilpalm/Oil%20Palm%20data.pdf). The study site encompasses approximately 800 hectares, and the state administration has proposed expanding the property by an additional 61,000 hectares. On August 18, 2021, the Indian government launched the National Mission on Edible Oils-Oil Palm

(NMEO-OP), aiming to expand the cultivation of oil palm trees across 6.5 lakh hectares of land. This objective involves a significant growth of 3.28 lakh hectares in the northeastern states alone, and an additional 3.22 lakh hectares across the country over the next five years. The Mizoram government has been actively advocating for the expansion of oil palm since 2005. The Mizoram Agriculture Department states that oil palm is a suitable crop that may effectively contribute to soil and moisture conservation, land restoration, ecological equilibrium, and ensuring food security for both rural and urban populations with limited resources. Additionally, it asserts that the cultivation of oil palm will facilitate the economic advancement of farmers (http://agriculturemizoram.nic.in).

A significant number of farmers had chosen the OPP as an aspect of the then-Mizoram state government's main program, the New Land Use Policy (NLUP). Numerous farmers in the Kolasib district cultivate palm oil continuously throughout the year as an important source of income, allowing small-scale landowners to participate in the industry. Due to the rising demand for palm oil, numerous local farmers have transitioned from jhumming to cultivating oil palm since it offers greater profitability and reliability.

The proposal to expand oil palm cultivation in Mizoram has sparked extensive arguments. Indeed, numerous environmentalists and non-governmental organisations (NGOs) expressed their objection to this approach. It is important to acknowledge that north-east India is the second most biologically varied region in the world, according to Grenyer (2006). It is debatable whether OPP in this area may degrade the land and make it unsuitable for future crops. Tinker (1963) completed one of the initial studies examining the enduring changes resulting from oil palm cultivation in West Africa. Over the first five years of the plantation, there was a noticeable increase in soil fertility, possibly due to the excessive application of fertilizers. However, in the subsequent period, the levels of potassium (K) and magnesium (Mg), as well as the pH of the soil, fell, while the levels of soil organic carbon (C) remained consistent (Kowal and Tinker, 1959).

There is a pressing concern arising from the introduction of oil palm plantations in Mizoram and its plans for future expansion. The state government's primary initiative shows the main concern surrounding oil palm expansion, which is a threat towards deforestation. However, in Mizoram, oil palms may also be favoured over jhumming due to their permanent cultivation, which helps prevent the ongoing destruction of fresh forest areas. As stated by Raman (2014), the outcome of OPP is a notable reduction in forest cover, as the transformation of land for farming permanently hinders the regrowth of forests in those regions. There is a significant amount of land, around 1000 hectares, that has been specifically allocated for palm cultivation.

A survey on farmer's perception conducted by Sati and Vangchhia (2017), indicated that there is a decline in soil quality in OPP, and that farmers are concerned about the potential negative impact on the environment and further that factors such as soil fertility play a significant role in determining the sustainability of livelihoods. The establishment and potential expansion of oil palm plantations in Mizoram have ignited political and environmental debates. There are many misconceptions and uncertainties surrounding OPP; while some have started to replace it, others have only just begun to adopt it. Thus, it is crucial to carry out preliminary research and evaluation in the field. The study seeks to explore the current socioeconomic status of farmers and the various factors that impact their choice towards OPP. The study also examined the farmers' level of satisfaction, the difficulties they encounter on their land, their management techniques and marketing strategies, and how they perceive the OPP in relation to certain environmental issues.

An overview of the oil palm industry highlights numerous uncertainties have been ingrained in Mizoram by farmers, locals, environmental organisations, and other stakeholders. Economic prospects have been considered in conjunction with ecological impact. It is believed that the expansion of oil palm plantations poses an environmental and soil ecology risk. However, it has contributed significantly to the income of producers (Basiron 2007; Feintrenie et al., 2010 & Sati and Vanchhia, 2017). In recent times, a considerable number of producers have ceased oil palm cultivation in favour of alternative agricultural practices. Areca was introduced primarily as a substitute for the oil palm crops. Mono plantation has been implemented in the majority of plantation fields; nevertheless, it is recommended to adhere to proper sowing procedures and management. This significantly facilitates the development of additional advantageous plant varieties, including ground cover legume crops. For commercial plantations, where the introduction of another crop is more likely to degrade soil quality, sustainable practices are an urgent necessity.

Annually, the demand for palm oil continues to rise. North-east India is home to 67% of the country's remaining biodiversity (Phrang, 2018). From 2014 to 2021, local farmers sold FFBs to the company at a rate of Rs. 5.50 per kg. However, as determined by the price fixation committee of Mizoram, the rate have increase to Rs. 10.00 per kg in 2021. Recently, the price increase has prompted numerous producers to expand their plantations. The government encourages settled agriculture with oil palm plantations. Farmers experience consistent income growth over time through oil palm cultivation as compared to jhum cultivation. Additionally, by fulfilling their obligation to pay land tax, they also secure the renewal of their land lease. As a result of oil palm plantations, the greenhouse gas balance changes (Hamer, 1981) and the quality of the soil and water gets worse (Fitzherbert et al., 2008). Also, turning forest ecosystems into oil palm plantations has caused a lot of species to go extinct (Fitzherbert et al., 2008; Foster et al., 2011; Koh and Wilcove, 2008). Mizoram's agriculture has traditionally relied on shifting cultivation to support a large number of rural livelihoods. Given the lack of economic benefits that shifting cultivation offers to the local population, a considerable number of farmers have chosen to advocate for oil palm cultivation as a replacement practice. An additional concern is the establishment of numerous OPP in the southern region of Kolasib district following the clearance of primary and secondary forests.

Even though some researchers haven't found any major negative impacts of oil palm plantations on the local climate, biodiversity loss, groundwater, or soil quality (Seca et al., 2014; Nadeesha et al., 2016), many others have found a direct link between oil palm plantations and negative environmental impacts, such as higher carbon emissions, soil erosion, air and water pollution, and plant biodiversity loss (Danielsen et al., 2009; Koh and Wilcove, 2008, 2009; Sheil et al., 2009). As previously stated, there is a strong drive by the Central Government to promote oil palm cultivation throughout the nation, with a particular emphasis on the North Eastern States (Grenyer et al., 2006). The purpose of the research performed in Kolasib district is to quantify the degree of soil degradation under oil palm plantations and determine whether the effects of this cultivation make the land unsuitable for subsequent cropping. Soil properties and nutrients are critical to the health and productivity of any plantation. Oil palm production necessitates a sufficient supply of macronutrients in the field. Significant amounts of nitrogen, phosphorus, and potassium are required by palm oil trees (Hanum et al., 2016). Deficiency in nitrogen is frequently linked to the process of topsoil erosion. It causes a general stiffening of the pinnae, which will cause them to lose their glossy sheen, as well as a reduction in the quantity and size of viable fruit clusters. When nutrients are scarce, leaves are shorter than when they are abundant. The diameters of the trunk and bunches are diminished. Instigated by a deficiency in potassium, these lesions transform into orange or reddish-orange spots, and desiccation begins at the peripheries and ends of the pinnae. Potassium deficiency in soils characterised by a low capacity to retain water can result in the premature and expeditious desiccation of oil palm fronds (http://ipipotash.org/udocs/Nutrient Management of the Oil Palm.pdf). The productivity of oil palms is influenced by the supply of soil nutrients.

Despite ideal palm tree plantations require only 143 trees per hectare of land, they produce one of the highest yields of biomass and oil per unit area among oilseed commodities. Oil palm cultivation encompasses a total area of 0.35 million hectares across sixteen states in India, such as Kerala, Andhra Pradesh, Karnataka, and Tamil Nadu (Ministry of Agriculture and Farmers Welfare, 2019).

A considerable number of farmers in Mizoram somehow renounced all hope and opted to remove palm trees from their fields in favour of cultivating alternative crops, including rubber trees, Areca or vegetable crops. In many cases, palm residues that remain are burned prior to the introduction of other crops. As a result, tonnes of carbon are allegedly released into the atmosphere. As palms are a significant source of carbon sequestration potential and a revenue crop, palm resource management is critical for maximising this potential.Regular replacement of established plantations and alterations in land use may lead to heightened carbon concentrations in the surrounding environment.

Monocropping has a tendency to concentrate the demand for specific nutrients needed by the selected crop. Over time, this can result in a decrease in nutrients in the soil. Monocropping practices, like OPP, have a number of detrimental effects on soil quality. These impacts can lead to a variety of soil-related issues and are often associated with a restricted species diversity. Despite the recent introduction of pineapple intercropping, it remains unsuccessful. When introduced alongside palm trees, most intercrops produced suboptimal results or were unsuitable for harvesting. Opting to boycott oil palm is not the sole course of action, as the production of oil from an alternative commodity has the potential to impact even more expansive regions. As an alternative, it has been proposed to increase the efficiency and productivity of existing plantations while allocating a portion of the revenue generated to protect other forested areas.

Inadequate access roads frequently lead to the abandonment of a number of isolated palm tree farms, leaving a significant number of plantations unharvested.

Harvesting from each and every plantation would constitute one method of environmental impact mitigation. Clearing a primary and secondary forest for oil palm plantation expansion leads to deforestation. Establishing oil palm plantations on a limited scale in cleared areas may be more feasible and environmentally sustainable, based on insights gained from analogous ecological and cultural environments in neighbouring Southeast Asian countries. The current study will aid producers in comprehending the worth and importance of each crop under cultivation. There are numerous palm trees that are neglected and abandoned. All of these are regarded as having some environmental impact; consequently, farmers will strive to produce goods from each plantation in order to contribute to the sector's sustainability. This strategic management will yield ecological and productivity benefits. The findings from this study have the scope to halt the deforestation process for the establishment of oil palm plantations in the future and propose effective land management strategies. The majority of oil palm plantations in Mizoram exhibit inadequate management practices. The corporation Godrej Agrovet limited offers complimentary nursery services to farmers. Typically, fronds are removed during the harvest process. Nevertheless, the extracted fronds are subsequently deposited on the field, albeit at a certain distance from the tree. It was evident from the empirical examination that the utilisation of chemical fertilisers in the palm field was not conducted on a consistent basis, and the application of fertilisers was contingent upon the supply provided by the corporation. The majority of the palm field within the research area were not subject to systematic control by Agrochemicals. According to the farmer's statement, this situation can be attributed to a multitude of issues such as the absence of fertiliser supplies, insufficient labour force, and neglect, among others. The soil analysis of chemically treated was also challenging as a result of this inadequate management. Additionally, the farmer's excessive and yet irregular application of fertiliser is cause for concern. Stakeholders will possess the capacity to comprehend the detrimental effects of excessive fertiliser usage on the microbial ecosystem, as well as any chemical fertiliser runoff into the adjacent river that may indirectly endanger the health of villagers. This will facilitate the application of ammonium-based fertilisers in precise quantities by producers. Certain farmers may own land in a remote location, and when they decide to rely on a more cost-effective produce, transporting it for marketing purposes becomes an extremely difficult task.

The research findings will hold substantial importance as they will persuade the state government that it is more economically and ecologically advantageous to construct a link road to an existing plantation situated at a distance, as opposed to clearing primary forest once more.

The proliferation of oil palm plantations, despite substantially bolstering farmers' income, has generated considerable concern regarding its impact on the soil environment and quality management. The condition of the soil is critical for farmers in Buhchangphai, where agriculture continues to be the primary source of income for the majority of the population and where the majority of their income is derived from their fields.

Preserving soil quality is a significant obstacle in rural areas where agriculture provides the majority of the livelihood. The current research was motivated by the fact that despite the expansion of the oil palm plantation, no scientific study on its environmental impact assessment has been conducted in the state to identify the potential environmental risks associated with oil palm cultivation.

Intensive monoculture practices implemented in oil palm plantations frequently lead to the reduction of biodiversity and the simplification of ecosystems. In order to make way for the monoculture, native vegetation is frequently cleared, thereby reducing the diversity of plant species. Plantation farms containing juvenile palms have a greater extent of open canopy, which leads to considerably drier conditions and temperatures that are up to 6.5°C higher than those found in old growth forests (Hardwick et al., 2015). Older palm trees have a closed canopy, stand approximately 13 metres tall, and are more effective at mitigating microclimatic conditions (Luskin and Potts, 2011). Paths separating planting rows, cleared circles encircling palm bases, and mounds of dead fronds contribute to the ground-level structural complexity. It is anticipated that the relative canopy will influence the abundance, diversity, and richness of species in the OPP field.

In comparison to forests, the terrestrial plant communities of plantations in Sumatra, Indonesia, are extremely species-deficient, lacking forest trees, lianas, epiphytic orchids, and indigenous palms, among other key components of forest vegetation (Danielsen et al., 2009). As far as local farmers in Mizoram are concern, OPP exhibit a diminished species richness in comparison to primary and secondary forests. Furthermore, the conversion of forests to oil palm plantations leads to substantial shifts in the composition of species assemblages. In addition to quantifying the species abundance under OPP, this study will also propose potential future intercropping crops for local farmers.

The district of Kolasib is selected over others due to the fact that oil palm trees prefer tropical lowlands with lower elevations. Furthermore, the southern region of Kolasib, including Buhchangphai, offers an ideal topography for oil palm cultivation. The reported area dedicated to oil palm cultivation in the Kolasib district was 87 ha in the fiscal year 2005-2006. However, this figure has since escalated to 1739 ha in the fiscal year 2019-2020. The oil palm plantation is progressing towards expansion in the state without conducting any pre-existing ecological and environmental assessments. Both soil fertility rate and soil chemical properties are critical components of soil that are significantly impacted by the conversion of forests to oil palm plantations (Handayani, 1999; Dewi, 2007). The primary aim of this research is to ascertain the condition of the soil in oil palm plantations by analysing its physicochemical characteristics. As a result, the primary objective of the study was to determine how changes in soil quality occurred with the passage of time and between varying ages of oil palm cultivation.

In order to provide practical feedback, conducting research on the effects of OPP on soil quality in Mizoram is necessary. Soil evaluation and analysis are imperative due to the susceptibility of oil palm to environmental stressors, which can potentially disrupt soil fertility. Basuki (2014) found that as the age of oil palm increases from 3, 5, 7, 9, 14, and 16 years, the content of C-organic, cation exchange capacity, and exchangeable H and Al changes. Furthermore, pH H_2O, pH KCl, N-total, P-available, Ca, K, and Na exchangeable all decrease.

The study examines the influence of varying ages of oil palm plantations on the physical and chemical qualities of the soil, biodiversity of plants, micro communities and enzymes in the soil, socio-economic aspects, and land usage in the defined area. Research articles on the impact of oil palm plantations in north-eastern India are scarce. The proposition to extend the plantation underscores the necessity of scrutinising its repercussions in one of the oil palm focal districts in northeast India. The abundance of conflicting accounts is a significant challenge that requires scientific investigation and inquiry in the Kolasib environment. The Mizoram state's lack of authentic publications or documentation of environmental impact assessments necessitates a thorough study and evaluation. These studies are expected to identify potential risks and offer necessary evidence for the cultivation of the area. The aim of this study is to assess changes in soil quality, soil microbial communities, and plant species diversity caused by the cultivation of oil palm at different stages of growth.

Chapter 2

Review of Literature

2.1. Oil palm plantation

The oil palm (*Elaeis guineensis* Jacq.) trees have become a major agricultural crop, despite facing numerous environmental challenges. According to Koh and Wilcove (2008), economic growth has primarily driven the growth and development of oil palm plantations in countries like Indonesia and Malaysia. Due to its broad cultivation in tropical areas, oil palm is very significant for the economies of the food, cosmetics, and diesel industries (Corley and Tinker, 2016).

The forest clearance for oil palm cultivation has led to the destruction of many animal and plant habitats; consequently, their numbers have decreased greatly (Koh and Wilcove, 2008). In addition to this, oil palm plantations underwent a substantial increase that led to disasters like deforestation, habitat destruction, and a decrease in biodiversity (Fitzherbert et al., 2008; Danielsen et al., 2009). Besides, the adverse environmental effects of different farming practices employed in oil palm plantation development (e.g., the use of agrochemicals and land clearing techniques) add to the issue of environmental contamination (soil erosion, water pollution, and air pollution).

In Mizoram, a north-eastern Indian state, there is a new development-friendly attitude towards oil palm as a major cash crop, which gives hope to the rural population regarding their economic situation (Sati and Vangchhia, 2017). A debate is currently underway regarding the expansion of oil palm plantations in Mizoram, particularly in the Kolasib district, with a particular focus on potential environmental impacts. Mizoram, blessed with ecosystems rich in biodiversity and prone to vulnerability, currently faces a conflict between balanced agricultural development and biodiversity conservation.

In this article, the author focuses on the ecological effects of oil palm plantations around Kolasib district in Mizoram. While this review intends to present a combination of the latest findings on soil physico-chemical properties, microbial biomass carbon (MBC), soil enzymes, and plant diversity from existing research, it also hopes to offer some perspectives and discussions on the impacts of oil palm cultivation on the area. This condensed review of ecological processes is critical for evidence-based and long-term action plans on oil palm production sustainability.

Palm oil, which is collected from the pulp of oil palm trees, stands out in yield as well as efficiency as compared to high-yielding seeds of soybean and rapeseed oil (Basiron, 2007). The variety of oil palm (*Elaeis guineensis* Jacq.) has gradually turned into one of the main components of the worldwide agrarian system, mainly in the tropics. For now, oil palm has been of exceptional interest due to its high oil yield and adaptability, and the commodity is used in various industries (Corley and Tinker, 2016). Furthermore, oil palm plantations, which are economically significant, lead to a variety of environmental and social problems. Oil palm plantations have to cut down forests and peatlands, which results in a reduction of forest cover and biodiversity in many tropical regions (Fitzherbert et. al., 2008; Koh and Wilcove, 2008). On the other hand, some experts claim that oil palm cultivation problems in terms of land clearing, pesticides, and monoculture are linked with sustainability and environmental issues (Danielsen et al., 2009).

The oil palm production expansion necessitates a better balance between socio-economic development and environmental conservation for its popularity to remain. Sustainable processes such as agroforestry, organic farming, and certification schemes aimed at minimising harm while at the same time exploiting the economic potential of oil palm become possibilities (Basiron, 2007; Feintrenie et al., 2010). Oil palm plantations are by far the biggest reason for forest clearance in tropical areas, mainly in Southeast Asia as well as in Brazil and the Amazon. The large-scale conversion of forests and peatlands to oil palm plantations has resulted in the depletion of habitats for wildlife (Fitzherbert et al., 2008). Such habitat destruction causes a huge ransacking of biodiversity and ecological balance that is devastating for species that are adapted to forest ecosystems.

The expansion of oil palm plantations has revealed consequences such as biodiversity loss, and some species are at risk of going extinct. Species that completely depend on forests, like orangutans, tigers, and many bird and insect species, face the threat of population decline as well as degradation of habitats due to the loss of their natural habitats (Fitzherbert et al., 2008). Habitat fragmentation and population undersupply aggravate the probability of species extermination. The reaping of oil palm bears negative impacts on climate change by causing deforestation, land clearing and peatland drainage. Conversion of forest ecosystems, that are rich with carbon, into oil palm monoculture plantations results in consequential emissions into the atmosphere leading to greenhouse gas accumulation (Koh and Wilcove, 2008). Moreover, the gauze of peatlands as a result of oil palm plantation in which carbon stored is released contributes to the effects of climate change.

Emphasising the environmental and social problems associated with oil palm plantations, a strong advocacy for sustainability and responsible policy governance comes about in the palm oil industry. Actions like the Roundtable of Members of Sustainable Palm Oil (RSPO) are examples that set up the certification standard as well as the best practices (Basiron, 2007). Despite this, the industry still faces difficulties in enrolling and maintaining these standards.

In a nutshell, oil palm cultivation shows the necessity of a combination of economic, ecological, and social perspectives. On the one hand, oil palm cultivation offers significant economic benefits and produces globally needed products, but on the other hand, its expansion necessitates the careful management of environmental issues such as ecosystems, biodiversity, and local communities.

Government initiatives that articulate oil palm growth support the growth of oil palm plantations in India, especially in the northeast, as a way to meet the rising demand for palm oil. Additionally, the oil palm cultivation in the north-eastern state of India, Mizoram, has become another variable because it is a quest for improving economic growth and creating jobs.

Still, oil palm plantation expansion in Mizoram and other northeastern states has been very speedy, and this poses a big issue. To evaluate the consequences of oil palm plantation expansion, there is a noticeable lack of ecological and environmental studies (Kashyap and Dutta, 2020). Environmental impact assessments (EIA) are relevant tools to determine the environmental consequences of land-use conversions (e.g., from natural habitats to agricultural landscapes).

For instance, in the case of Mizoram, the study of the ecological implications of oil palm cultivation is a subject that is relatively unsatisfactory, particularly concerning its impact on biodiversity, soil health, water resources, and local communities (Narayanasamy et al., 2020). The lack of a landscape-based level of ecological assessments casts doubt on environmental sustainability and the potential negative impacts of oil palm development on specific ecosystems and the indigenous population.

Conducting an adequate environmental impact assessment of oil palm plantations is critical since the northeastern states possess significant ecological sensitivity and valuable biodiversity, and their ecosystems are known for being vulnerable. The outcome of an assessment should be comprehensive so that it understands the cumulative effects of land use changes, identifies high-conservation-value areas, and considers the views of local stakeholders such as indigenous people and conservation organisations.

Using comprehensive ecological and environmental assessments, decision-makers, scientists, and responsible actors can take knowledgeable steps in the sustainable management of oil palm cultivation in Mizoram and the other Northeastern states. These assessments are critical in the development of sound environmental actions, the reduction of the likelihood of undesirable effects, and the preservation of the ecological region as an asset to future generations..

The chapter aims to provide a relatively wide background on ecological disturbances in oil palm plantations (*Elaeis guineensis* Jacq.), especially in the context of Kolasib District, Mizoram. The overview starts with giving the statistics of oil palm cultivation importance worldwide, highlighting the fact that the sector is paramount to different sectors like the food, cosmetics, and biofuel industries (Basiron, 2007; Feintrenie et al., 2010). Despite its importance to the economy, the oil palm plantation's growth has largely gone hand in hand with several controversies, environmental impact being among the major ones (Casson et al., 2007; Koh and Wilcove, 2008). The destruction of habitats, soil erosion, and water pollution from oil palm plantations draw attention to environmental sustainability (Danielsen et al., 2009; Fitzherbert et al., 2008).

In recent years, oil palm plantations have made significant strides in India, particularly in the north-eastern states like Mizoram (Obidzinski et al., 2012; Sati and Vanchhia, 2017). However, it is remarkable that there is no past ecological assessment, and there have been no environmental impact studies of the Kolasib District in particular (Frazão et al., 2013). It emphasises the importance of conducting a thorough literature review to establish an association between the existing research and its contribution to the identification of critical gaps for future inquiry.

Therefore, the review will discuss several of the main scientific aspects related to the ecology of oil palm plantations, starting with the physical properties of soil. Specifically, it includes the investigation of factors such as soil pH, organic carbon content, nitrogen availability, and phosphorus levels in soils and the effect of these factors on oil palm cultivation (Nelson et al., 2011; Situmorang et al., 2015; Basuki et al., 2015; Enaruvbe et al., 2021). However, the review will also touch on the changes in soil microbial biomass carbon (MBC), taking into account the age of the plantation and variation in soil management practices (Witter, 1996; Haron et al., 1998).

Furthermore, the impact of oil palm plantations on the activities of soil enzymes, for example, dehydrogenase, urease, and phosphatase, and their implications on soil health through nutrient cycling will also be explored (Zain, 2013; Harianti et al., 2017). The review will also examine the role of oil palm plantations on the plant community by considering the distribution and composition of plant species as influenced by age, management, and landscape characteristics (Danielsen et al., 2009; Hilwan and Santosa, 2019; Ali et al., 2021).

2.2 Soil Physico-chemical Properties

Set up and upkeep of oil palm plantations are typically giant factors for soil fertility, and they bring about many land changes like bulk density, water storage capability, and nutrient availability. Intensive literature reviews provide information about the relationships between these activities and the roles that they play in reducing soil fertility.

Bulk density, which is an indicator of soil compaction and pore space, is usually affected by oil palm cultivation practices. Research has shown that the conversion of forested land to oil palm plantations can result in increases in bulk density because of soil compaction from heavy machinery and repeated traffic during land preparation and maintenance activities (Basuki et al., 2014; Okon et al., 2017). Bulk density at high levels can impede root penetration and water infiltration, which in turn can result in reduced nutrient uptake by oil palm trees and a decline in soil fertility.

Water holding capacity (WHC) is another significant soil property that is affected by oil palm cultivation. While the effect on WHC is dependent on soil type and management practices, several studies have found changes in water retention capacity associated with oil palm plantations. Nadeesha and Weerasinghe (2016) observed that oil palm cultivation did not significantly affect WHC in comparison to natural forest soils in Sri Lanka, indicating little changes in soil moisture dynamics. Nevertheless, other studies have noted the possibility of alterations in WHC as a result of soil compaction and changes in organic matter content over time (Yeo et al., 2020).

The availability of nutrients in oil palm plantation soils is a major factor influencing soil fertility and plant productivity. The use of fertilizers and organic amendments in oil palm management practices can lead to changes in the nutrient levels and balance in the soil. Basuki et al. (2015) reported the changes in nutrient availability, such as nitrogen and phosphorus, with the increasing age of oil palm, implying the necessity of management practices in maintaining soil fertility. Nevertheless, overuse of fertilizers and poor nutrient cycling may create nutrient imbalances and environmental pollution, which are the challenges to soil fertility management in oil palm landscapes (Zain, 2013).

A study conducted by Salim et al. (2015) examined the seasonal variations of soil nutrients in different land uses, including natural forest, plantation, and grassland, in the Jhilmil Jheel wetland located in the Haridwar district of Uttarakhand, India.The soil pH under all three different land uses exhibited a consistent pattern, with higher levels observed in summer, followed by spring, winter, and the lowest levels observed in autumn. During different seasons, the soil organic carbon content varied across various land uses. The highest levels were observed in winter, followed by spring and autumn, while the lowest levels were found in summer. Nitrogen levels were found to be higher during the winter season and lower during the summer season. Land uses exhibited a consistent pattern in terms of organic carbon content and total nitrogen levels. Natural forest soils had the highest organic carbon content, followed by plantation soils, while grassland soils had the lowest levels. According to Yadav et al. (2019), soils showed higher phosphorus content during the winter season in the natural forest, followed by the plantation, and the lowest levels were found in the grassland. The soil chemical properties pH, EC, organic carbon, available sulphur, iron, manganese and copper were high in post-monsoon season while calcium carbonate available nitrogen, phosphorus, potassium and zinc were high in pre-monsoon season

In a study conducted by Shat et al. (2016), four different types of surface covers were examined using the OPP method. The researchers evaluated how the rates of soil loss were affected by factors such as initial soil moisture, saturated hydraulic conductivity (Ks), bulk density, and slope. Areas lacking protection from cover crops experience significant soil erosion rates, as indicated by the study. This condition typically arises during the process of site clearing and the dry season, when the soil becomes loose and less compact.

By carrying out several studies on the influence of the oil palm age on soil properties, we can gain valuable knowledge on the structure and disturbance of soil systems brought about by the establishment of oil palm plantations. One of those vital changes is soil pH, which is normally the one that reflects soil fertility and nutrient accessibility. In terms of soil pH, it rises during the first year of oil palm cultivation as the conversion of forest area to agricultural land kick-starts the oil palm plantation (Basuki et al., 2015). Only in the first three years did the pH of the soil rise. However, after that, the plant's ageing began to reveal the rate of acidification of the soil's global pH. In a study conducted by Nelson et al. (2011), the pH levels of three different zones were examined. The pH was found to be lowest in the WC (Weed Circle) zone at 5.5, highest in the FP (Frond Pile) zone at 6.0, and 6.4 in the BP (Between Palm) zone. The pH in the surface layer was found to be the lowest across all zones at the oil palm plantation site.

Basuki (2014) found that as the age of oil palm increases from 3, 5, 7, 9, 14, and 16 years, the content of C-organic, cation exchange capacity, and exchangeable H and Al changes. Additionally, the pH H_2O and pH KCl, N-total, P-available, Ca, K, and Na exchangeable all decrease. In cultivated soils, the carbon and nitrogen content generally decrease, as observed in various studies (Murty, 2002; Waldrop, 2000). Cruz et al. (2013) found a similar trend, showing that soil from oil palm plantations had lower concentrations of total carbon and total nitrogen, as well as a reduced C/N ratio compared to soil from forests.

Furthermore, researchers consider the carbon content of soil to be a critical parameter for assessing the soil's health and fertility. Studies highlight the fact that organic carbon in oil palm soil changes with age. It has been stable for some years, while others show high levels. Soil organic carbon follows the same trajectory as Basuki et al. (2015) previously proposed, in that it decreased during the early stages of cultivation but increased as the oil palm plantations got older. Over time, carbon buildup from both accumulated palm residues and litter may boost organic carbon (Sato et al., 2023). In addition to organic carbon content, nitrogen in the soil communicates the soil's total richness and encourages plant growth and ecosystem functions. Basuki et al. (2015) observed a decrease in the total nitrogen content during the transition from forested land to clearing and plantations, particularly in older plantations. The cons of low nitrogen availability include the high levels of nitrogen uptake by oil palm plants and the lowered nitrogen input from decomposed organic matter (Sato et al., 2023).

Besides, the amount of phosphorus in the soil and its availability for plant roots are key factors that account for the number of crops grown. Basuki et al. (2015) found that the phosphorus levels increased with the age of oil palm plantations. Researchers observed a decrease in phosphorus levels at old oil palm plantations, in contrast to those in forests. This is likely the result of an excessive phosphorous requirement by oil palm trees, and natural replenishment through fertilization is very difficult to achieve (Nadeesha and Weerasinghe, 2016).

Sato et al. (2023) point out that the age of the oil palm plantation is very important to the state of the soil such as its pH, organic carbon content and level of nitrogen and phosphorus. On the contrary, the results magnify the need to take into account the age of land under plantation in all soil management programs which will ensure continued fertility and productivity of oil palm landscape. The soil of oil palm planation undergoes major changes in its properties as it ages. These mainly depend on the type of process, i.e., whether short-term or long-term process. Short-term implications are generally evident at the early stages of the start-up when the planting has just been initiated, conversely, long-term effects become more manifest as the plantation ages and develops.

In the initial phases of plantation establishment, changes in land use and strong land preparation primarily cause blasts and brief influences on soil properties. This can lead to erosion, compaction, and unfavourable changes in the levels of the building blocks of nutrients (Basuki et al., 2014). For instance, Baski et al. (2014) discovered that the soil pH increased in the first few years of oil palm plantations where the process of clearing forest land occurred together with the use of agricultural inputs such as lime. According to Basuki et al. (2015), increasing the age of oil palms from 3, 5, 7, 9, 14, and 16 years old soil results in an increase in C-organic, cation exchange capacity, exchangeable-H, and exchangeable-Al. On the other hand, the pH H_2O, pH KCl, N-total, P-available, and Ca, K, and Na exchangeable values decrease. Nevertheless, other research has demonstrated that the amount of soil organic carbon in palm plantations decreases after a change in land use (in areas that were formerly forests), and this decline continues to decrease as the plantations age (Dhandapani et al., 2019; Dhandaani et al., 2020).

Despite this, the long-term impacts of mature oil palm plantations on the soil microsphere's characteristics gradually become apparent at different development stages. The accumulation of matter and nutrients from oil palm residues and ash piles on the earth through root exudates is one of the results (Haron et al., 1998). A buildup like this can improve the soil's physical characteristics, such as soil fertility, organic carbon content, and microbial mass, with time (Yeo et al., 2020).

While short-term tillage of oil palm can lead to aggravation of soil degradation and nutrient loss, it can also result in nutrient depletion, particularly in older farmlands. The continuous uptake of nutrients by the oil palm trees and the low supply of nutrients by the fertilizers could lead to some soil nutrients becoming imbalanced and depleting (Nadeesha and Weerasinghe, 2016). Studies have established the fact that the levels of soil pH, organic carbon, and nitrogen in maturing oil palm plantations are starkly lower than those in the initial stages of plantation (Basuki et al., 2015). Moreover, the common misuse of agrochemicals and herbicides in oil palm plantation management exacerbates soil degradation and depletes soil life forms (Zain, 2013).

Water retention capability and infiltration rate, for example, influence soil hydrology as a result of the physical properties of soil changing over time. Changes in the soil structure of mature oil palm plantations, including a shift towards a more compacted configuration, may lead to altered drainage patterns that promote runoff and erosion (Shat et al., 2016). Based on the findings of the soil physico-chemical analysis by Sato et al. (2023), it was observed that the age of the palm tree had a direct impact on the soil fertility, with lower fertility levels being linked to older trees.

Understanding these temporal shifts is extremely important concerning the development of sustainable soil management practices that reduce soil degradation and safeguard the long-term productivity of oil palm planting area In general, the relationship between oil palm cultivation and soil fertility is complex and multi-faceted, with several factors affecting soil properties and nutrient cycles. Knowing these links is crucial for developing sustainable soil management practices that maintain soil fertility and productivity in oil palm plantations in the long run.

2.3. Soil Microbial Biomass Carbon (C_{mic}) and Soil Enzymes

Microbial biomass carbon (Cmic) and soil enzymes are of paramount importance in nutrient cycling, organic matter decomposition, and overall soil health in oil palm plantations. A systematic literature review reveals the dynamics of MBC and soil enzyme activities, as well as their effects on soil fertility and ecosystem function.

Microbial biomass carbon (Cmic) is a sensitive indicator of soil microbial activity and organic matter turnover in oil palm plantations. Research findings in this area have revealed that changes in tillage, grazing, and soil attributes can drastically change the Cmic. Haron et al. (1998) discovered that microbial biomass and organic matter accumulation occurred over time with the age of oil palm plantations, consequently leading to an increasing Cmic. On the other hand, Sato et al. (2023) found a positive correlation between the age of palm oil and Cmic and proved that organic carbon inputs in the soil are a significant factor in such microbial communities' retention. Blanchart et al. (2007) also concluded in their studies that the reduction in enzyme activity can be due to a decrease in the level of soil organic matter, which contributes to the substrate for soil enzymes. In several studies, soil physico-chemical changes often brought a change in soil enzyme activity and microbial biomass carbon. The change in soil physical structure also results in a reduction in pore spaces, and subsequent soil compaction may impede substrate accessibility and enzyme mobility (Wood et al., 2015).

Soil enzymes, including dehydrogenase, urease, and peroxidases, play crucial roles in nutrient mineralization, organic matter degradation, and soil organic matter transformation. Harianti et al. (2017) conducted a study that revealed fluctuations in soil enzyme activities during oil palm cultivation, with the level of enzyme activity varying depending on soil depth and management regimes. They noted that phosphatase activities tended to be higher than those of urease, which seemed to indicate the key role of phosphorus cycling in oil palm fields. Zain's (2013) study also identified agrochemical use as a major contributor to enzyme activity reduction in plantation soil, which in turn affected microbe life and enzyme dynamics.

In oil palm plantations, the relationship between microbial biomass carbon, soil enzymes, and fertility reaffirms the importance of prioritising sustainable soil management to ensure soil health and yield. By replenishing and revitalising the organic matter content of soils through the use of cover crops, mulching materials, and organic compounds, microorganisms will become more active and will produce enzymes commonly used for nutrient cycling and the overall health of the soil (Sato et al., 2023). To minimise the harmful effects of herbicides on soil microbial communities and enzyme activities, it is important to decrease the appropriate combination of agrochemical inputs and adopt an integrated pest management system (Zain, 2013). Setting up smart soil management programmes to improve soil fertility, plant productivity, and ecosystem resilience requires an understanding of the interactions between MBC and the rate of soil enzymes in oil palm plantations.

Microbial biomass carbon plays a vital role in nutrient cycling and soil fertility and serves as a great indicator of soil productivity. Oil palm cultivation thus has a profound influence on it. Using oil palm plantations as a case study for the microbial biomass carbon soil reveals the properties of the soil microbial community and how it shows the response to the environment and management practices.

The organic matter content of the soil is one of the key considerations in oil palm plantations. Many scientists have studied how oil palm plantations affect the levels of soil organic matter content. Haron et al. (1998) conducted research in West Malaysia and made the point that the C_{mic} of the oil palm plantations, the older they are, the higher the C_{mic}. The study revealed that, with time, organic matter and microbial biomass trends increased, resulting in higher levels of C_{mic} in the older oil palm plantations compared to the younger ones. Furthermore, Basuki et al. (2014) revealed that C_{mic} concentration increased with the tea plantation age, a fact that indicates the critical role of soil organic input in a balanced state of the microbial population.

Although such relations could be complicated because of the variety of factors involved, oil palm cultivation and C_{mic} are more than ever entangled. Methods of management such as fertiliser dope and weed control act as disruptive agents, affect soil microbial communities, and diminish C_{mic} levels. It was Zain (2013) who revealed herbicide usage in oil palm plantations led to microbial suppressive effects that drove down the MBC levels. More to that, the study by Enaruvbe et al. (2021) indicated that carbon in soil and soil total nitrogen were higher under oil palm plantations than rubber plantations, suggesting that cryptic biota might be different across different plantation types.

Other than the decreasing C_{mic} levels in the natural ecosystems due to the replacement of oil palm plantations with soil, it will also affect the ecosystems negatively. In the research by Yeo et al. (2020), on the transition of secondary forests to oil palm crops, the actors of the process were observed, with changes in macroinvertebrate density and C_{mic} with the age of the plantation. Additionally, they observed an increase in biomass carbon with time application, suggesting that the soil microbiology community may be adaptable to the new oil palm cultivated habitats.

By and large, the effect of oil palm plantations on the C_{mic} is pointed out to show how the practice of conservation agriculture is meant to sustain the fertility of the soil and soil quality. Maintaining the microbial biomass and the stability of the palm oil landscapes' functions can be achieved through the continued application of soil organic carbon inputs, the decrease in agrochemical use, and the conservation of biodiversity.

Several factors, including plantation age, soil management practices, and environmental conditions, influence the balancing act of microbial biomass carbon density in the soil under an oil palm plantation. What makes an oil palm age change very valuable is that it guarantees an evaluation of the soil health and biodiversity in these landscapes. Numerous studies have established that they might increase when the age of the oil palm plants rises. In a study carried out by Haron et al. (1998), the older oil plantation stands had more C_{mic} than the younger ones concerning West Malaysia. However, the increase in C_{mic} level was said to have been caused by an increase in the total microbial biomass and the accumulation of organic matter over time, thus highlighting a positive relationship between the age of oil palm and microbial biomass.

The inevitable change in microbial biomass carbon with the oil palm age does not restrict soil health, but rather enhances many other ecosystem services. As the number of microbes increases, nutrient cycling processes like decomposition and mineralization become even more important. This makes the soil more fertile and productive (Frazão et al., 2013). A study by Yeo and colleagues (2020) found that the long-term transformation of oil palm plantations was accompanied by a rise in C_{mic} level, which was a sign that such changes nurtured soil biodiversity and the resilience of the ecosystem.

Overall, it is found in the studies conducted on the age and microbial biomass carbon of oil palm that the land use should be sustainable to keep soil health as well as environmental sustainability in oil palm vegetation intact. A common strategy for maintaining C_{mic} levels in oil palm plantations includes greater inputs of soil organic carbon, less agrochemical use, and the conservation of soil biodiversity, all of which support ecosystem functioning.

The soil enzymes are factors in nutrient recycling and organic matter breakdown, which control soil fertility and ecosystem functionality in oil palm plantations. Numerous studies have examined soil enzymes like dehydrogenase, urease, and phosphatase, serving as crucial markers of agricultural landscape quality. Harianti et al. (2017) published research about soil enzyme activities in oil palm plantation soils. They came up with the range of phosphatase activity, which was 2–6 μg g−1 h−1. This indicates that phosphorus is readily available in the soil. The proposed research pointed out that the plant's ability to truly take up the phosphate added with fertiliser was not fully met because of the complicated associations between the soil enzymes and the availability of nutrients in oil palm ecosystems.

Nelson et al. (2011) investigated the relationships between soil enzymes and ecological zones in an oil palm plantation and discovered that each ecological zone tended to have a distinct enzyme level. They explained that it was soil pH that determined the enzyme activity; the higher the pH, the higher the enzyme activity. Furthermore, the research team discovered a further reduction in enzyme activity or its limitation to the vicinity of the oil palm tree trunk, suggesting a localized impact.

Zain (2013) experimented to assess the influence of herbicide applications on the soil microbe community and enzyme activity in oil palm plantations. In contrast to the control samples, the enzyme activities of the tested soils have been greatly inhibited by herbicides, with the degree of inhibition depending on the specific type and rate of herbicide use. The oil palm business's farming practices could potentially disrupt enzyme activities and ecological processes in the landscape. Plantations of oil palm in general are focused on enzyme activities by which microbial processes and dynamics of the nutrient cycle are essential. The researchers can expand their knowledge about the influencing factors of soil enzymatic activities, such as management practices and environmental conditions, thus assessing the health care and sustainability of oil palm agricultural systems.

The study of soil enzyme functions, as well as the effect of soil health on nutrient cycling in oil palm plantations, is critical to understanding the ecological processes that are active in the ecosystem. Enzyme actions such as dehydrogenation, urination, and phosphatisation perform a major role in the nutrient illiquid, the decomposition of organic substances, and, in general, the wellbeing of the soil (Grayston et al., 2001).

Additionally, scientists realised that biochemical reactions conducted by soil enzymes in oil palm plantation lands might vary from one another and depend on different components such as soil physiochemical properties, land management practices, and the age of plantations (Abd. Rahman et al., 2016). For instance, soils possessing ideal physico-chemical characteristics like pH, moisture content, and nutrient availability stand out. Their compounds have better levels of soil enzymes compared to the ones where the population is not sufficient (Dariah et al., 2014; Wood et al., 2015).

The interaction between soil enzyme performance and soil health can be very sophisticated because the enzymes represent microbial action and organic matter turnover in the soil at the same time. Enzyme activities tend to be the highest in soils with higher soil fertility, shorter nutrient cycling times, and ecosystem harmony (Lal, 2004). On the other hand, highly activated enzymes may indicate that there is an imbalance in the soil between some nutrients or stress factors that can degrade and reduce production (Guillaume et al., 2015).

Furthermore, the age of oil palm plantations may also influence the enzyme activities in the soil, which show less enzyme activity in the younger plantations than the older plantations (Abd Rahman et al., 2016). This can happen with the gradual addition of organic matter and microbe biomass over time, increasing enzyme production and activity to foster the process of decomposition (Guillaume et al., 2015). Realising the interconnection of soil enzyme activities, soil health, and nutrient cycling plays a decisive part in ensuring longevity in oil palm farming. Oil palm plantation sites can preserve soil fertility and ecosystem stability by applying soil enzyme-promoting management practices that use organic matter, cover crops, and reduced levels of chemical additives (Lal, 2004). However, enzyme activities in soil serve as a prime level of assessment of soil health and the exchange of nutrients in oil palm communities. Considering the effects of enzyme dynamics on soil fertility and the environment, researchers as well as agronomists can come up with the best strategies to manage the soil quality and the environment of oil palm cultivation.

2.4. Natural Habitats and Species diversity

The widespread destruction of natural habitats for plants, which is the main issue of concern today, is no longer just associated with tropical regions. A lot of research has tried to find out how oil palm crops impact biodiversity, showing both positive and negative effects on vegetation choice and structure.

Danielsen et al. (2009) found that biodiversity in oil palm plantations is less dense than in a natural forest ecosystem. This leads to the clearing of native vegetation, making oil palm trees the dominant single species in the monoculture plantation. A lesser presence of understory vegetation consisting of trees, lianas, and epiphytic plants was also noted in oil palm plantations (Danielsen et al., 2009).

Essandoh et al. (2011) reveal that the establishment of oil palm estates had a significant negative impact on plant species diversity. In their study, they identified the abundance of weed species in oil palm plantations, leading to the replacement of native diversity with that of undisturbed ecosystems. The invasion by the weed species may displace the original vegetation and further decrease the number of species within the landscapes of oil palm plantations (Esdano et al., 2011).

Chromolaena odorata, *Mikania cordata*, and *Mikania micrantha* were prevalent in well-established oil palm plantations; they exhibited competition with the oil palm for nutrients, moisture, and sunlight, ultimately resulting in a decline in yield (Pride, 2010; Lam et al., 1993). The Poaceae and Asteraceae families exhibited the greatest abundance and distribution, respectively. Widespread were the Asteraceae species *Chromolaena odorata*, *Aspillia africana*, and *Melanthera scandens*; the Poaceae species *Mallotus oppositifolius*; and the Euphorbiaceae species *Panicum maximum* and *Imperata cylindrical*. It is possible to use *Nephrolepis bisserata* as cover in the plantation, according to the results of this study. The potential efficacy of this approach surpasses that of any herbicide due to the extensive variety of weed vegetation (Essandoh et al., 2011).

Although at times, some plant species could prosper or thrive within oil palm plantations, resulting in vegetation diversity, such understanding is critical because there can also be some species that might not be benefiting from the environment. Hilwan and Santosa (2019) report contradictory results concerning flora diversity after land-use change from planting oil palm. Certain vertebrates or invertebrates had a declining or threatening tendency, whereas others gained abundance in the plantation, invaded, and colonized. Besides, the previous research by Frazão et al. (2013) and Yeo et al. (2020) has, thus, indicated the possibility that plant diversity will continue or resume if old oil palm plantations are allowed to age and vegetation cover; similarly, ecological processes will go on over time.

To begin with, the impact of oil palm plantations on plant variety can be explained as being dependent on parameters such as landscape context, management methods, and plantation age. The change in agriculture from mixed systems to oil palms also comes with a decrease in the number of native plant species, but there are still some plant species that have the resiliency to become a well-adapted part of the new environment. Understanding the various stands of oil palm plants influences the development of land management strategies that prioritize biodiversity's sustainability.

The literature on plant diversity and plant composition has captured plantation activities such as establishment and management in indirect and direct impact assessment activities. Fitzherbert et al. (2008) demonstrated that the conversion of natural habitats into oil palm plantations resulted in a three-quarters reduction in plant diversity. The analysis concluded that the oil palm area exhibits less diversity compared to intact forests, with the height dominance of oil palm trees replacing most plant species. The removal of trees and the displacement of people after land clearance directly contribute to the loss of diversity in our native environment (Fitzherbert et al., 2008).

The study agrees with the work of Enaruvbe et al. (2021) and Guillaume et al. (2016), which showed that oil palm plantations hurt plant diversity by changing the make-up of communities and the number of species that live there. After planting oil palm plantations, the studies showed low native plant diversity, with midmarket weed species being the most competitive species in the new environment. Secondly, oil palm plantations alter forestlands, which, in turn, causes the loss of native plant species' habitats and further reduces plant diversity (Enaruvbe et al., 2021; Guillaume et al., 2016).

However, it's important to note that oil palm cultivation can influence plant diversity, leading to the emergence of specific patterns under specific conditions like the plantation's age, landscape, and management practices. For example, according to Hilwan and Santosa (2019) and Yeo et al. (2020), even though large-scale plantations may have a huge impact on biodiversity, plant diversity can stabilize or recover over time due to the spread of vegetation cover and the resumption of ecological processes. Furthermore, some plant species maintain themselves while adapting to changing stress and survive in oil palm areas, so they strengthen the area's diversity (Hilwan and Santosa, 2019; Yeo et al., 2020). Overall, the journal publications show that oil palm growing season often leads to loss of plant biodiversity and plant vegetation replacement. Notwithstanding this, the reactions of plant communities to the establishment and host management of plantations are very complicated and mixed, signifying that more research should be done for a better understanding of the long-term ecological issues concerning plant diversity that may result from oil palm agriculture.

Research into the quantity, distribution, and number of species of plants within an oil palm plantation's landscape is a requirement in the process of analysing the ecological impacts of the plantation in the establishment and management of the said plantation. The findings from Ali et al. (2021) in the state of Johor, Malaysia, show that there are plenty of weeds with diverse species, especially in oil palm smallholder plantations. The study revealed thoroughly, there were 4199 individuals belonging to 17 species and 35 genera in 19 family groups. The research highlighted the altered composition of some of the generic weeds such as *Chromolaena odorata* and *Panicum maximum* in growing oil palm (Ali et al., 2021).

Furthermore, studies by Hilwan and Santoso (2019) as well as Yeo et al. (2020), demonstrated the consequences of the conversion of different kinds of forest land use to plantations, including oil palm plantations. Santosa and Hilwan (2019) discovered that the plant species composition has changed in a natural habitat after cutting down the vegetation of the oil palm plantation. Some species have become less common, while others remain or have become even more abundant in the transformed environment. Addressing a similar question, the study "Oil Palm Landscapes Accommodate Biodiversity in Sumatra, Indonesia," published by Yeo et al. (2020), observed that secondary vegetation under oil palm landscapes can be commonly used to grow a wide range of plants, including those that play a pivotal role in ecosystem services like pollination and biological control.

Frazão et al. (2013) as well as Hutwan et al. (2017) reveal that plant diversity may vary depending on the preceding land use of the oil palm plantations. Frazão et al. (2013), in a study about the diversity of plants in oil palm plantations defined by the pastures and the native rainforest, found the two land-use types differentiated by the number of species and how they were structured. Moreover, Hutwan et al. (2017) discovered differences in the undershrub vegetation within oil palm plantations across

Sumatra and West Sumatra, which suggests that regional factors are another important factor in explaining the plant diversity patterns.

The research shows the intricacy of plant diversity dynamics that are generally connected to several factors, such as the type of land use, management practices, and regional considerations. Being aware of these processes is crucial so that they can be used to guide actions in energy crop-related regions.

2.4.1. Factors Influencing Plant Diversity

A range of factors, including the age of the plantation, the management practices, and the landscape structure, can influence the varieties of plants in an oil palm plantation. Many recent research projects shed light on these aspects (issues) and their functions in preserving the biodiversity of oil palm trees.

Basuki et al. (2015) conducted research on the impact of oil palm age on plant diversity, revealing that younger plantations typically exhibit lower biodiversity compared to their older counterparts. This pattern was primarily caused by the gradual increase in the number and species of plants in the mature plant garden over time. In the same manner, Sato et al. (2023) established that plant diversity increased with the age of the oil palm plantations. The old palms overtook the young ones, which had a higher plant species than the younger plantations.

In oil palm plantations, weed control and other management activities aimed at controlling and destroying understory vegetation significantly contribute to biodiversity loss. Ali et al. (2021) determined that the methodology practiced by smallholder oil palm farmers for weed control affected the total number and variety of plant species in the landscape. The use of herbicides and other weed control measures influences the pattern of plant communities, causing species composition to shift to adapt to managed areas.

Besides this, land features like the proximity of forest patches and the connectivity of the habitat can act as signals for distinguishing the level of biodiversity in oil palm landscapes. As evidenced by Yeo et al. (2020), a flora community similar to secondary vegetation within and in the middle of oil palm plantations can generate a large range of plant types that are refuges for native species, thereby increasing the whole ecosystem's biodiversity. Moreover, Hutwani et al. (2017) found that undergrowth plants in oil palm plantations across different geographical contexts likely differ in structure and composition, leading to a variable diversity of plant species in this agroforestry or secondary vegetation across regions. In short, these findings indicate that merely increasing or decreasing the number of oil palm plantations is not always effective in improving plant diversity. Several other factors such as conversion age, management practices and landscape features should be considered when evaluating the plant diversity in oil palm plantations. It can enable the identification of trade-offs and implications among these various factors. They become instrumental tools for creating conservation and land management plans that will contribute to biodiversity conservation and make it advantageous in oil palm-dominated areas.

Changes in vegetation composition of oil palm plantations and their further repercussions concerning ecosystem organization and functionality are of large scale. Such essence should be comprehended, to evaluate sustainable land protection methods and to protect biological value in landscapes composed of oil palm.

An example of an ecosystem's higher diversity maybe when it can be more stable to environmental disasters and manage the critical ecological processes so well. For example, tall grassland, mono-species peat swamps and evergreen forests can provide four important ecosystem services, such as soil stability, nutrient cycling, and pest control (Hooper et al., 2005). Biodiversity of plant communities tends to increase ecosystem resilience to loss of species as long as functional redundancy is common, which means that multiple species may perform similar ecological functions (Cardinale et al., 2012).

Furthermore, ecosystem functions can be affected through plant diversity changes by such processes as resource limitation and habitat structure alteration. Similarly, several plants established could potentially favour soil fertility through nutrient cycling and organic matter decomposition (Tilman et al., 2014). Likewise, the diversity of plant communities enables various animal species including insects, herbivores, and predators to live there maintaining diversity among higher trophic-level animals in the ecosystem (Tscharntke et al., 2012).

However, the impacts of oil palm plantations on biodiversity through diversity loss can affect the stability and the working of ecosystems. Per se, monoculture plantations are often connected with simplified plant communities that are less resistant to environmental stressors and have more probability of having disease outbursts or pests (Tscharntke et al., 2012). Similarly, biodiversity loss may adversely affect other ecological processes such as nutrient cycling and formations of the ecosystem structure, and this may result in reduced soil productivity in the long run (Díaz et al., 2007).

To mitigate the negative environmental impact that is linked to changes in plant diversity within oil palm landscapes, strategic measures at the landscape level are crucial and should provide more biodiversity through increasing connectivity and native vegetation restoration (Perfecto and Vandermeer, 2010). Similarly, agroforestry and planting different species of plants within oil palm plantations is another way to improve the ecosystem's diversity and give extra things like proper soil health, species diversity conservation, and ecosystem resilience as well as climate change mitigation (Tscharntke et al, 2012; Clough et al., 2016).

Overall, the implications of a diversity loss in the oil palm plantation on the ecosystem should be comprehended to formulate and apply eco-friendly land management strategies that sustain both the production of agriculture and biodiversity protection as well as ecosystem resilience.

2.5. Socio economic impact

Oil palm plantations are widely recognised as a significant catalyst for economic growth in Indonesia due to their contribution to government revenues and creation of job opportunities in rural regions (Basiron 2007 and Feintrenie et al., 2010).

The expansion of oil seed plantations involves buying land and also relocating people which leads to social conflicts and a violation of their human rights. Smallholder farmers and indigenous people are at a higher risk of losing their lands (Feintrenie et al, 2010), such as land ownership, labour problems, and the fairness of revitalising the impacted local communities are the main conflicts occurring in areas where oil palm plantations are going to be planted. However, in describing the socioeconomic conditions of villages in Mizoram that practise OPP, Sati and Vangchhia (2017) compared and contrasted the output of cereals and OPP and analysed the crop productivity of OPP. Their research indicates that OPP yields an income greater than fifty percent greater than that of conventional crops. This indicates that expanding OPP has the capacity to foster future agrarian progress in rural regions. The findings indicate that the general public holds a favourable opinion of OPP, with over 70% of farmers believing it to be a viable crop.

In order to minimise the adverse effects and drawbacks of oil palm plantations and optimise their economic benefits in Indonesia, policymakers must implement measures to limit the utilisation of forested areas for plantation expansion, enforce current regulations on the allocation of concessions and environmental management, enhance supervision of labour practices, acknowledge the rights of traditional land use, and ensure that agreements regarding the transfer of customary land are transparent and legally binding (Obidzinski et al., 2012).

Unlike Malaysia and Indonesia, the Indian agricultural system treats the cultivation and processing of oil palm as an integrated project due to the specific needs of oil palm fruits (Owolarafe and Arumughan, 2007). The palm seed must undergo a conversion process to obtain its value as palm oil. In India, the cultivation and processing of palm fruit involve a significant number of farmers. The success of this process depends on the location of the processing unit in their area. To have their Fresh Fruit Bunches (FFB) processed, oil palm farmers must send them to the processing unit. The planning of the processing centre must be done meticulously, ensuring it is not far from the farmers' fields. This proximity is crucial to prevent losses caused by the highly perishable nature of the oil palm fruit. Oil palm fruits must be processed within 24 hours of harvesting due to their limited lifespan. Hence, given the socio-economic and agricultural conditions in India, it is crucial to prioritise the establishment of oil palm processing facilities. The Indian Government, through the Technology Mission, offers a subsidy of Rs.12500/ha for planting materials and cultivation, covering a portion of the total cost of Rs. 38000/ha, during the initial 4 years of plantation development (Owolarafe and Arumughan, 2007).

Chapter 3

Materials and Methods

3.1 Study site and soil sampling

Plantation sites containing various years of palm trees were identified in the oil palm plantation (OPP) field of Buhchangphai ($24^0$19'69"N $92^0$38'81"E), located approximately 22 kilometres from the district capital Kolasib. An initial selection was made from plant samples representing the ages of three years, five years, ten years, and fifteen years. Soil sample has been collected from the designated the palm tree plantation site which is located approximately between 60m to 70m altitude and soil is also collected from undisturbed forest. Soil under palm tree is collected from two distinct locations or plots, denoted as Plot 1 and Plot 2, respectively. Samples for Plot 1 is collected from the core zone at 1.5 m from the main trunk within the weeded circle and and Plot 2 is collected from buffer zone at 4 m from the main trunk within the palm avenues.

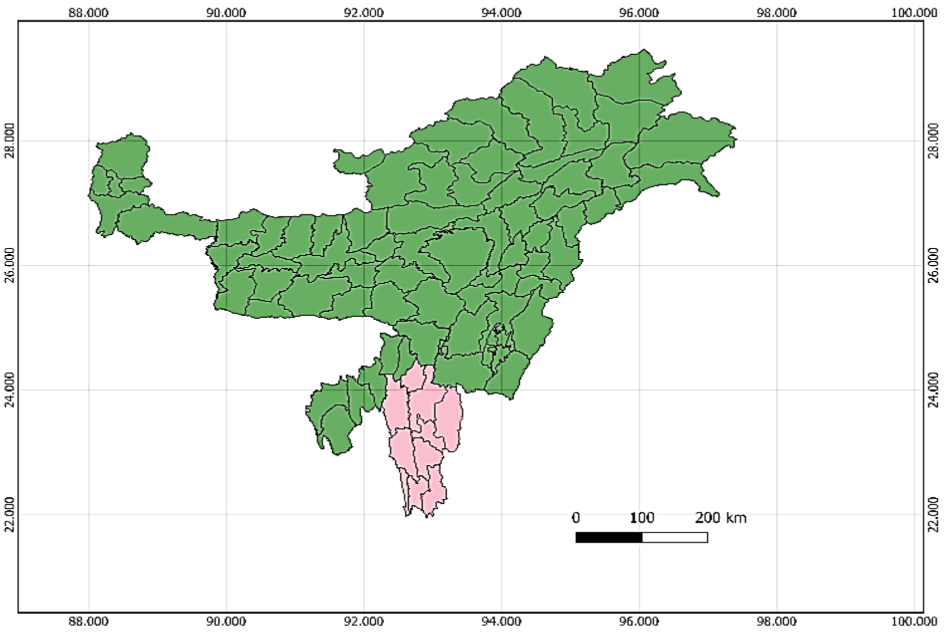

Figure 3.1: Map of North East India showing Mizoram

Soil samples were collected on April, August, and December for three consecutive year between 2019 - 2021. The V method of soil sampling was utilised to acquire data on soil depths ranging from 0 to 15 cm. At the time of sample collection, precautions were taken to make it free from possible contamination. Soil samples were placed in sterile plastic bags and stored in an ice box before being transported to the laboratory on the same day for analysis. The analysis of all physicochemical properties of soil was conducted at the Botany Research Lab, PUC. There is no utilisation of outsourced data in the research.

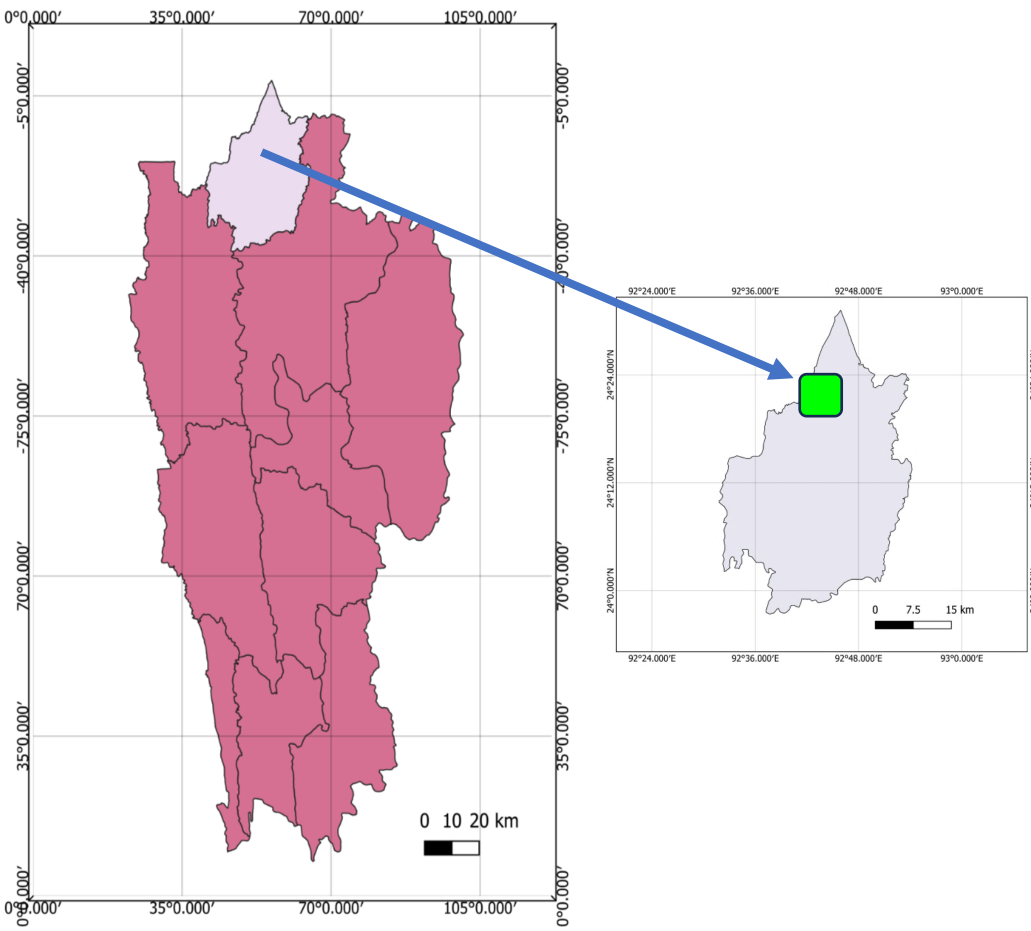

Figure 3.2: Map of the study site at Buhchangphai, Kolasib District, Mizoram

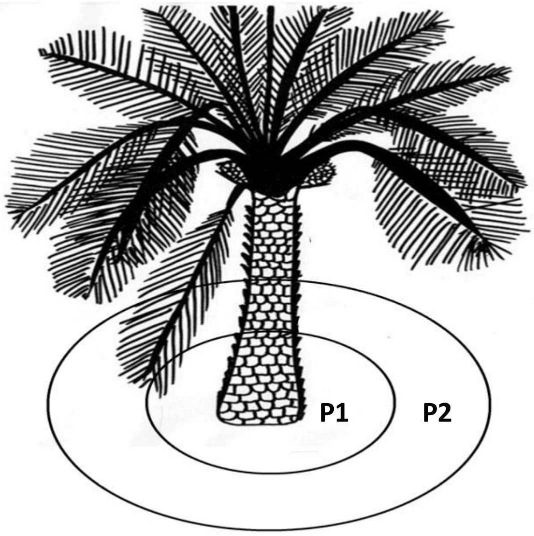

Figure 3.3: soil sample collection site of Plot 1 (P1) and Plot 2 (P1).

3.2 Soil physico-chemical properties

3.2.1 Soil pH

The soil pH was measured using the method described by Jackson (1973). A beaker was filled with 50 ml of distilled water and 20 g of recently collected soil was added to it. The soil water mixture underwent stirring for a duration of 5 minutes using a magnetic stirrer. The solution was allowed to stand overnight and the pH was measured using an electronic digital pH metre. Precautions are taken after each reading which involve flashing the electrode with distilled water and dried using tissue paper.

3.2.2 Soil Moisture content

Soil moisture content was determined by Misra 1968. 10 g of freshly collected soil sample was place in a moisture box. It was then subjected to oven drying at a constant temperature of 105˚C for a duration of 24 hours. in a hot air oven at 105˚C for 24 hrs. The sample was again reweighed and the soil moisture content was then calculated using the following formula-

$$\textit{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 10$$

Where, W_1 *= initial weight*

W_2 *= final weight.*

3.2.3 Water Holding Capacity

The soil's water holding capacity (WHC) was determined using the keen box method as outlined by Piper (1944).

A Whatman No. 1 filter paper with a perforated hole of approximately 0.75mm in diameter was placed on the bottom of a keen-box, and its weight was measured. A quantity of 10 gm of soil that had been dried in an oven at a temperature of 100-105°C was carefully placed at the bottom of a container called a keen box and then weighed. The keen-box, together with soil samples, was partially immersed in water (up to one fourth) overnight. sharp-edged container, together with the soil, was removed and let to stand in order to remove any surplus water before measuring its mass. The water retention capacity of a soil sample is determined using the following formula:

$$\text{Soil Water Holding Capacity (\%)} = \frac{B - (C + D)}{(C - A)} \times 100$$

Where,

A = Weight of empty Keen's box

B = Weight of saturated soil + Keen's box

C = Weight of oven dried soil + Keen's box

D = Weight of wet filter paper

3.2.4 Bulk density

The bulk density of the soil was determined applying the technique outlined by Anderson and Ingram in 1993. A metallic cylinder of known mass and volume was inserted into the soil surface subsequent to its clearance. The tube was removed and soil inside the tube were collected. Soil samples were oven dry to at 105°C a constant weight. The bulk density is calculated using the given formula:

$$\text{Soil Bulk Density} = \frac{\text{Weight of oven dried soil (g)}}{\text{Volume of soil corer (cm}^3\text{)}}$$

Where,

Volume of soil core =$3.14r^2h$

r =inside radius of cylinder (cm)

h =height of cylinder

3.2.5 Soil Organic Carbon

The Walkley and Black (1934) method was employed to determine the organic carbon. 1 g of air-dried properly sieved (0.2 mm) soil samples is added to a 500 ml conical flask. 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated sulphuric acid (H_2SO_4) are added once more. The flask was swirled for 1 minute to mix and is left to stand for approximately 30 minutes. The contents were diluted to 200 ml with distilled water, followed by the addition of 10 ml of orthophosphoric acid and 1 ml of diphenylamine indicator. The solution's colour changes to a blue-violet shade. The solution was titrated using 0.5 (N) ferrous ammonium sulphate till a brilliant green colour appeared. In addition, a blank titration was conducted simultaneously. The organic carbon content was then calculated by the following:

$$SOC\ (\%) = \text{N} \times 0.003\ \frac{B-S}{W} \times 100$$

Where,

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

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

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

W = Weight of soil taken

3.2.6 Total Nitrogen content

The AOAC (1995) micro-Kjeldahl digestion technique was employed to ascertain the total nitrogen (N) level of the sample. The process has three primary stages: digestion, distillation, and titration. In digestion process, mixture consisting of 1 g of soil, 10 ml of concentrated sulphuric acid, and 5 g of catalyst combination (250 g of K_2SO_4, 50 g of $CuSO_4$, $5H_2O$, and 1 g of metallic selenium powder) was introduced into the digesting tube. Then, the digestion tube was subjected to heating at 100 °C until the frothing ceased. The temperature of the block was raised to 400 °C until the sample exhibited a brilliant green or colourless appearance. After the digesting tube had cooled down, it was inserted into the distillation apparatus. After that, 40 ml (40%) of NaOH was added to it. The material that had undergone digestion was thereafter subjected to gradual heating. The resulting ammonia was then mixed with a solution containing 5% boric acid and a combination of indicators (0.066g methyl red + 0.099g Bromocresol green dissolved in 95% alcohol). This mixture was contained in a 250 ml conical flask. The pink hue undergoes a transformation to a green colour as a result of the absorption of ammonia. The green distillate was subjected to titration using a 0.02N solution of sulphuric acid until it reverted back to its original pinkish colour. Reading was recorded and the percentage of nitrogen is calculated by using the following formula.

$$Nitrogen(\%) = \frac{R \times N \times at.wt.Nitrogen \times 100}{W \times 1000}$$

Where,

R = sample tier – blank tier

N = Normality of acid

W = Weight of sample

3.2.7 Available Soil Phosphorus

The determination of available phosphorus is conducted using the ammonium molybdate method as described by Olsen et al. in 1954. A soil sample weighing 2.5 g was placed in a 100 ml conical flask. Activated charcoal and 50 ml of Olsen's reagent (0.5 molar sodium bicarbonate with a pH of 8.5) were then added.

The contents were agitated for a duration of 30 minutes using a mechanical shaker and subsequently passed through a filter paper of Whatman No.1. 5 ml of the transparent filtrate was transferred into a 25 ml volumetric flask. 5 ml of ammonium molybdate solution, which contains 400 ml of 10N HCl per litre, was added slowly to the solution. The contents were gently agitated to expel the carbon dioxide liberated from the solution. Distilled water was poured down the sides to increase the capacity to approximately 22 ml. 1 ml of recently diluted $SnCl_2$ solution was added to the mixture. The contents were gently agitated and the volume was adjusted to 25 ml using distilled water. The measured intensity of the produced blue colour was recorded at a wavelength of 660 nm, relative to a blank sample. The calculation for accessible phosphorus was performed using the provided formula and expressed in kilogram per hectare (kg/ha).

$$\text{Available Soil Phosphorus}\left(\frac{Kg}{ha}\right) = R \times \frac{V}{v} \times \frac{1}{s} \times \frac{(2.24 \times 10^6)}{10^6}$$

Where,

V = total volume of extractant (ml)

v = volume of aliquot taken for analysis (ml)

S = weight of soil (g)

R = weight of phosphorus in the aliquot in µg (from standard graph)

3.2.8 Soil Potassium content

The quantification of potassium in the soil sample was conducted using flame photometric method as elucidated by Ghosh and his colleagues in 1983. The soil sample, weighing 5 g, was mixed with a solution of 1N ammonium acetate ($NH_4CH_3CO_2$) and the mixture was then shaken for a duration of 5 minutes. The solution was then filtered using a Whatman No. 1 filter. The first aliquot of the filtrate was discarded. Subsequently, a flame photometer was employed to measure the potassium concentration in the remaining extract. The amount of exchangeable potassium in soil was determined using the formula:

$$\text{Soil Exchangeable Potassium}\left(\frac{Kg}{ha}\right)=R\times\frac{V}{W}\times 224\times\frac{10^6}{10^6}$$

where,

R = ppm of K in the extract (obtained from standard graph)

V = Volume of the soil extract in ml

W = Weight of dry sample taken for extraction in gram

3.3. Soil Enzyme Activities and Microbial Biomass Carbon

3.3.1 Dehydrogenase Activity (DHA)

The method described by Casida et al. (1964) was used to determine dehydrogenase activity in soils. This method entails the enzymatic reduction of a tetrazolium salt by the dehydrogenase enzyme found in the soil. In order to analyse the soil sample, a precise measurement of 1 g of fresh soil was taken and then placed into a test tube that was both clean and dry. Next, a precisely measured quantity of 0.1 g of calcium carbonate ($CaCO_3$) was introduced into the tube. A volume of 1 millilitre of a solution containing 1% of 2,3,5 Triphenyl Tetrazolium Chloride (TTC) was added cautiously to the sample. Subsequently, the mixture was delicately agitated for a brief duration to ensure even dispersion of the solution. The tubes were further sealed and placed in an incubator for a duration of 24 hours at a temperature of 30 degrees Celsius. The slurry was filtered using Whatman No.1 filter paper. The process of extracting triphenyl formazan (TPF) involved using concentrated methanol in multiple portions, added one after another, in a 50 ml volumetric flask. The spectrophotometer measured the intensity of the pink colour generated at a wavelength of 485 nm, using methanol as the reference (without soil). The dehydrogenase activity was quantified as μgTPF ml^{-1} per 24 hours.

3.3.2 Acid Phosphatase (APase)Activity

The assay for soil acid phosphatase activity was conducted in accordance with the methodology described by Tabatabai and Bremner (1969). In this method, 0.1g soil sample that had undergone air-drying is measured and 0.25 ml of toluene was added to the sample soil. For a period of ten minutes, the mixture was left undisturbed in order to facilitate the thorough extraction of the diverse components that were present in the soil. The experimental setup comprised 4 ml of modified universal buffer (MUB) at a pH of 6.5 and 1 ml of a solution containing p-Nitrophenyl Phosphate (p-NP) at a 0.115 molar concentration. Following a brief period of agitation, the solution was container-sealed with a cotton stopper and incubated at a temperature of 37°C for one hour. Following that, simultaneously incorporated into the mixture were 1 ml of 0.5 M $CaCl_2$ solution and 1 ml of 0.5 M NaOH solution. Following this, the mixture that was produced was subsequently filtered through Whatman No. 1 filter paper. The yellow filtrate of p-nitrophenol phosphate (phosphoric acid) was quantified at a wavelength of 410 nm using the spectrophotometer. Following the contribution of $CaCl_2$ and NaOH to the soil-free mixture, 1 ml of p-NP was introduced as a control before proceeding with filtration. The activity of acid phosphatase was measured in μg p-NP ml^{-1} hr^{-1}.

3.3.3 Urease Activity

The soil urease activity was determined using the buffer method described by Kandeler and Gerber (1988). A 100 ml conical flask was filled with 5g of fresh soil. Then, a solution containing 2.5 ml of urea and 20 ml of borate buffer was added. After stoppering the flask, it was incubated at a temperature of 37°C for a duration of 2 hours. After the period of incubation, a 30 ml solution of KCl was introduced, and the flask was agitated for 30 minutes prior to filtration. A control experiment, using 2.5 ml of distilled water, was conducted following the same procedure as described earlier. The urea solution was added at the end of the incubation period, right before introducing KCl. A volume of 1 ml of transparent filtrate was transferred using a pipette into a flask with a capacity of 50 ml. Afterward, 9 ml of distilled water, 5 ml of Sodium Salicylate/NaOH solution, and 2 ml of sodium dichloro-isocyanate solution were introduced. The mixture was left undisturbed for 30 minutes at an ambient temperature. The measurement was conducted at a wavelength of 690nm using a spectrophotometer. The urease activity in soil, measured in micrograms of NH_4-N per gram of soil per hour, was determined using the following formula:

(µg NH4-Nml-1 x V x 10) / (dwt x 5)

The dry weight of 1g moist is denoted by dwt, the volume of the extract is V (52.5 ml), the dilution factor is 10 ml, and the soil used in the assay weighs 5g.

3.3.4 Soil Microbial Biomass Carbon

To determine the amount of carbon that is present in the soil microbial biomass, the method of chloroform fumigation-extraction described by Pothoff (2008) was employed. A total of 10 g of fresh soil were collected and then fumigated with 5 ml of chloroform in a petri dish. The sample was kept in a desiccator at a temperature of 25 °C and in the dark for a period of 24 hours. A second batch of soil, weighing 10 g, was collected in the same way, but this time without the use of fumigation. An extraction was performed on both fumigated and non-fumigated samples by placing them in 100 ml flasks and shaking them at a speed of 200 revolutions per minute while adding 40 ml of 0.5M potassium sulphate (the ratio of the extractant to the soil was 4:1). The next step was to filter it with a piece of folded filter paper. A blank and 0.6 ml of K_2SO_4 soil extracts were collected in a test tube, and then 1.4 ml of citric acid buffer was added to the mixture. After carefully adding 1 ml of the ninhydrin reagent and thoroughly mixing it, the containers were then prepared for sealing with loose aluminium covers. For the purpose of ensuring that any precipitate that may have formed as a result of the addition of the reagents was completely dissolved, the test tubes were heated vigorously for a period of 25 minutes in a water bath with a boiling temperature. In order to achieve a uniform mixture, this process was helpful in breaking down any solid particles that were present and fully incorporating them into the solution. In the end, 4 ml of a mixture composed of water and ethanol in proportions of 1:1 was carefully added to the solution. In order to guarantee that the solution was homogenous, it was thoroughly mixed, and then the absorbance was measured using a spectrophotometer at 570 nm.

3.3.5 Statistical analysis

Every single experiment was carried out in triplicate, and the mean values along with the standard error of the mean were computed. With the help of SPSS16, we determined the correlation coefficient (r) and the one-way analysis of variance (ANOVA) for each parameter. We took into consideration statistical significance at a level of $p \leq 0.05$. It was also possible to determine the nature of the association between the selected soil properties by employing Pearson's correlation. Principal component analysis was done with R software.

3.4 Plant species diversity

3.4.1 Quadrat method:

To analyse the diversity of vegetation, quadrats of 1m X 1m size were laid randomly in 1 ha of oil palm field. A total of 100 quadrats were laid in 1 ha of land. The size of the quadrat for sampling was determined by following Ellenberg and Muller – Dombois (1974)

3.4.2. Herbarium specimen collection:

A meticulous extraction process was employed to procure the plant specimens, encompassing all appendages present at the moment of collection: roots, stem, leaves, and any flowers. The procedures outlined by Jain and Rao (1977) and Womersley (1981) were followed during the herbarium collection and preparation process.

Prior to the pressing process, plant specimens were meticulously organised to maximise the preservation of identifying characteristics. The positioning of fruits, flowers, and leaves was such that they displayed a visually pleasing arrangement without overlapping when viewed from various angles. In order to make it easier to attach specimens to herbarium paper and prevent the plant material from shrinking and wrinkling, the plant press was kept at a tight setting. In order to ensure that plant material can be stored on herbarium paper for a long period of time without losing its physical characteristics, the process of pressing must effectively flatten the plant and remove moisture in a timely manner.

3.4.3. Plant identification

The plant specimens collected from the study site were identified with the help of different sources. It was identified with the help of expert from Pachhunga University College, taxonomist from Mizoram University, local people and regional floras of the book of Mizoram Plant (Sawmliana, 2003).

3.4.5. Quantitative Analysis

Quantitative data on species abundance, frequency, and density were collected for each of the study sites, following the method outlined by Curtis and McIntosh in 1950.

Density: Species density was calculated by determining the numerical strength of each individual species. The calculation is done using the following formula

$$\text{Density} = \frac{\text{Total number of individuals of species in all quadrats}}{\text{Total number of quadrats studied}} \text{X} \quad 100$$

Frequency: It defines the dispersion of various species within a defined region, utilising percentages as a measure. A random sampling method was employed to investigate the study area, wherein observations were conducted at various locations to document the species found in each sampling unit or quadrat. The calculation is performed utilising a precise formula. It is calculated by the following formula.

$$\text{Frequency}(\%) = \frac{\text{Number of quadrats in which the species occured}}{\text{Total number of quadrats studied}} \text{X} \quad 100$$

Abundance: Species abundance is a way to quantify the number of individuals from various species within a community, relative to the space they inhabit. The quantification can be calculated using the following equation.

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occured}} \text{X} \quad 100$$

3.4.6. Importance Value Index (IVI)

By employing the importance value index, it becomes possible to measure the ecological success and dominance of a species using just one numerical value. This index is made up of three characteristics: relative frequency, relative density, and relative dominance (Misra, 1968). The determination of a species' dominance is determined by counting the total number of tree, shrub, and herb species. It is measure using the following formula.

3.4.7. Species diversity indices

Species diversity indices were calculated using PAST software (Version 4.0.3) . The following diversity indices were used in the study of plant diversity of the study area.

(a) Shannon diversity index (H') $H' = \sum_{i=1}^{S} pi.Inpi$

Where,

S = No. of species in an area.

pi = proportion of individuals observe in the i^{th} species.

In = natural logarithm

(b) Simpson's index of diversity (1-D)

$$D = \sum_{i=1}^{S} \frac{ni(ni-1)}{N(N-1)}$$

Where,

N = Total number of the individuals in each sample

ni = No. of individuals of species in that area

(c) Species Evenness, Pielou's evenness index (1975)

$$E = H'/InS$$

Where,

H' = Shannon's index value

S = Total number of species

3.5. Socio economic impact

The quantitative approach (Bryman, 2012) was used for the study of socio economic impact of OPP among farmers. Household survey to farmers were conducted for the study. Observation of plantation area, harvesting process and also visit to buyer company in Mizoram i.e Godrej oil palm mill at Bukvannei, Kolasib is an importance part in this research for the analysis of socio-economic status of oil palm farmers. Questionnaires and interview are both used to collect information in the study. Questionnaire comprises of 28 questions of both open ended and close ended questions. It includes general profile of farmer, cultivation challenges, management, harvesting, economic return, satisfaction and other related issues.

The sample were randomly selected from farmers having more than 1 ha of plantation field within Kolasib district. The sample consist of 20 farmers randomly selected from the list of farmers that maintain by Godrej Agrovet Ltd. The survey was conducted during 2019 in Kolasib. Oil palm cultivation occupies a significant portion of the district of Kolasib and therefore it is chosen over other district in Mizoram for the study of socio-economic impact of oil palm plantation in Mizoram.

***Figure 3.4**: Sample collection and analysis during the study period*

Chapter 4

Soil Physico–chemical property

4.1 Introduction

Soil serves as the foundation for agriculture and is a vital component of the planet's ecosystem. The ability to cultivate crops is contingent upon soil, rendering it an indispensable element for the survival of life forms on the planet. Soil is a dynamic and intricate compound due to its composition, which comprises mineral particles, organic matter, gases, liquids, water, and diverse forms of micro living organisms. Soil is an essential medium that is required for the germination, growth, and development of plants. Climate, progenitor materials, topography, time, and living organisms are all significant determinants in soil formation (Jenny, 1941). Its fertility is crucial because soil functions as a repository for essential nutrients that have a direct influence on the development, well-being, and efficiency of agricultural crops.

The evolution, demise, and resurgence of agricultural civilizations have been impacted by the management and utilisation of water and soil resources by humans (Harlan et al., 1992; Hillel, 1992). Soil has historically been an indispensable resource for agricultural productivity and the sustenance of communities. The management and utilisation of soil resources have played crucial roles in determining the progress or downfall of civilizations. The reliance of human beings on the soil for sustenance and food production has its origins in ancient civilizations and persists in modern agricultural techniques. In the absence of efficient soil management, the regeneration and flourishing of civilizations would be arduous.

Good soil possesses favourable chemical and physical properties. Functional development, habitat construction, and plant growth are all impacted by the soil's physical and chemical properties (Callaway, 2001). Depending on factors such as vegetation, geographical location, climatic conditions, human activities, and land management practices, the soil characteristics of a given area can vary considerably.

Monitoring the physical properties of soil is crucial for comprehending its condition. The physical characteristics consist of porosity, density, texture, and water-retention capacity. It exerts an impact on plant growth through its manipulation of the circulation of oxygen, water, and nutrients. The physical composition of the soil facilitates the anchoring and growth of plant roots. Soil that is properly structured facilitates root penetration, expansion, and nutrient uptake. Additionally, the chemical composition of the soil can also have an effect on its physical properties. The chemical properties of soil are predominantly influenced by the interplay of diverse chemical constituents among soil particles and in the soil solution, as well as the composition of inorganic and organic compounds. The chemical component of soil is unquestionably vital, as it governs the ideal balance of nutrients contained within the soil. Chemical properties are essential for plant development and growth, as well as the preservation of soil fertility. Degradation of soil quality results from undesirable changes in soil properties; therefore, it is essential to comprehend how the interaction of chemical properties in the soil affects its capacity to store and release nutrients.

According to Salim et al. (2015), the three main nutrients are nitrogen (N), phosphorus (P) and potassium (K). Together they make up the NPK. One of the important factors to determine quality of soil and serves as sources of nutrients for improving physical and biological properties of soils in addition to productivity is soil organic carbon content. The nutrient transformation and its availability in soils depend on pH, clay minerals, cation and anion exchange capacity (Reddy and Reddy, 2010).

The effective management of soil nutrients significantly influences the yield potential of agricultural lands. Degradation of soil quality is a significant worldwide concern, with the majority of these processes being more pronounced in tropical regions compared to temperate climates (Mandal, 2007). A prudent and scientific approach to managing soil resources is critical at the present moment, as the security and quality of soil are prerequisites for the production of goods in every nation.

The assessment of functional changes in soil can be determined using physical, chemical, and biological properties as soil quality indicators (Wander and Bollero, 1999). Indicators for monitoring agricultural land management could be estimated based on changes in soil physical, chemical, and biological properties (Hartemink, 1998; Arshad and Marting, 2002).

Soils are home to an extensive variety and quantity of biomass and biodiversity from soil organisms (Nielsen et al., 2015). Furthermore, they produce and store the majority of the carbon and nutrients required for life (Brevik and Sauer, 2015).

4.2 Result

4.2.1 Soil pH

The soil pH ranges from 5.36 to 5.85 in the plantation field during the study period (2019–2021). Records from the plantation site show that the highest soil pH of 5.85 was observed at 3 years in plot 2 during August 2019, while the lowest pH of 5.36 was found at the 10 years plantation site (plot 1) in December 2021. The pH value at the UD site ranges from 5.70 to 5.93 during the study period. The pH level showed negligible variation across different plantation ages, with a significant difference also observed between plots 1 and 2. The month of August shows the highest pH in all three years, while December and April show par.

Unlike 10 years and 15 years of plantations, which do not show significant variations, the pH of 5 years and 10 years shows a consistent significant value in all three seasons at both plot 1, i.e., $p \leq 0.034$, $p \leq 0.42$, and $p \leq 0.041$, and plot 2, i.e., $p \leq 0.021$, $p \leq 0.022$, and $p \leq 0.021$, respectively.

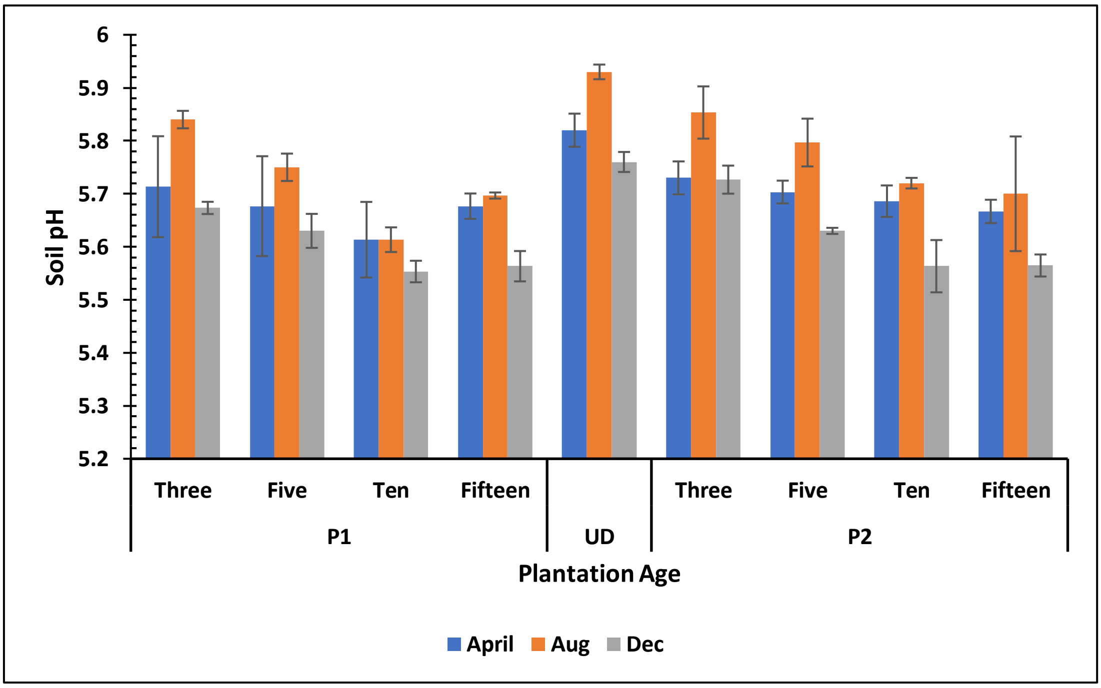

Figure 4.1: *Soil pH in different oil palm plantation age and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3)*

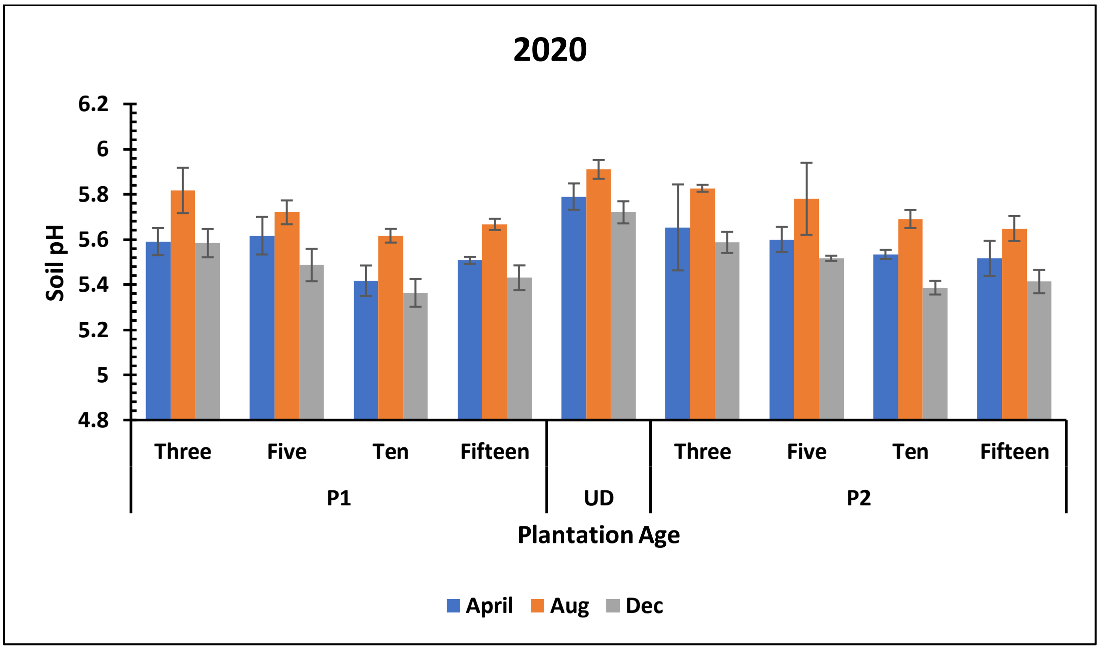

Figure 4.2: *Soil pH in different oil palm plantation age and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3)*

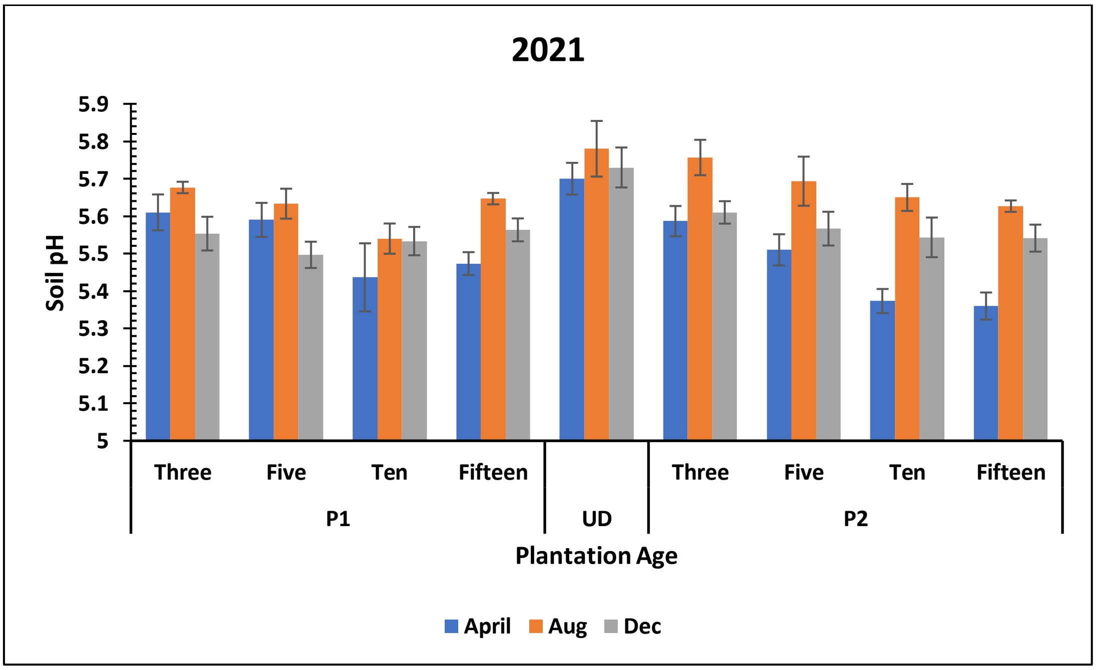

Figure 4.3: *Soil pH in different oil palm plantation age and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3).*

Table 4.1: One-way ANOVA of pH level in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Sl. no	Source of variation (P1 X Age X UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	23.568	.000*	22.074	.000*	26.663	.000*
2	3 X 5	10.000	.034*	8.679	.042*	8.895	.041*
3	5 X 10	16.000	.016*	9.763	.035*	8.672	.042*
4	10 X 15	11.250	.028*	2.990	.159 NS	.062	.816
5	3 X 10	33.800	.004*	20.192	.011*	23.143	.009*
6	3 X 15	8.643	.042*	84.045	.001*	10.471	.032*
7	5 X 15	.100	.768 NS	18.241	.013*	3.670	.128 NS
8	3 X UD	64.474	.001*	10.256	.033*	11.250	.028*
9	5 X UD	96.000	.001*	26.978	.007*	39.062	.003*
10	10 X UD	82.639	.001*	34.978	.004*	64.654	.001*
11	15 X UD	42.422	.003*	83.613	.001*	33.800	.004*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.2: One-way ANOVA of pH level in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Sl. no	Source of variation (P2 X Age X UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	21.734	.000*	24.105	.000*	12.250	.001*
2	3 X 5	4.840	.161 NS	2.627	.180 NS	2.588	.183 NS
3	5 X 10	413.796	.021*	13.225	.022*	13.796	.021*
4	10 X 15	4.364	.105 NS	3.348	.141 NS	.636	.470 NS
5	3 X 10	10.500	.032*	7.314	.045*	10.881	.030*
6	3 X 15	2.455	.192 NS	21.160	.010*	6.527	.063 NS
7	5 X 15	.250	.643 NS	13.141	.519 NS	2.911	.163 NS
8	3 X UD	9.046	0.40*	7.924	.048*	8.471	.044*
9	5 X UD	45.375	0.003*	23.838	.008*	25.941	.007*
10	10 X UD	172.735	.000*	105.625	.001*	28.265	.006*
11	15 X UD	58.266	.002*	78.766	.001*	14.440	.019*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.2. Soil Moisture Content

The soil moisture content (SMC) ranges from 13.11% to 23.84% in the plantation field, while the SMC level at the UD site ranges from 19.26% to 27.36% during the study period. The plantation site records indicate that plot 2 (23.84%) and plot 1 (21.89%) experienced the highest SMC in 3 years during August 2019, respectively. The lowest level of SMC (13.11%) was observed in 10 years of OPP during December 2020. There was a significant variation in levels of SMC among different plantation ages, as well as between plots 1 and 2. During the study period, August had the highest SMC. When comparing April and December, April demonstrated a higher SMC in 2019 and 2020, but a lower SMC in 2021 compared to December.

The difference in level of SMC between 5 years and 10 years of OPP shows a consistent and significant variation in all three seasons at both plot 1 and plot 2. Tables 4.3 and 4.4, respectively, illustrate this significant variation. It is clear from the table that UD sites show significant differences when crossing with different ages of plantations.

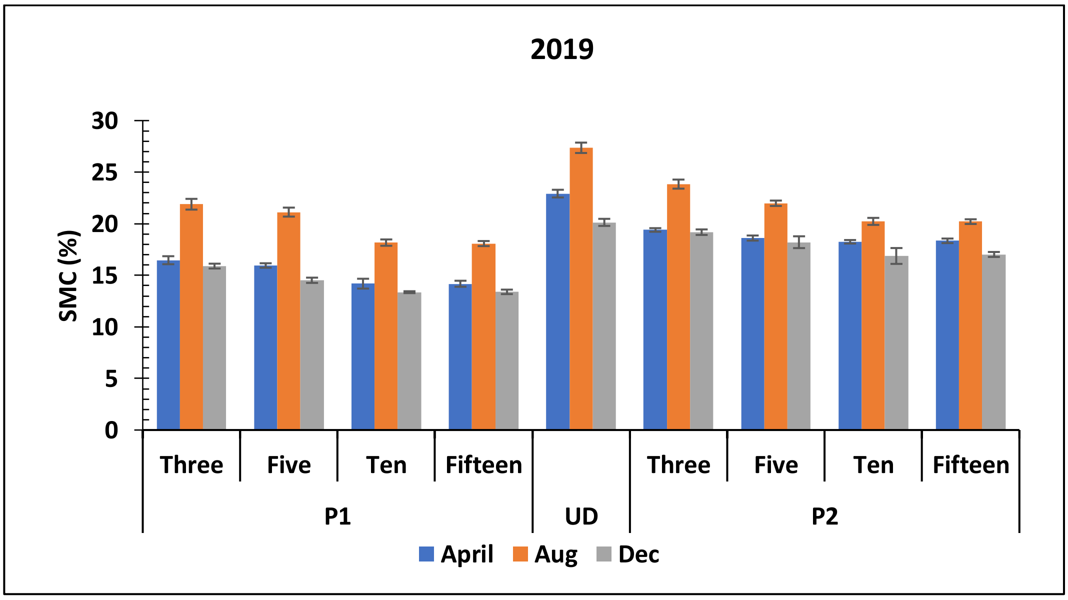

Figure 4.4: *Soil Moisture Content of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3).*

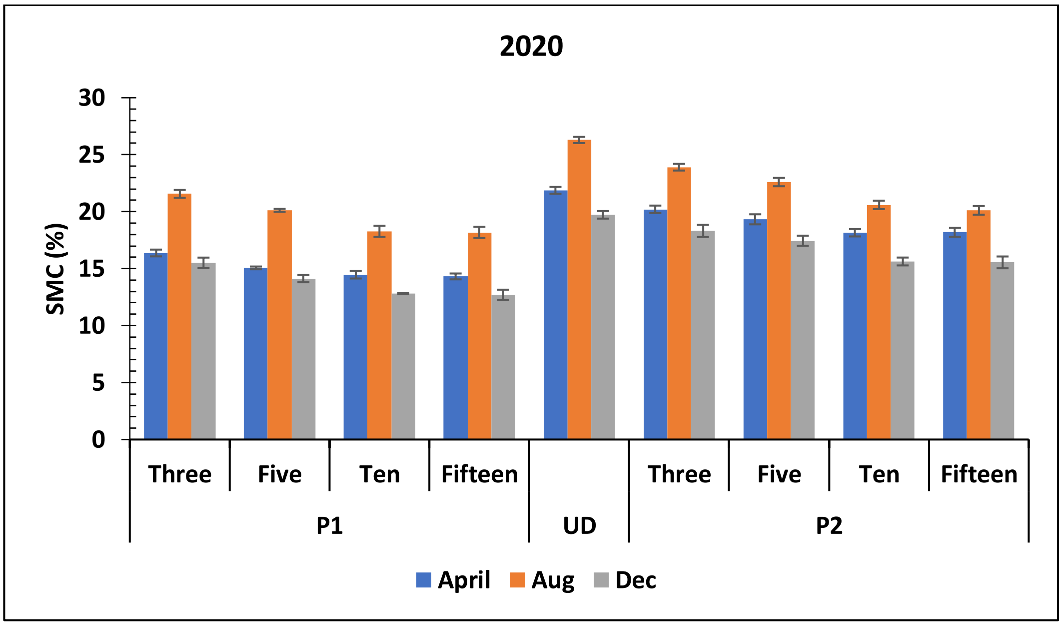

Figure 4.4: *Soil Moisture Content of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3).*

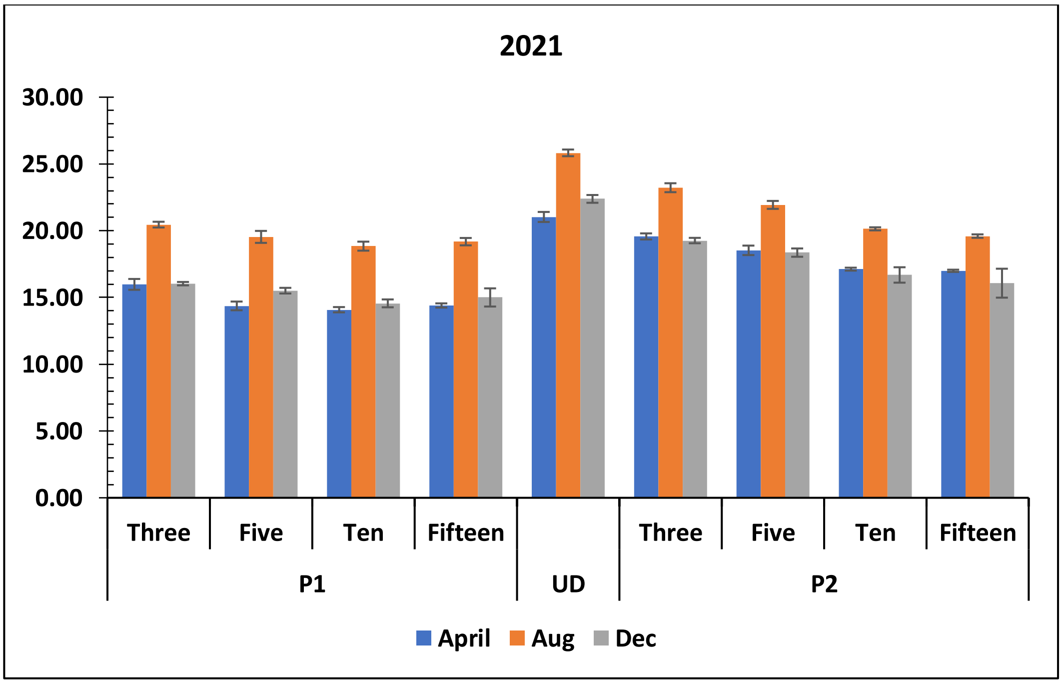

Figure 4.6: *Soil Moisture Content of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3).*

Table 4.3: One-way ANOVA of Soil Moisture Content in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Sl. No	Source of variation (P1 X Age X UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	272.475	.000*	247.202	.000*	480.127	.000*
2	3 X 5	9.311	.038*	5.795	.074 NS	22.592	.009*
3	5 X 10	76.892	.001*	210.422	.000*	34.139	.004*
4	10 X 15	7.223	.055 NS	93.749	.001*	.914	.393 NS
5	3 X 10	120.404	.000*	113.182	.000*	176.629	.000*
6	3 X 15	124.160	.000*	33.629	.004*	95.046	.001*
7	5 X 15	70.917	.001*	64.642	.001*	17.109	.014*
8	3 X UD	238.163	.000*	156.272	.000*	584.440	.000*
9	5 X UD	262.781	.000*	350.848	.000*	740.278	.000*
10	10 X UD	336.823	.000*	637.565	.000*	1.804E3	.000*
11	15 X UD	323.137	.000*	226.313	.000*	1.160E3	.000*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.4: One-way ANOVA of Soil Moisture Content in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Sl. no	Source of variation (P2 X Age X UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	99.247	.000*	187.359	.000*	118.288	.000*
2	3 X 5	31.361	.005*	6.862	.053 NS	15.048	.018*
3	5 X 10	23.711	.008*	13.225	.022*	31.413	.005*
4	10 X 15	1.508	.287 NS	.740	.438 NS	2.321	.202 NS
5	3 X 10	318.798	.000*	35.654	.004*	73.829	.001*
6	3 X 15	108.324	.000*	54.988	.002*	77.503	.001*
7	5 X 15	9.588	.036*	28.074	.006*	29.164	.006*
8	3 X UD	76.745	.001*	165.175	.000*	64.776	.001*
9	5 X UD	96.897	.001*	318.972	.000*	214.050	.000*
10	10 X UD	120.918	.000*	365.083	.000*	379.857	.000*
11	15 X UD	113.735	.000*	455.472	.000 NS	593.195	.000*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.3. Soil Bulk Density

The level of soil bulk density in different plantation age and undisturbed forest during the study period has been presented in figure 4.7, 4.8 and 4.9. Highest soil bulk density 1.42 gcm^{-3} was recorded in 10 years during the month of December 2020. Among different age of plantation, 3 years showed the lowest bulk density. The soil bulk density consistently increases from 3 years till 10 years plantation. Plot 1 show higher bulk density than plot 2 in all plantation age and all sampling season. It is clear from the figure that soils of undisturbed forest shows lower bulk density as compared to different age of plantation.

Soil bulk density in the different plantation age show a wide range of variation. Significant difference at $p \leq 0.05$ was mostly observed between plantation ages and undisturbed forest during the study period. Insignificant variation was observed between 10 years and 15 years plantation during the study period except in August 2019 (P1) where significant difference was recorded at $p = 0.019$. Insignificant variation was also observed between 3 years and 5 years in April 2019 where $p = 0.069$.

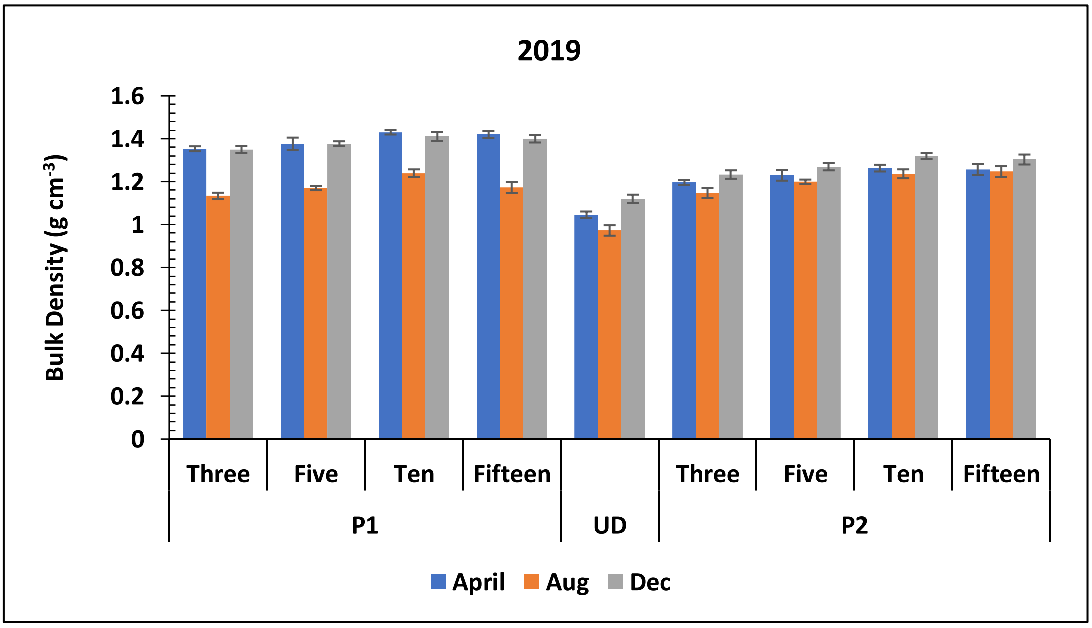

Figure 4.7: *Soil Bulk Density of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019. Each value were represented as mean ± SD (n=3)*

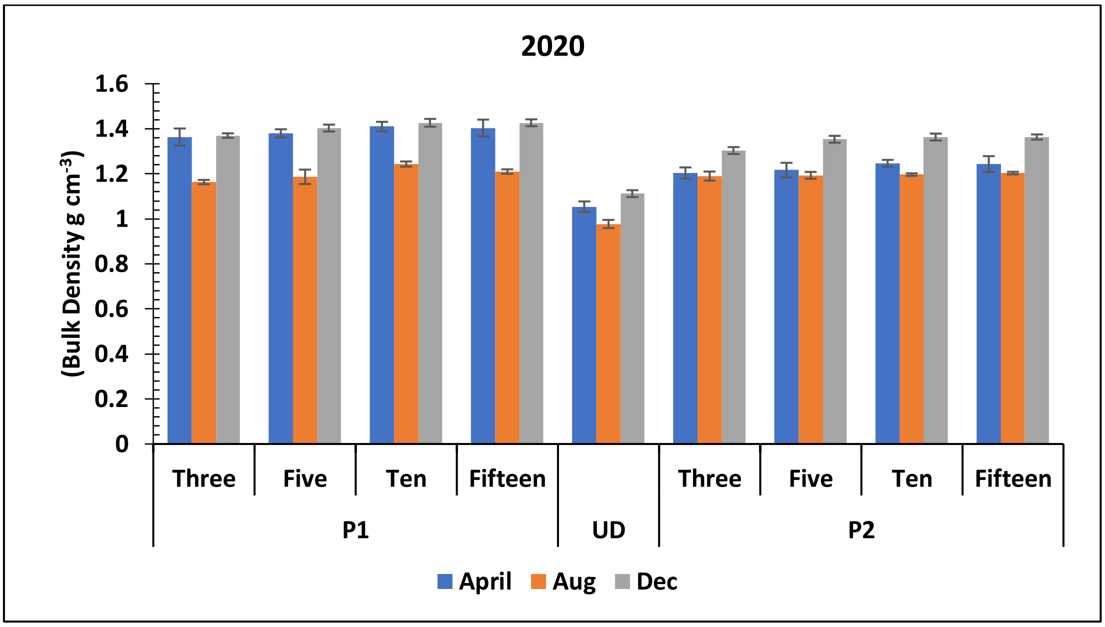

Figure 4.8: *Soil Bulk Density of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020. Each value were represented as mean ± SD (n=3)*

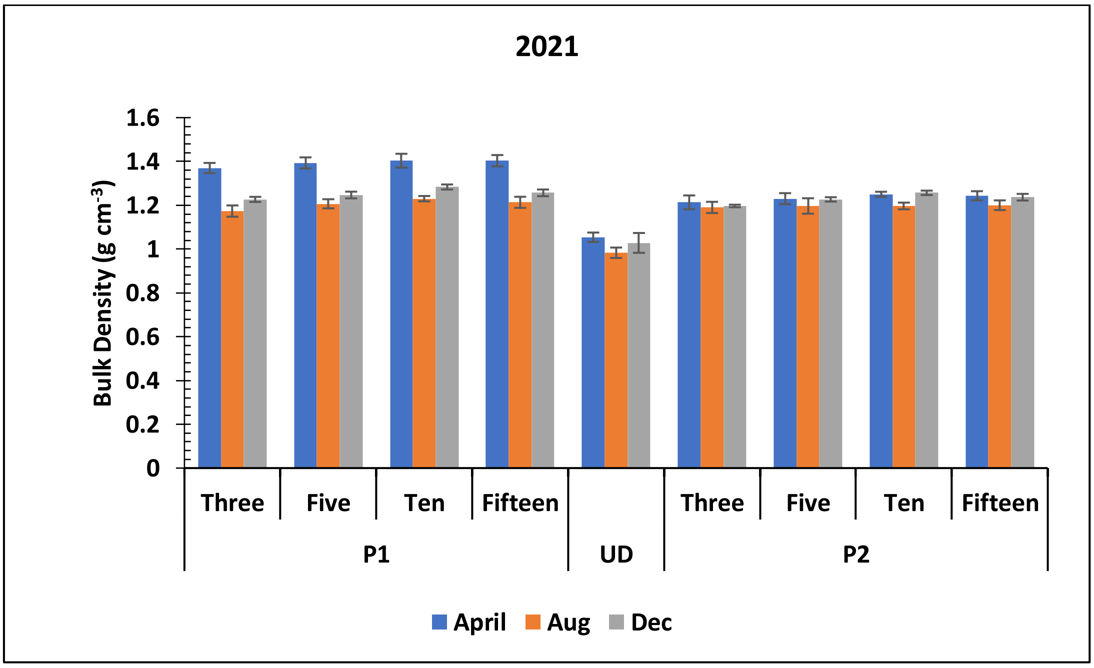

Figure 4.9: *Soil Bulk Density of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021. Each value were represented as mean ± SD (n=3)*

Table 4.5: One-way ANOVA of Soil Bulk Density in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Sl. no	Source of variation (P1 X Age X UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	691.136	.000*	85.493	.000*	270.465	.000*
2	3 X 5	6.125	.069 NS	12.100	.025*	13.091	.022*
3	5 X 10	36.571	.004*	36.750	.004*	11.000	.029*
4	10 X 15	1.500	.288 NS	14.28	0.019*	1.000	.374 NS
5	3 X 10	75.571	.001*	64.000	.001*	37.786	.004*
6	3 X 15	57.143	.002*	5.538	.048*	22.562	.009*
7	5 X 15	24.143	.008*	.045	.842 NS	3.769	.124 NS
8	3 X UD	1.312E3	.000*	106.625	.000*	560.777	.000*
9	5 X UD	1.519E3	.000*	196.347	.000*	624.763	.000*
10	10 X UD	2.423E3	.000*	269.677	.000*	931.556	.000*
11	15 X UD	2.299E3	.000*	107.394	.000*	486.957	.000*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.6: One-way ANOVA of Soil Bulk Density in different soil samples such as 3 years (3y), 5 years(5y), 10 years (10y) and 15 years(15y) from plot 2 and undisturbed forest (UD).

Sl. no	Source of variation (P2 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	246.733	.000*	118.457	.000*	99.982	.000*
2	3 X 5	25.000	.007*	11.636	.027*	9.308	.038*
3	5 X 10	25.000	.007*	17.286	.014*	18.750	.012*
4	10 X 15	.500	.519 NS	.818	.417 NS	2.500	.189 NS
5	3 X 10	200.000	.000*	31.696	.005*	96.571	.001*
6	3 X 15	40.500	.003*	34.615	.004*	40.091	.003*
7	5 X 15	6.400	.065 NS	19.600	.011*	6.250	.067 NS
8	3 X UD	586.569	.000*	80.829	.001*	121.812	.000*
9	5 X UD	555.224	.000*	260.354	.000*	139.752	.000*
10	10 X UD	1.222E3	.000*	332.333	.000*	424.028	.000*
11	15 X UD	420.484	.000*	309.047	.000*	242.194	.000*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.4. Soil Water Holding Capacity

The water holding capacity (WHC) in the soil of different ages of plantation shows variation ranging from 31.50% in 10 years (P1) to 49.90% in 3 years (P2). The UD site ranges from 51.48% to 63.85% during the study period, and it shows a high level of WHC as compared to oil palm plantation soil. There was a small variation in the WHC (%) of the soil samples, especially in April and August. However, the WHC for the different plantation years shows a consistent decrease from 3 to 10 years. However, there is only a negligible change in soil after 10 and 15 years of planting. During the study period, P2 showed higher WHC with respect to P1 at all plantation ages.

One-way ANOVA of soil WHC in different soil samples shows that there is a highly significant variation between undisturbed forest and different plantation years at $p \leq 0.05$. Significant variation was reported among different ages of plantations in different seasons except between 10 and 15 years, which shows an unsignificant level of $p = 0.364$ in April (P1) and $p = 0.331$ (P1) in August.

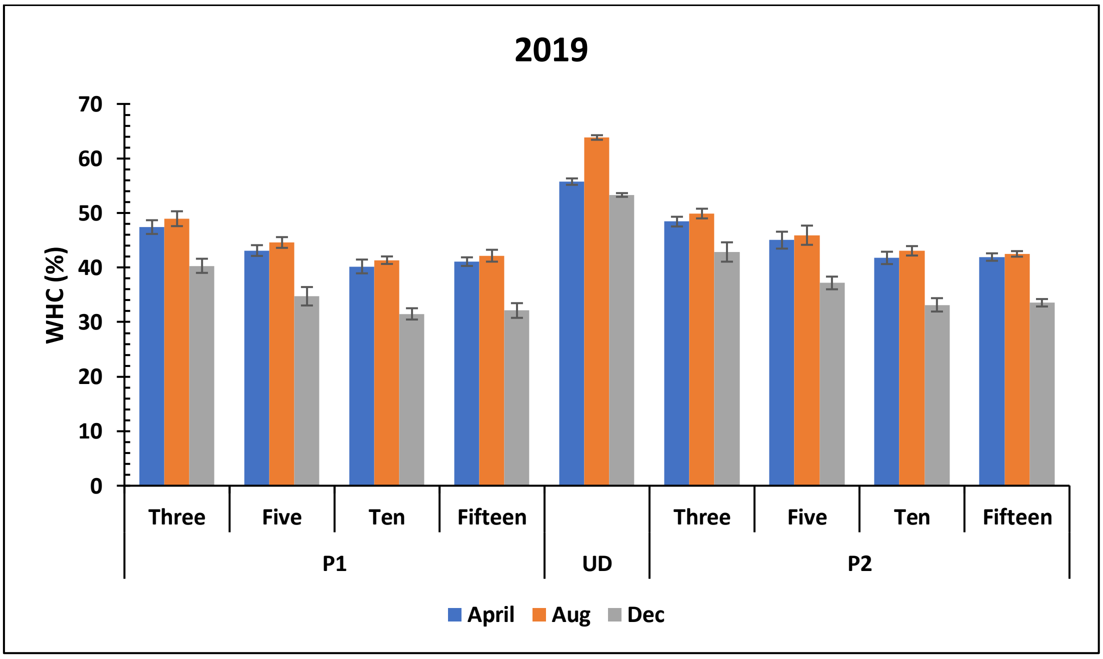

***Figure 4.10**: Soil Water Holding Capacity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019. Each value were represented as mean ± SD (n=3.)*

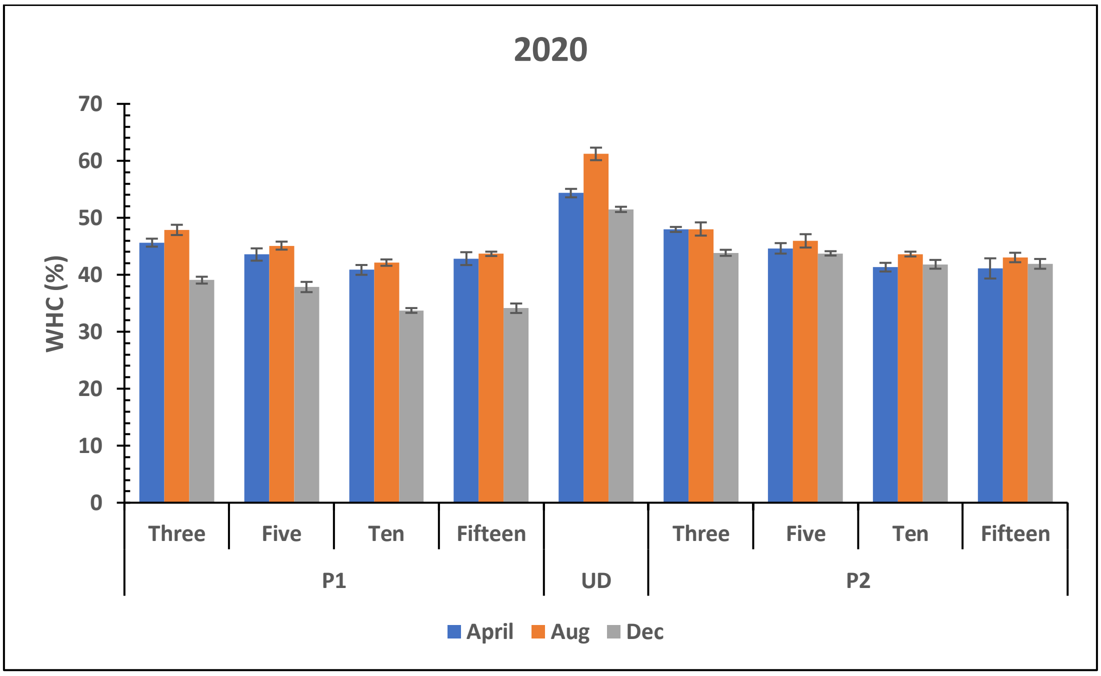

Figure 4.11: *Soil Water Holding Capacity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020. Each value were represented as mean ± SD (n=3)*

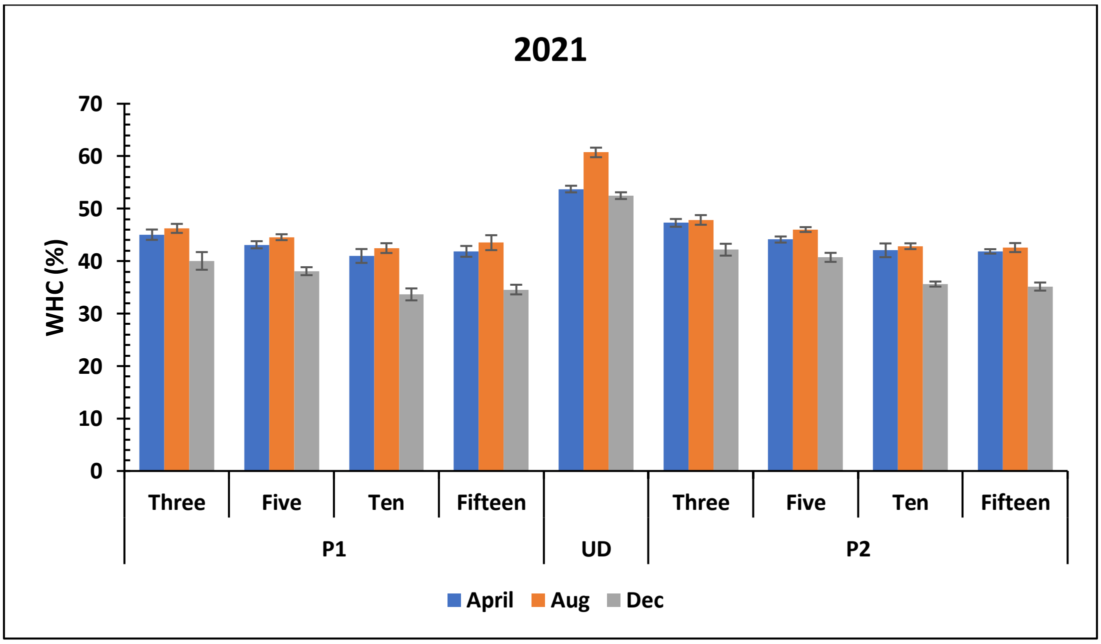

Figure 4.12: *Soil Water Holding Capacity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021. Each value were represented as mean ± SD (n=3)*

Table 4.7: One-way ANOVA of Soil Water Holding Capacity in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 and undisturbed forest (UD).

Sl. no	Source of variation (P1 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	28.452	.000*	65.968	.000*	63.519	.000*
2	3 X 5	4.817	.054	6.349	.055 NS	37.422	.004*
3	5 X 10	9.926	.034*	21.879	.009*	187.443	.000*
4	10 X 15	1.047	.364 NS	1.220	.331 NS	382.293	.000*
5	3 X 10	12.796	.023*	14.750	.018*	300.617	.000*
6	3 X 15	10.716	.031*	11.077	.029*	6.809	.059 NS
7	5 X 15	7.771	.049*	8.213	.046*	7.999	.047*
8	3 X UD	11.463	.028*	39.599	.003*	15.400	.015*
9	5 X UD	56.205	.002*	171.726	.000*	19.534	.012*
10	10 X UD	79.301	.001*	254.044	.000*	15.887	.016*
11	15 X UD	78.940	.001*	210.956	.000*	4.389	.104

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.8: One-way ANOVA of Soil Water Holding Capacity in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 and undisturbed forest (UD).

Sl. no	Source of variation (P2 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	43.509	.000*	111.022	.000*	115.663	.000*
2	3 X 5	10.865	.030*	12.163	.025*	21.469	.010*
3	5 X 10	7.617	.043*	6.367	.045*	16.963	.015*
4	10 X 15	1.231	.329 NS	.956	.384 NS	.220	.663 NS
5	3 X 10	64.196	.001*	91.208	.001*	60.502	.001*
6	3 X 15	134.627	.000*	156.836	.000*	71.846	.001*
7	5 X 15	17.572	.014*	10.466	.032*	21.850	.009*
8	3 X UD	19.341	.012*	92.725	.001*	56.407	.002*
9	5 X UD	34.703	.004*	111.868	.000*	194.588	.000*
10	10 X UD	66.405	.001*	207.184	.000*	292.180	.000*
11	15 X UD	82.270	.001*	207.184	.000*	374.351	.000*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.5. Soil Organic Carbon content

The level of SOC in different age of plantation ranges from 1.25% to 2.0% and details on the level of SOC for different plantation age in different season have been presented in figure 4.13 to 4.15. It is clear from the figure that UD site has higher SOC as compared to plantation site and also soil from plot 2 show higher level of SOC as compared to plot 1. There is a great change in SOC content from 5 years to 10 years while the difference in level of SOC between 10 years and 15 years was reported to be negligible.

There is a highly significant variation in SOC between UD site and different plantation age. Significant variation was also observed between plantation age at $p \leq 0.05$ especially between 3 years to 5 years and also between 5 years to 10 years. However, insignificant level of difference was reported between 10 years and 15 years during the study period. This insignificant level of variation was recorded at both P1 and P2.

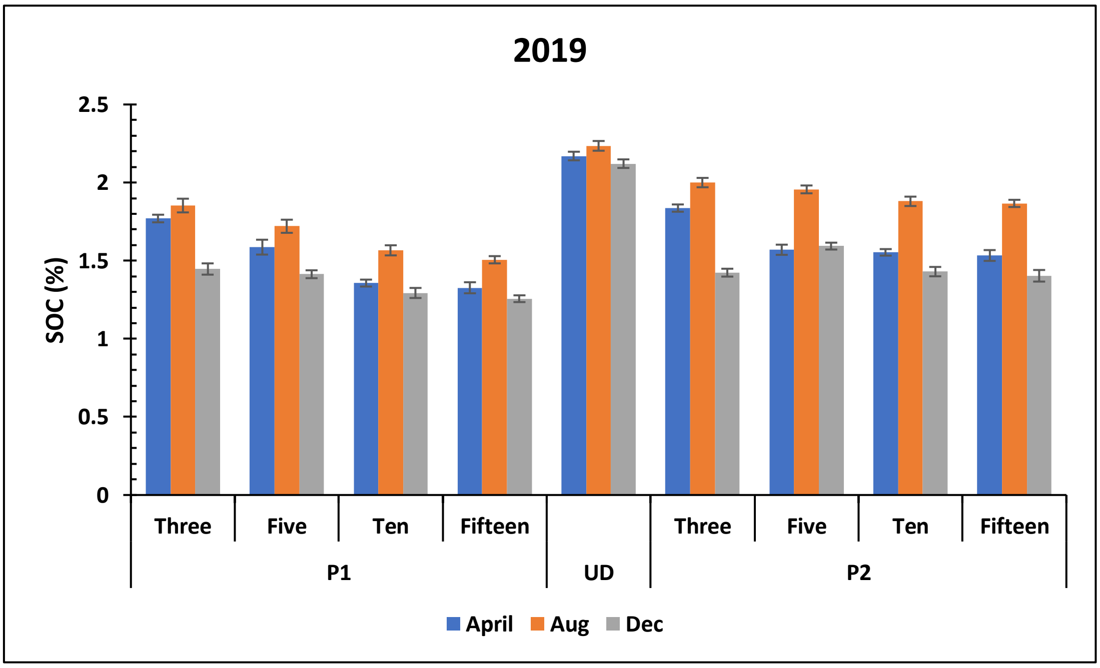

Figure 4.13: *Soil Organic Carbon (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019. Each value were represented as mean ± SD (n=3)*

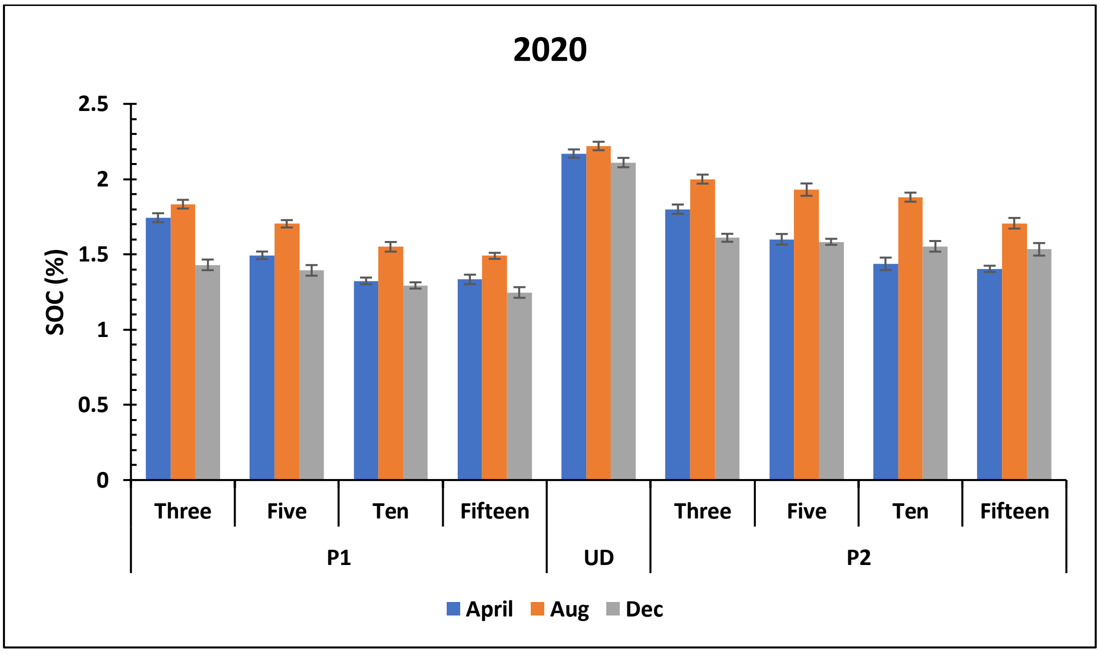

Figure 4.14: *Soil Organic Carbon (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020. Each value were represented as mean ± SD (n=3)*

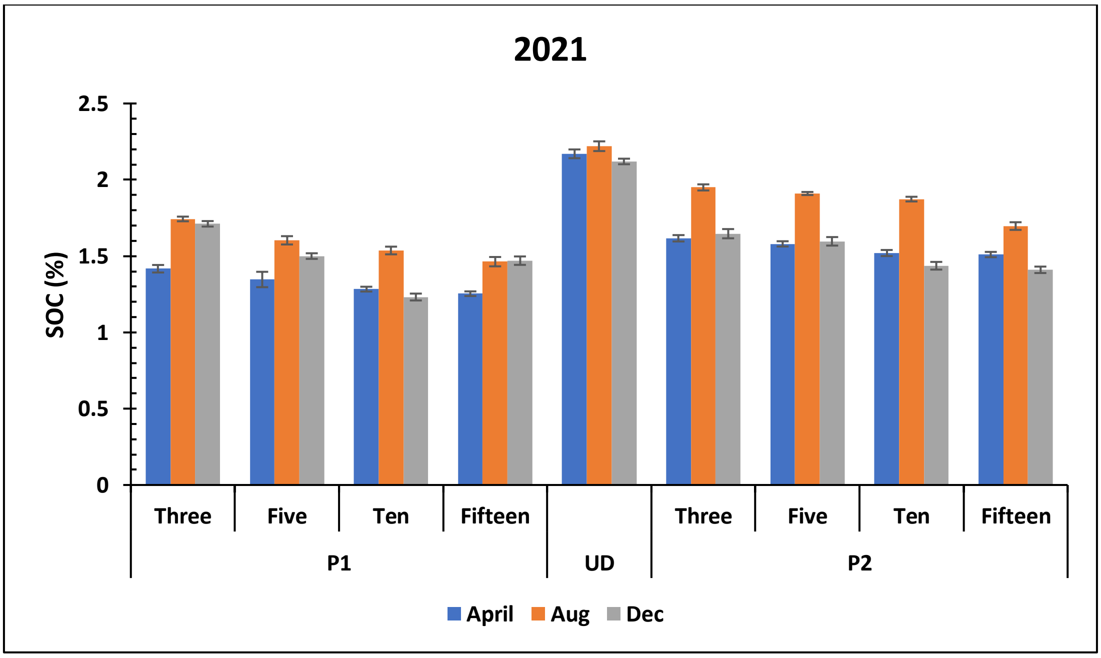

Figure 4.15: *Soil Organic Carbon (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021. Each value were represented as mean ± SD (n=3)*

Table 4.9: One-way ANOVA on the level of Soil Organic Carbon (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1(P1) and undisturbed forest (UD).

Sl. no	Source of variation (P1 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	392.660	.000*	371.162	.000*	883.459	.000*
2	3 X 5	43.282	.003*	21.924	.009*	52.155	.002*
3	5 X 10	39.769	.003*	80.485	.001*	376.962	.000*
4	10 X 15	3.184	.149 NS	3.536	.133 NS	2.500	.189 NS
5	3 X 10	530.632	.000*	105.209	.001*	515.565	.000*
6	3 X 15	1.672E3	.000*	137.069	.000*	601.929	.000*
7	5 X 15	64.145	.001*	146.812	.000*	491.636	.000*
8	3 X UD	669.150	.000*	198.716	.000*	272.217	.000*
9	5 X UD	306.244	.000*	1.041E3	.000*	1.236E3	.000*
10	10 X UD	1.508E3	.000*	2.093E3	.000*	7.638E3	.000*
11	15 X UD	3.431E3	.000*	3.442E3	.000*	1.453E4	.000*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.10: One-way ANOVA on the level of Soil Organic Carbon (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Sl. no	Source of variation (P2 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	338.225	.000*	162.546	.000*	571.948	.000*
2	3 X 5	6.897	.058 NS	6.149	.068 NS	20.909	.056 NS
3	5 X 10	248.909	.000*	40.620	.003*	117.600	.000*
4	10 X 15	1.060	.361 NS	.640	.469 NS	1.306	.317 NS
5	3 X 10	142.516	.000*	33.231	.004*	480.129	.000*
6	3 X 15	183.192	.000*	40.000	.003*	301.786	.000*
7	5 X 15	483.801	.000*	52.021	.002*	62.500	.001*
8	3 X UD	129.634	.000*	140.522	.000*	350.464	.000*
9	5 X UD	515.955	.000*	753.121	.000*	5.688E3	.000*
10	10 X UD	1.228E3	.000*	556.811	.000*	3.115E3	.000*
11	15 X UD	1.933E3	.000*	571.373	.000*	1.195E3	.000*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.6 Soil Total Nitrogen

During the study period, total N content showed changes at different plantation ages. Figure 4.16, 4.17 and 4.18 presented the change in soil TN during the study period. TN in 10-year-old oil palm soil is relatively low in all seasons as compared to other ages of plantations. The soils of the UD site show a higher TN content than all ages of plantations. In P1, the level of TN decreases significantly up to 10 years; however, the soils of 15-year-old trees exhibit a slight increase in TN compared to 10 years of plantation. However, in P2, the difference in soil TN content between 10 and 15 years is inconsistent, with a tendency towards a decrease.

The soil total nitrogen at the plantation site shows significant variation with respect to the change in age of the palm tree and also with respect to the change in season during the study period. However, most of the variation in TN between 10 and 15 years does not show a significant difference. It was reported that the UD site shows a significant difference in crossings with different ages of plantations.

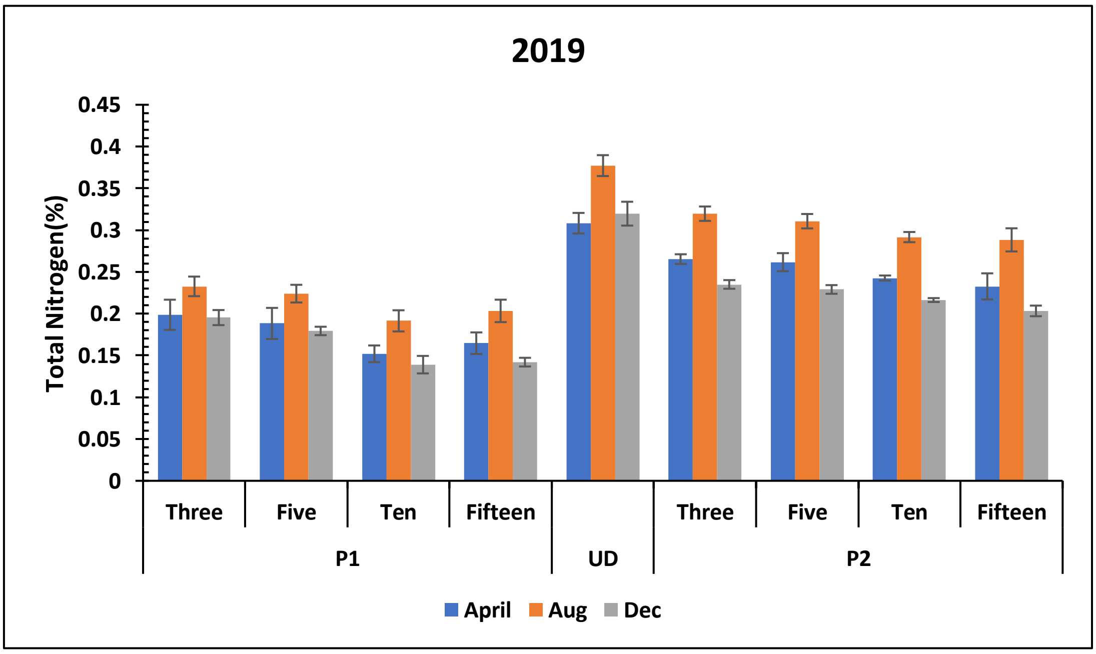

Figure 4.16: *Soil Total Nitrogen (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3).*

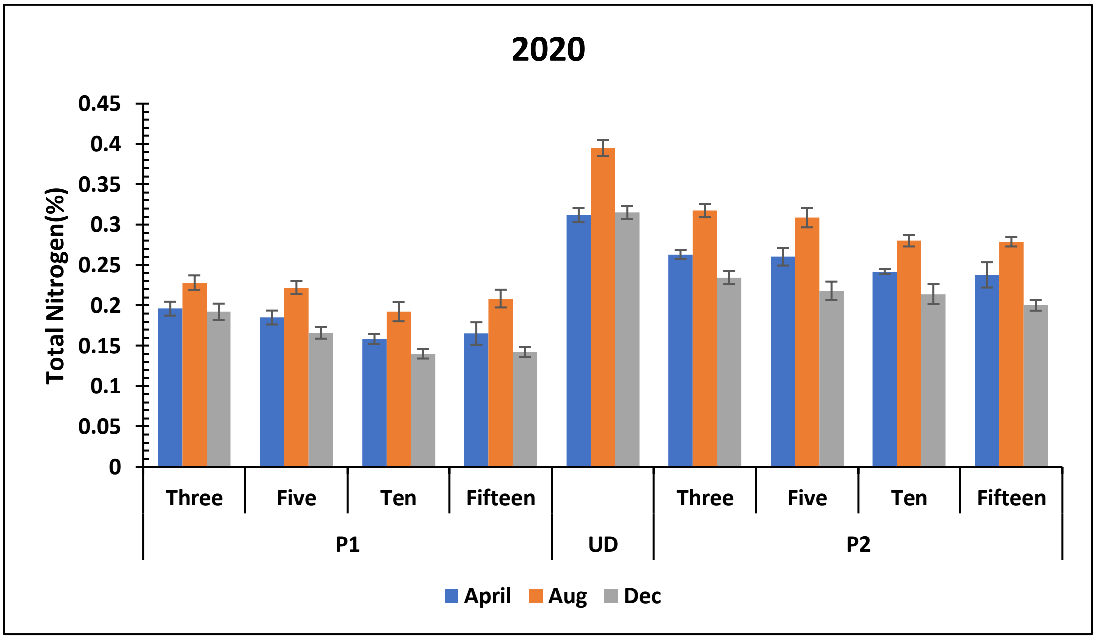

Figure 4.17*: Soil Total Nitrogen (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3).*

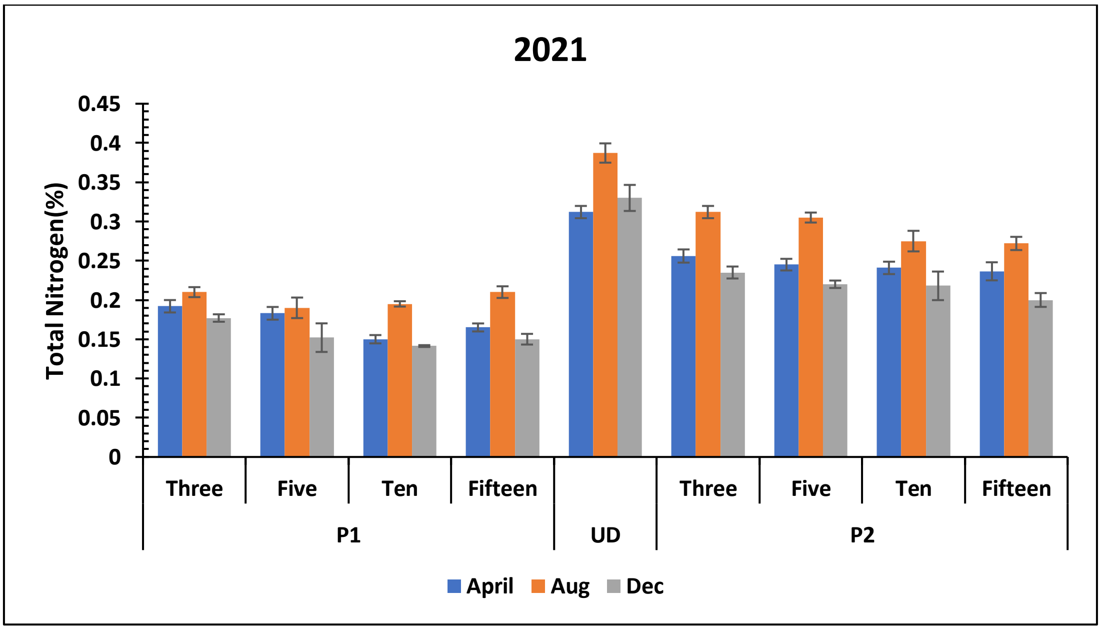

Figure 4.18: *Soil Total Nitrogen (%) of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3).*

Table 4.11: One-way ANOVA on the level of Soil Total Nitrogen (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Sl. no	**Source of variation (P1 x Age x UD)**	**April**		**August**		**December**	
		F-value	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**
1	3 X 5 X 10 X 15 X UD	166.710	.000*	115.308	.000*	463.046	.000*
2	3 X 5	3.971	.117 NS	.904	.396 NS	7.200	.055 NS
3	5 X 10	52.860	.002*	11.670	.027*	130.723	.000*
4	10 X 15	2.024	.228 NS	1.261	.324 NS	.692	.452 NS
5	3 X 10	76.561	.001*	17.103	.014*	102.004	.001*
6	3 X 15	26.141	.007*	8.126	.046*	78.769	.001*
7	5 X 15	13.925	.020*	4.383	.104 NS	79.898	.001*
8	3 X UD	188.413	.000*	222.143	.000*	415.310	.000*
9	5 X UD	240.899	.000*	274.324	.000*	1.061E3	.000*
10	10 X UD	410.130	.000*	337.594	.000*	2.313E3	.000*
11	15 X UD	267.583	.000*	278.973	.000*	1.652E3	.000*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.12: One-way ANOVA on the level of Soil Total Nitrogen (%) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Sl. no	**Source of variation (P2 x Age x UD)**	**April**		**August**		**December**	
		F-value	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**
1	3 X 5 X 10 X 15 X UD	23.030	.000*	36.684	.000*	242.167	.000*
2	3 X 5	.269	.631 NS	1.635	.270 NS	2.000	.230 NS
3	5 X 10	8.618	.043*	9.699	.036*	14.887	.018*
4	10 X 15	1.183	.338 NS	.145	.723 NS	11.102	.029*
5	3 X 10	36.125	.004*	21.063	.010*	32.330	.005*
6	3 X 15	11.529	.027*	11.045	.029*	44.678	.003*
7	5 X 15	6.995	.057 NS	5.611	.077 NS	29.351	.006*
8	3 X UD	30.797	.005*	45.166	.003*	375.093	.000*
9	5 X UD	24.739	.008*	60.460	.001*	430.140	.000*
10	10 X UD	83.513	.001*	120.471	.000*	898.131	.000*
11	15 X UD	43.842	.003*	70.125	.001*	574.533	.000*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.7. Soil Available Phosphorus

The difference in the level of available phosphorus in the soil has been presented in figures 4.19 to 4.21. It was observed that there is a consistent decrease in the level of available phosphorus from 3 years to 10 years, but marginal changes were observed between 10 years and 15 years. Soil phosphorus content in different plantation ages ranges from 10.52 kg ha^{-1} to 16.24 kg ha^{-1} in P1 and from 10.71 kg ha^{-1} to 20.50 kg ha^{-1} in P2. Among the different seasons, December showed a high level as compared to August and April during the study period. The UD site shows a much higher level of phosphorus as compared to the plantation site.

On performing a one-way ANOVA at a significant level of variation of $p \leq 0.05$, it was observed that there is a significant difference between the plantation site and the UD site. Significant variation was mostly observed among different ages of palm trees. However, an insignificant value was obtained between 3 and 5 years, as shown in the table 3.15 and 3.16.

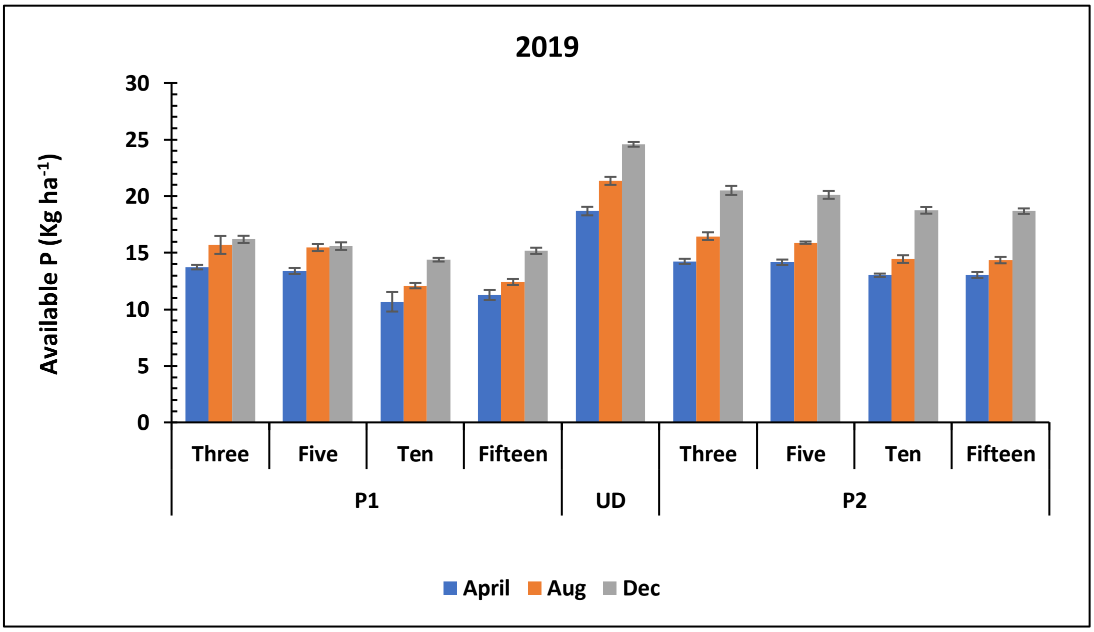

Figure 4.19: *Soil available Phosphorus Kg ha-1 of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019. Each value were represented as mean ± SD (n=3)*

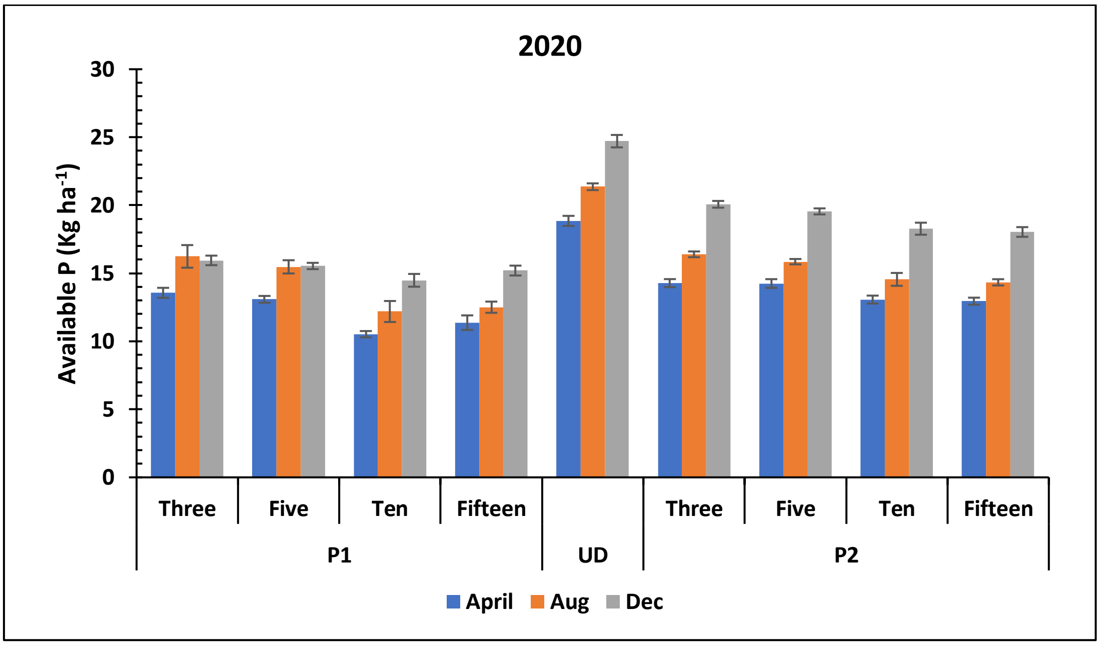

Figure 4.20: *Soil available Phosphorus Kg ha-1 of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020. Each value were represented as mean ± SD (n=3)*

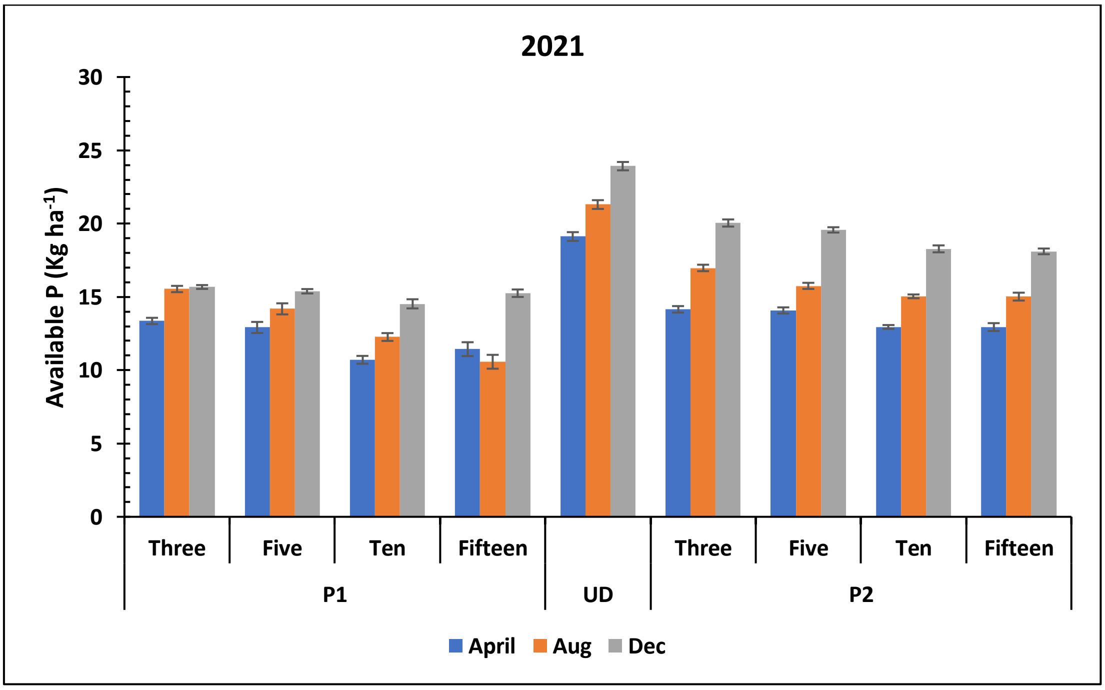

Figure 4.21: *Soil available Phosphorus Kg ha-1 of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021. Each value were represented as mean ± SD (n=3)*

Table 4.13: One-way ANOVA on the level of Soil Available Phosphorus (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Sl. no	Source of variation (P1 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	97.066	.000*	175.471	.000*	546.543	.000*
2	3 X 5	3.372	.140 NS	.247	.646 NS	9.457	.037*
3	5 X 10	26.621	.007*	214.519	.000*	29.722	.005*
4	10 X 15	1.127	.348 NS	2.389	.197 NS	17.063	.014*
5	3 X 10	35.340	.004*	56.812	.002*	340.398	.000*
6	3 X 15	76.702	.001*	46.322	.002*	38.466	.003*
7	5 X 15	50.047	.002*	163.435	.000*	2.570	.184 NS
8	3 X UD	140.890	.000*	100.729	.001*	813.757	.000*
9	5 X UD	153.485	.000*	243.665	.000*	649.635	.000*
10	10 X UD	156.176	.000*	657.706	.000*	1.081E3	.000*
11	15 X UD	244.434	.000*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.14: One-way ANOVA on the level of Soil Available Phosphorus (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Sl. no	Source of variation (P2 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	129.630	.000*	170.589	.000*	170.811	.000*
2	3 X 5	6.377	.065 NS	7.467	.052 NS	4.398	.104 NS
3	5 X 10	17.065	.014*	20.729	.010*	196.654	.000*
4	10 X 15	.002	0.965 NS	.249	.644 NS	.230	.656 NS
5	3 X 10	54.000	.002*	22.580	.009*	27.989	.006*
6	3 X 15	42.146	.003*	18.450	.013*	27.664	.006*
7	5 X 15	14.013	.020*	9.629	.036*	436.142	.000*
8	3 X UD	123.184	.000*	159.442	.000*	118.265	.000*
9	5 X UD	127.792	.000*	261.426	.000*	239.171	.000*
10	10 X UD	136.691	.000*	298.696	.000*	319.442	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$.

NS Not significant

4.2.8. Exchangeable soil Potassium

The level of potassium during the study period has been presented in figure 4.22 to 4.24. It is clear from the study that soil in UD site has a much higher level of K as compared to soils in different age of plantation. In plantation site, changes was also observe for both P1 and P2. Among the season, August shows a high level of exchangeable K while April and December show par. The highest level of soil K was observed in 3 years plantation at P2 (244.13 Kg ha^{-1}) while the lowest K level was recorded in 10 years plantation at P1 (152.33 Kg ha^{-1}). The overall result has indicated that soil potassium in P2 is higher as compare to P1 in the plantation site.

Soil exchangeable K showed significant variation with the increase in age of oil palm plantation. Soils of UD site and 10 years palm tree consistently show high level of significant variation during the study period. Insignificant variation was observe in between 3 years and 5 years and also in between 10 years and 15 years. Soil sample at P1 site show high level of significant with UD as compare with P2.

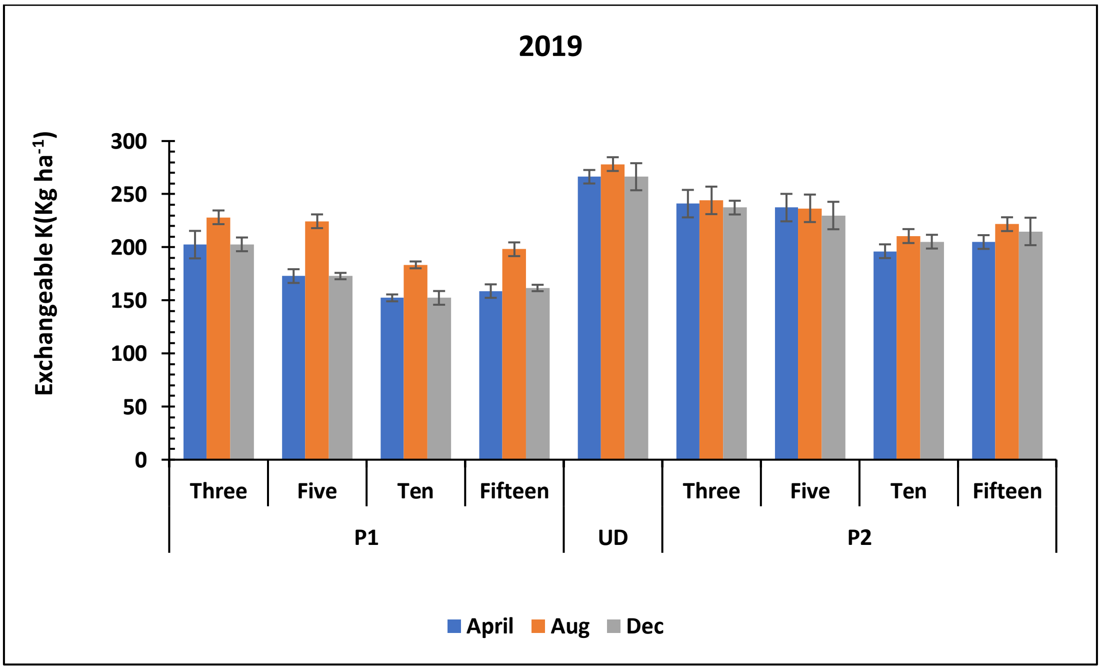

Figure 4.22: *Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2019. Each value were represented as mean ± SD (n=3)*

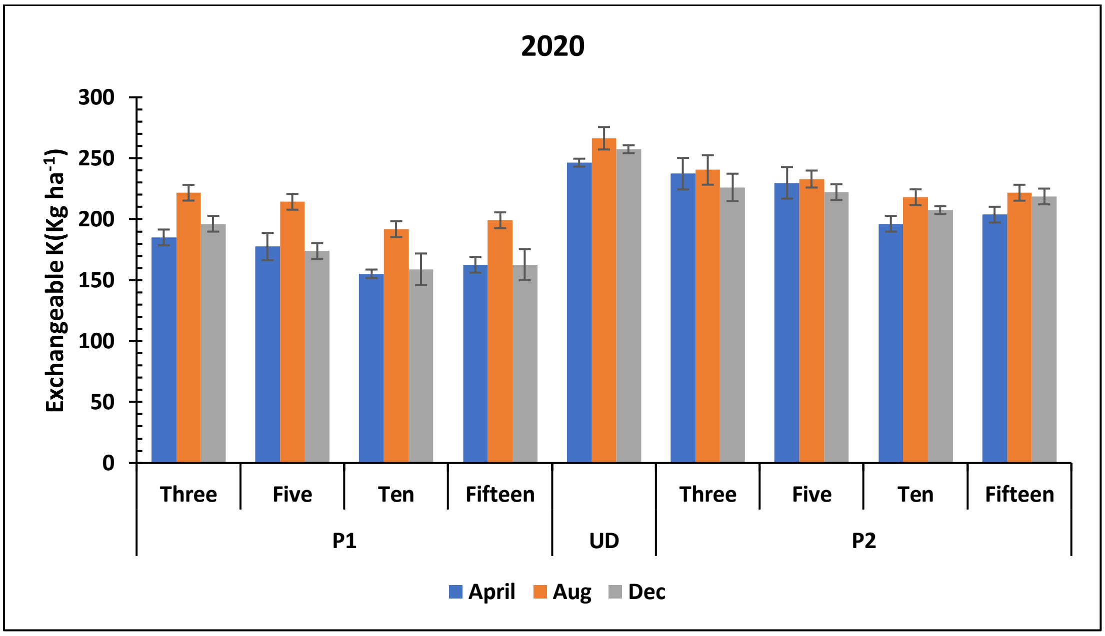

Figure 4.23: *Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2020. Each value were represented as mean ± SD (n=3)*

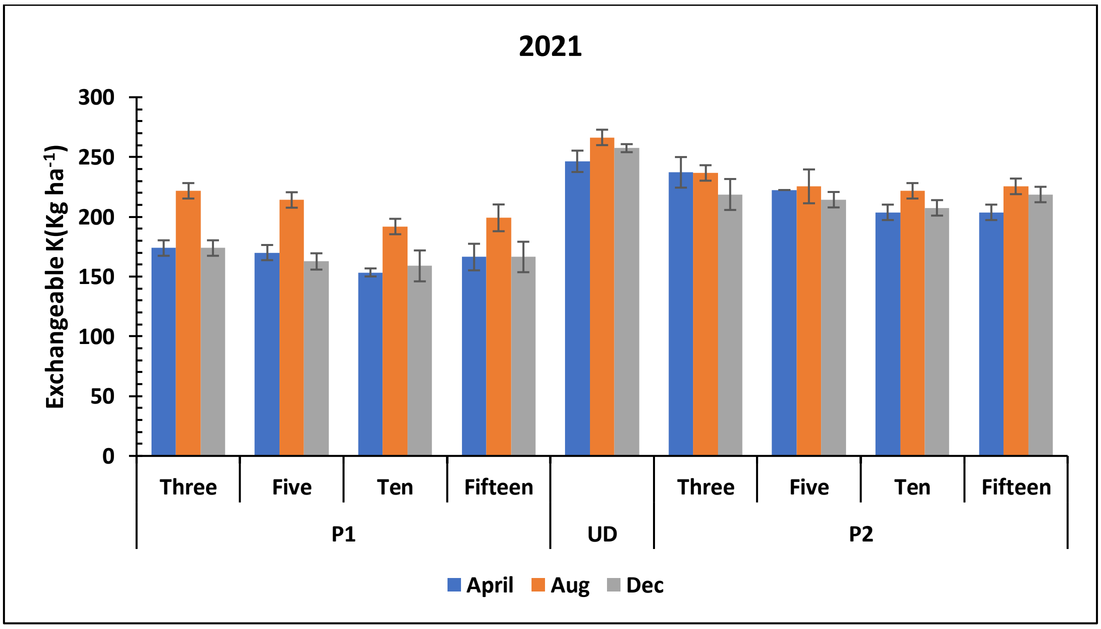

Figure 4.24: *Soil exchangeable Potassium (Kg ha-1) of different plantation ages (3y, 5y, 10y and 15y) and undisturbed (UD) forest site in 2021. Each value were represented as mean ± SD (n=3)*

Table 4.15: One-way ANOVA on the level of Soil exchangeable Potassium (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 1 (P1) and undisturbed forest (UD).

Sl. no	Source of variation (P1 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	24.632	.000*	81.812	.000*	1.506E3	.000*
2	3 X 5	4.765	.094	32.000	.005*	9.457	.037*
3	5 X 10	24.200	.008*	24.200	.008*	29.722	.005*
4	10 X 15	5.219	.084 NS	5.000	.089 NS	17.063	.014*
5	3 X 10	12.938	.023*	145.800	.000*	340.398	.000*
6	3 X 15	8.463	.044*	60.500	.001*	38.466	.003*
7	5 X 15	4.527	.100 NS	4.500	.101	2.570	.184 NS
8	3 X UD	9.724	.038*	32.653	.005*	1.499E3	.000*
9	5 X UD	94.367	.001*	94.367	.001*	1.504E3	.000*
10	10 X UD	191.210	.000*	191.210	.000*	1.519E3	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$.

NS Not significant

Table 4.16: One-way ANOVA on the level of Soil exchangeable Potassium (Kg ha^{-1}) in different soil samples such as 3 years, 5 years, 10 years and 15 years from plot 2 (P2) and undisturbed forest (UD).

Sl. no	**Source of variation (P2 x Age x UD)**	**April**		**August**		**December**	
		F-value	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**
1	3 X 5 X 10 X 15 X UD	9.927	.002*	7.632	.004*	1.454E3	.000*
2	3 X 5	.000	1.000 NS	.500	.519 NS	4.398	.104 NS
3	5 X 10	24.200	.008*	8.628	.043*	196.654	.000*
4	10 X 15	12.500	.024*	3.262	.145 NS	.230	.656 NS
5	3 X 10	24.200	.008*	14.661	.019*	27.989	.006*
6	3 X 15	7.591	.048*	7.208	.055 NS	27.664	.006*
7	5 X 15	7.200	.055 NS	3.209	.148 NS	436.142	.000*
8	3 X UD	7.843	.0411*	7.843	.0411*	1.446E3	.000*
9	5 X UD	7.843	.0411*	9.802	.0169*	1.453E3	.000*
10	10 X UD	45.082	.003*	30.106	.005*	1.462E3	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$.

NS Not significant

4.3. Discussion

During the study period, the soil sample's physicochemical properties exhibited temporal and spatial variation. The present study revealed that soil physico-chemical quality significantly decreases in oil palm plantations as compared to undisturbed forests. Reduced pH, soil moisture, water retention, and increased soil bulk density were observed as the plantation increased in age, particularly in the active growing phase. In comparing the soil quality of different ages of oil palm, the research has found that soil quality declines with the increase in age of a plantation, particularly prior to its maturity stage. It was clear from the study that soil physical quality was greatly deteriorated in oil palm plantation sites as compared to natural forests, where reductions in soil pH, soil moisture and increased soil bulk density was observed during the study period, and this could be due to the conversion of natural forests to cultivated land (Bossuyt et al., 1999).

In the present study, the overall soil's physical quality has deteriorated mainly after three years. Due to the fact that oil palm can be harvested after three years, it is believed that soil compaction can occur as a result of soil disturbance caused by humans during harvesting, especially in areas where harvesting operations are concentrated. Soil compaction decreases the amount of empty space in the soil, which restricts the movement of water into the soil and the growth of roots. This has a negative effect on the overall structure and fertility of the soil (Tey and Brindal, 2012). The increased bulk density of soil under oil palm trees in comparison to undisturbed forests is likely due to compaction caused by human activities during cultivation and management (Tellen and Yerima, 2018). Additionally, it has been reported in the present study that plot 1 exhibits a higher bulk density in comparison to plot 2 which may be due to the fact that plot 1 experienced regular disturbance during harvesting and management process.

In the present study, soil nutrient quality largely decreased in the oil palm plantation site as compared to undisturbed forest, and soil CNPK level was also observed to decrease with an increase in the age of palm tree. The decrease in soil nutrient quality with increase in age of palm tree may be due to an increase in root biomass and higher accumulation of nutrients as the plant grows. Sato (2023) noted that as the palm tree grows, its root system expands in the soil, leading to an increase in nutrient absorption. Oil palm trees are highly nutrient-demanding, necessitating significant quantities for their growth and fruit production. As oil palm trees mature, the ongoing absorption of nutrients from the soil by the trees can result in the depletion of essential elements such as nitrogen, phosphorus, and potassium. The process of depletion can lead to a gradual decline in soil fertility (Corley and Tinker 2016). A decline in soil nutrients was observed during the active growing phase, particularly in 10 years plantation where there is a significant increase in fruit production, specifically during this growth phase. The yield obtained from a 5-year-old plantation was 93.93 kg of fresh fruit bunch yield (FFB) per palm per year, with a deviation of 25.53 kg and a total yield of 13.97 t ha-1. The plantation, which was 9 years old, produced a yield of 178.92 kg of fresh fruit bunch yield (FFB) per palm per year (equivalent to 26.33 t ha-1). The yield deviation was 50.62 kg. This was 48 percent higher than the yield of palms that were 5 years old (Madhavilatha et al., 2001).

It was observed during the study period that leaf litter production under oil palm plantation is considerably reduced as compared to undisturbed forest. This may result in reduced carbon and nitrogen (Cruz et al., 2013) in this area. Guillaume et al. (2018) in their study on soil character change under oil palm plantation, also observed comparable trends with the present research, including an increase in soil bulk density and a reduction in soil carbon content and nitrogen levels which they believe is due the decrease in litter under oil palm tree. A decrease in soil organic carbon (SOC) below a critical threshold, according to Fageria (2012), causes soil structure degradation, water retention capacity reduction, diminished soil aggregation and aeration, and increased soil bulk density. Our present study also found that the core zone (P1) experienced a greater decline in soil quality than the P2 zone in the plantation site. In this P1 zone, leaf litter is comparatively scarcer and soil organic carbon content is greatly reduced. The overall soil physico-chemical properties are also poor in P1 as compared to P2. Therefore, it is critical to understand the effects of leaf litter reduction in oil palm trees on soil quality. This is because, via the process of decomposition by microorganisms, leaf litter is an essential source of nutrients for the soil. A reduction in the input of leaf litter has the potential to disrupt the nutrient cycling processes within the soil. This can result in a reduced supply of vital nutrients that are necessary for plant growth. The above mentioned disruption may result in adverse consequences for the soil's fertility and overall quality. Basuki et al. (2014) also suggest that the elimination of vegetation cover during the establishment process is responsible for the reduction in organic carbon levels at oil palm plantation sites. The vegetation cover is the primary contributor to the observed detritus on the soil surface. Furthermore, their research validates the steady decline of organic carbon, nitrogen, and available phosphorus as the age of the palm progresses until it reaches its mature stage.

Given that P1 exhibits lower soil quality compared to P2, it is imperative to reassess the land management system in the study area, particularly in the P1 zone. There were little to no remnants of fronds, weeds, or leaves in the core zone. The majority of deceased fronds are primarily located within the buffer zone. The practice of intensive manual hand weeding can also be considered an erosive force that is practiced by farmers in the study area. In the absence of adequate weed cover, soil erosion can happen, resulting in the depletion of top soil and vital nutrients necessary for soil fertility (Clough et al., 2016). Weeds can enrich the soil by adding organic matter through the decomposition of their leaves and the turnover of their roots, thereby improving soil fertility and structure. Manual hand weeding eliminates the presence of organic matter on the soil surface, thereby decreasing the amount of organic material needed to maintain soil quality (Kristensen and Thorup-Kristensen, 2004).

The result of the present study shows that there is a continuous decrease in soil quality under oil palm plantation from 3 years to 10 years. However, there was only a negligible change in soil physico-chemical quality from 10 years to 15 years. Similar research by Syahrinudin et al. (2016) and Kotowska et al. (2015) has indicated that the levels of soil organic matter in oil palm plantations have a tendency to reach a stable state after an initial period of decrease. Although there may be a decrease in soil organic matter during the initial growth phase of the trees, it typically stabilises at a relatively consistent level as the plantation becomes more mature. The enduring nature of soil organic matter can enhance the long-term integrity of soil quality. Yeo et al.

(2020) also observed a similar trend, reporting that plantations that were 20 years old had higher levels of carbon (C), nitrogen (N), and organic matter (OM) compared to plantations that were 13 years old.

The result of the present research underlines the criticality of effective agronomic management of oil palm in order to mitigate its adverse effects on the soil. While the current study did not assess the management practices, it is hypothesised that a proper land management system could enhance soil quality through the implementation of measures such as reducing disturbance during harvesting, incorporating leguminous plant manure into the understory, and avoiding intensive hand weeding. To effectively achieve land sustainability, it is crucial to understand the changes in soil characteristics that result from land-use, especially in the agricultural sector (Tellen and Yerima, 2018). This present research findings may offer guidance for policy interventions aimed at reducing land degradation.

Chapter 5

Soil Enzyme Activity and Microbial Biomass Carbon

5.1. Introduction

Soil can be seen as a living tissue with intricate biochemical reactions driven by enzymes. Soils would essentially remain unchanged and devoid of life if not for enzyme reactions (Burns and Dick, 2022). Understanding the biochemical reactions of enzymes in soil is crucial in assessing soil fertility and improving soil/crop management practices. An assessment of soil enzyme activity is crucial for monitoring biological responses to environmental changes (Pankhurst et al., 1995; Pandolfini et al., 1997). Enzyme activities are frequently utilised as indicators of microbial activity and soil fertility, as noted by Kennedy and Papendick (1995) and Burns et al. (2013). Soil enzyme activities respond rapidly to natural and human-induced disturbances, as demonstrated by Verma et al. (2014). Hence, enzyme activities are valuable indicators of soil quality alterations due to environmental stress or management practices (Quilchano and Maranon, 2002). Although the components of enzymes found in soils can be derived from microorganisms, plants, or animals, Microorganisms are the primary supplier of enzymes in soils that supply most of the soil enzyme activity, with a substantial biomass, high activity in metabolism, as well as short lifetime under optimal conditions (Speir and Ross, 1978; Tabatabai, 1994).

Dehydrogenase, phosphatase, and urease activities are reliable indicators that quickly respond to changes in environmental conditions, modifications in land use, and alterations in soil management practices. These enzymes display a rapid response to disturbances such as changes in land use, tillage, fertilisation, and pollution. As a result, they act as important predictive indicators of soil fertility and health (Dick and Tabatabai, 2001).

Soil is teeming with various enzymes, including Oxidoreductases, Hydrolases, Isomerases, Lyases, and Ligases. Soil dehydrogenases are significant members of the Oxidoreductase enzymes class (Gu et al., 2009). Dehydrogenases are crucial enzymes in the soil environment and serve as a key indicator of overall soil microbial activity. They are found intracellularly in all living microbial cells. Examining the levels of DHA in soil samples provides valuable insights into the soil's biological properties. Soil DHA is a valuable tool for assessing microbial activity. The DHA content in soil is influenced by the functioning of different dehydrogenases, which play a crucial role in the enzyme system of microorganisms (Subhani et al., 2011).

Phosphates are a group of enzymes that have the ability to hydrolyze esters and phosphoric acid anhydrides. The name "phosphatases" refers to this activity. Phosphatases play a crucial role in the phosphorus cycle (Burns 1978), as they are responsible for catalysing the hydrolysis of organic forms of phosphorus into inorganic forms that are accessible to plants (Alef and Nannipieri 1995). Numerous microorganisms including fungi that live in the soil, are responsible for the release of phosphatases into their surroundings (Haas et al., 1992). Active exudation, leakage, or cell lyses are the three methods that facilitate the introduction of these phosphatases into the soil (Tadano et al., 1993).

Urease, an extracellular enzyme, facilitates the hydrolysis of urea into NH_3 and CO_2 (Das and Varma 2011). As reported by Martínez-Salgado et al. (2010), it can account for as much as 63% of the overall enzyme activity in soil. Urease is a commonly utilised biological indicator of soil owing to its exceptional susceptibility to alterations brought about by exogenous stimuli.

The conversion of the active constituents of soil organic matter (SOM) to nutrient elements that enhance soil fertility is dependent on two significant microbiological characteristics, namely microbial biomass and soil enzymes (Li et al., 2023). These characteristics are essential for sustainability. There is a complicated connection between the physiochemical characteristics of soil and the activity of soil enzymes and the biomass of microorganisms. It is possible to determine whether microorganisms require carbon, nitrogen, or phosphorus resources by analysing the correlation between the extracellular enzyme ratio (Yang et al., 2020) and the activities that correspond to it (Dong et al., 2021). Additionally, the composition of microbial biomass and enzyme activities are more susceptible to environmental factors (such as soil temperature, moisture, and pH) as well as human and animal activities (such as modification of land use, consumption of livestock, and trampling) (Armbruster et al., 2021; dos Santos et al., 2022).

As compared to the total organic matter content of the soil, the soil microbial biomass (SMB) has been identified to be a significantly more sensitive indicator of changing soil conditions (Powlson and Jenkinson, 1976). A soil that contains a high amount of organic matter and has a soil organic matter compound that is easily accessible has a tendency to have a higher microbial biomass content and activities. This is because the soil contains a greater quantity of the energy sources that microorganisms require.

5.2. Result

5.2.1. Dehydrogenase Activity (DHA)

The dehydrogenase activity of soil in the present study ranges from 0.234 µgTPF ml^{-1} 24 hrs^{-1} to 0.543 µgTPF ml^{-1} 24 hrs^{-1} in different plantation years. As the plantation ages, the DHA level decreases. The highest DHA was observed in 3 years for the plantation site. Among all plantation ages, P2 shows a greater level as compared to the P1 site. We observed a significant decline from 5 years to 10 years, and a negligible variation between 10 years and 15 years. Among the different seasons, August shows the highest value and December records a slightly higher value than April.

It was observed from the study that soil DHA in the UD site is significantly higher as compared to plantation site during the study period. The result also shows a significant variation among different ages of plantations at $p \leq 0.05$ and that P2 also shows a significant difference in DHA level as compared to P1. The highest significant level was observed between UD site and 10 years (P1). Among different ages of plantation, poor significant difference was reported between 10 and 15 years.

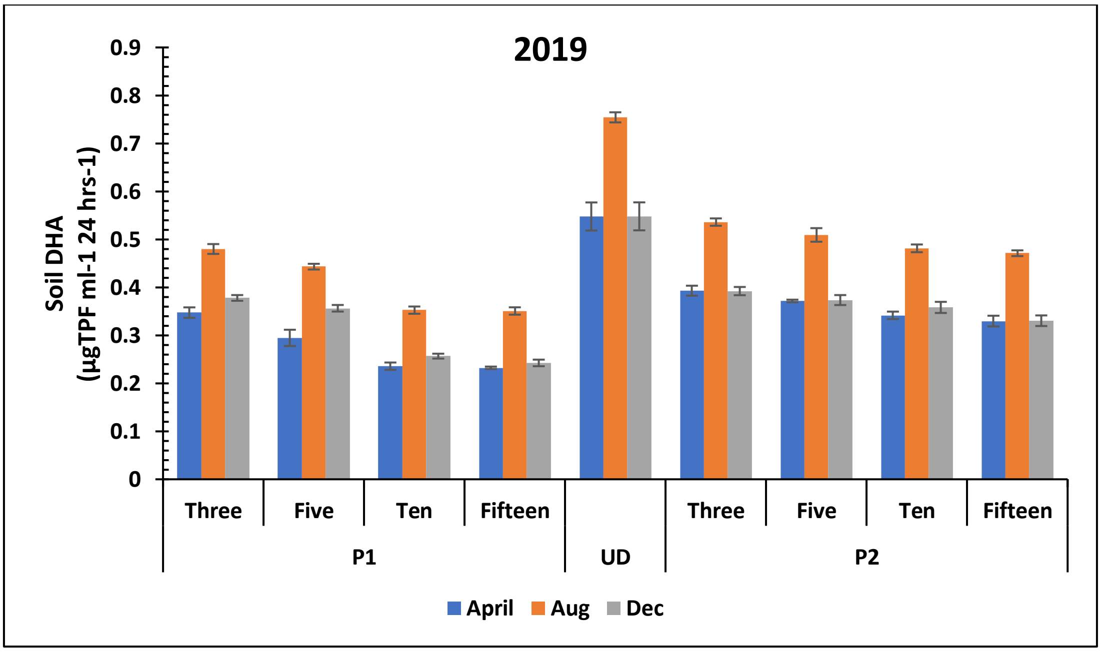

Figure 5.1: *Soil Dehydrogenase Activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3).*

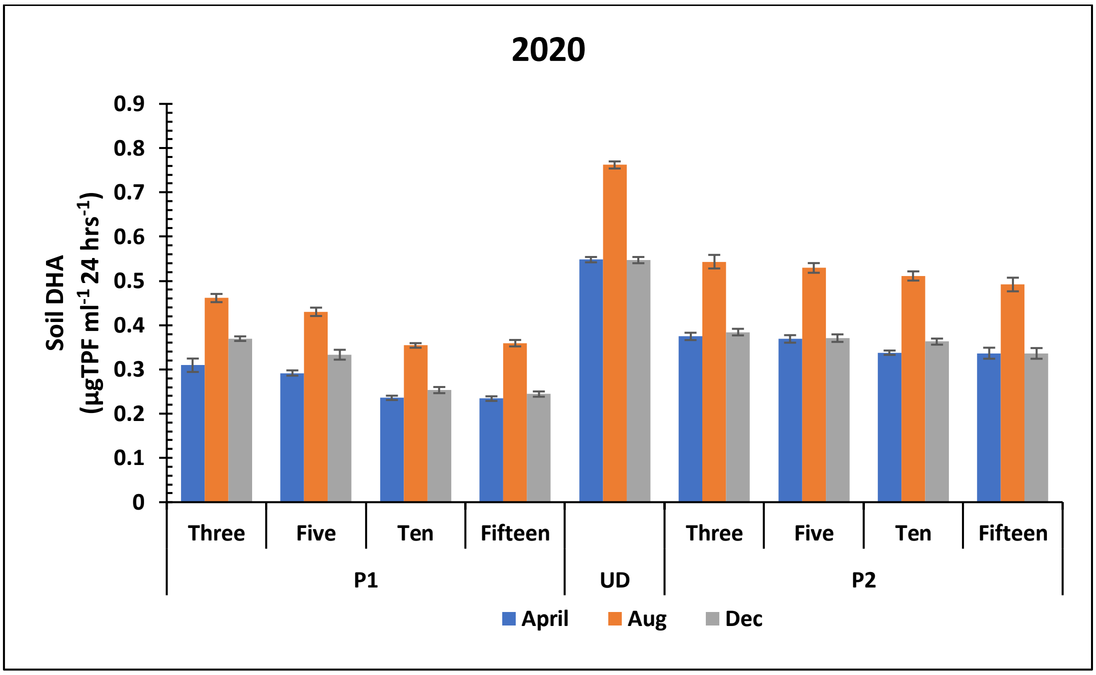

Figure 5.2: *Soil Dehydrogenase Activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3).*

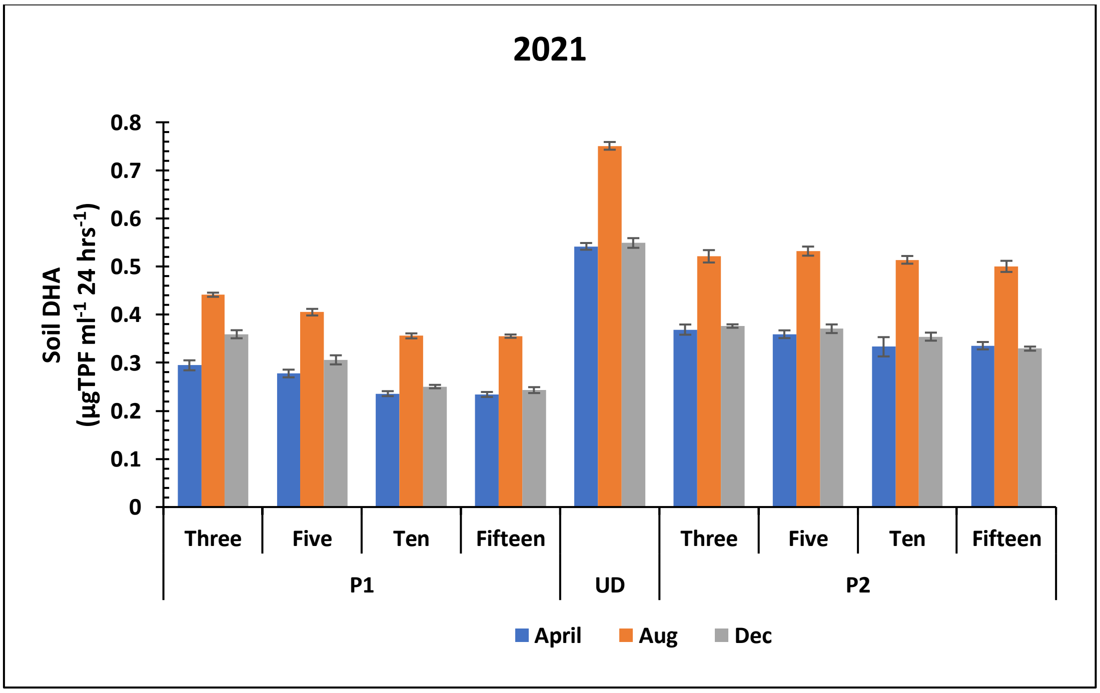

Figure 5.3: *Soil Dehydrogenase Activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3).*

Table 5.1: One-way ANOVA of Soil Dehydrogenase Activity (µgTPF ml^{-1} 24 hrs^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Sl. no	**Source of variation (P1 x Age x UD)**	**April**		**August**		**December**	
		F-value	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**
1	3 X 5 X 10 X 15 X UD	125.319	.000*	344.737	.000*	133.391	.000*
2	3 X 5	20.351	.011*	28.938	.006*	16.791	.015*
3	5 X 10	29.878	.005*	264.938	.000*	407.579	.000*
4	10 X 15	.513	.513 NS	.081	.790 NS	8.224	.056 NS
5	3 X 10	209.778	.000*	300.159	.000*	715.563	.000*
6	3 X 15	315.592	.000*	305.788	.000*	664.198	.000*
7	5 X 15	39.275	.003*	271.112	.000*	412.255	.000*
8	3 X UD	72.525	.001*	217.284	.000*	55.292	.002*
9	5 X UD	104.921	.001*	299.529	.000*	69.670	.001*
10	10 X UD	182.523	.000*	488.414	.000*	163.288	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

NS Not significant

Table 5.2: One-way ANOVA of Soil Dehydrogenase Activity (µgTPF ml^{-1} 24 hrs^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Sl. no	Source of variation (P2)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	63.361	.000*	121.724	.000*	55.655	.000*
2	3 X 5	3.361	.141 NS	.524	.509 NS	45.318	.003*
3	5 X 10	40.129	.003*	.031	.868 NS	55.650	.002*
4	10 X 15	2.297	.204 NS	9.184	.039*	64.811	.001*
5	3 X 10	30.451	.005*	.729	.441 NS	77.615	.001*
6	3 X 15	36.664	.004*	7.902	.048*	5.793	.074 NS
7	5 X 15	40.265	.003*	9.846	.035*	2.904	.164 NS
8	3 X UD	49.327	.002*	125.954	.000*	9.026	.040*
9	5 X UD	60.033	.001*	152.136	.000*	16.744	.015*
10	10 X UD	79.499	.001*	154.566	.000*	58.527	.002*
11	15 X UD	77.615	.001*	77.615	.001*	24.167	.008*

* Significant at $p \leq 0.05$

NS Not significant

5.2.2. Acid Phosphatase Activity

Acid Phosphatase (Apase) Activity show a significant variation between undisturb forest and different plantation age. Soil in undisturbed forest show a significantly higher Apase activity compare to oil palm plantation site during the study period. The study reported a consistent decrease in soil Apase activity as the age of the plantation increased, however, reaching its lowest point at 10 years. Although there is minimal disparity between 10 years and 15 years plantation, soil of 10 years palm tree show a lesser Apase activity as compared to 15 years. The overall soil Apase activity ranges from 79.993 to 102.85 µg p-NP ml^{-1} hr^{-1} in P1 site and from 96.17 to 110.37 µg p-NP ml^{-1} hr^{-1}. On comparing different season, August show high Apase activity while lowest was recorded in April.

Highly significant difference was reported between different plantation age and undisturbed forest for all season during the study period. Constant significant variation was recorded between 5 years and 10 years plantation. However, Insignificant variation was occasionally observe between 3 years and 5 years and also between 10 years and 15 years sample. The significant test of one way ANOVA for Apase activity in given in table 5.3 and 5.4.

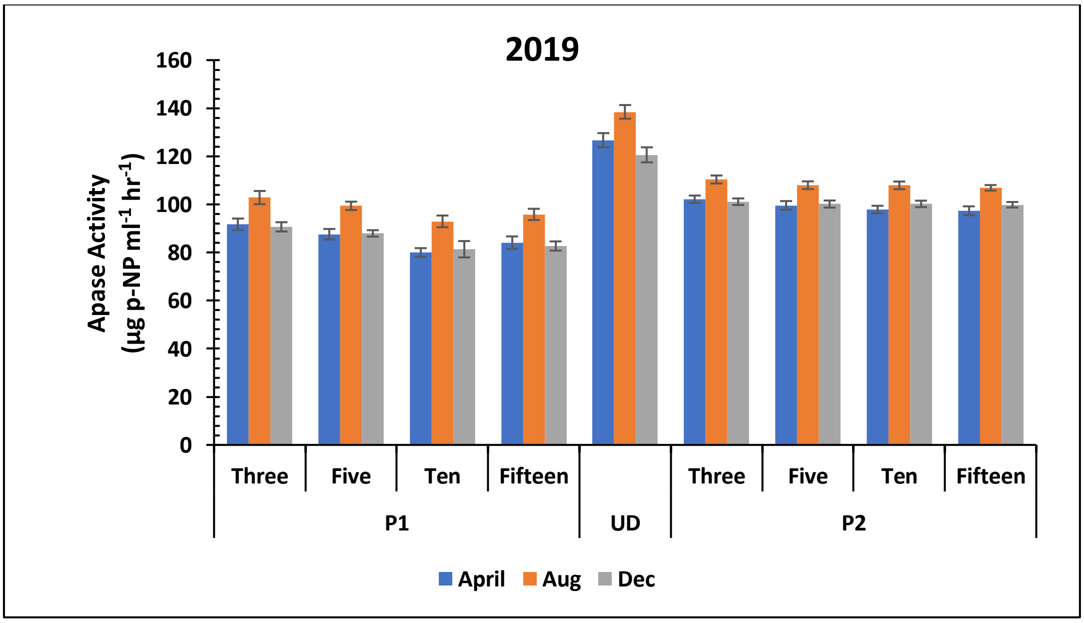

Figure 5.4: *Soil Apase activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2019. Each value were represented as mean ± SD (n=3)*

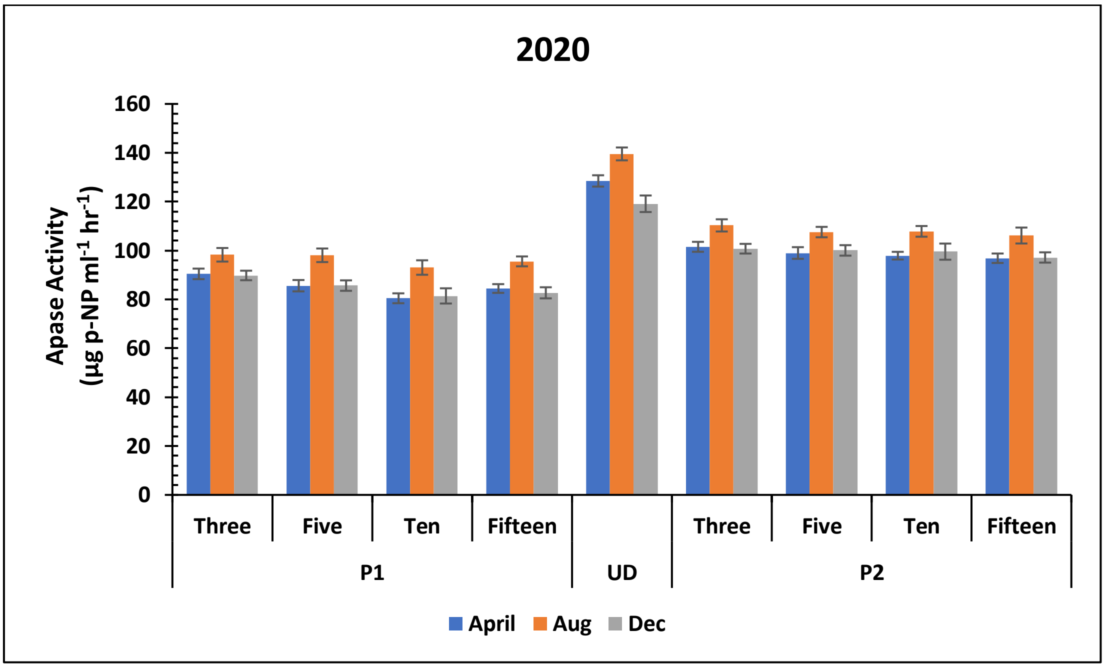

Figure 5.5: *Soil Apase activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2020. Each value were represented as mean ± SD (n=3)*

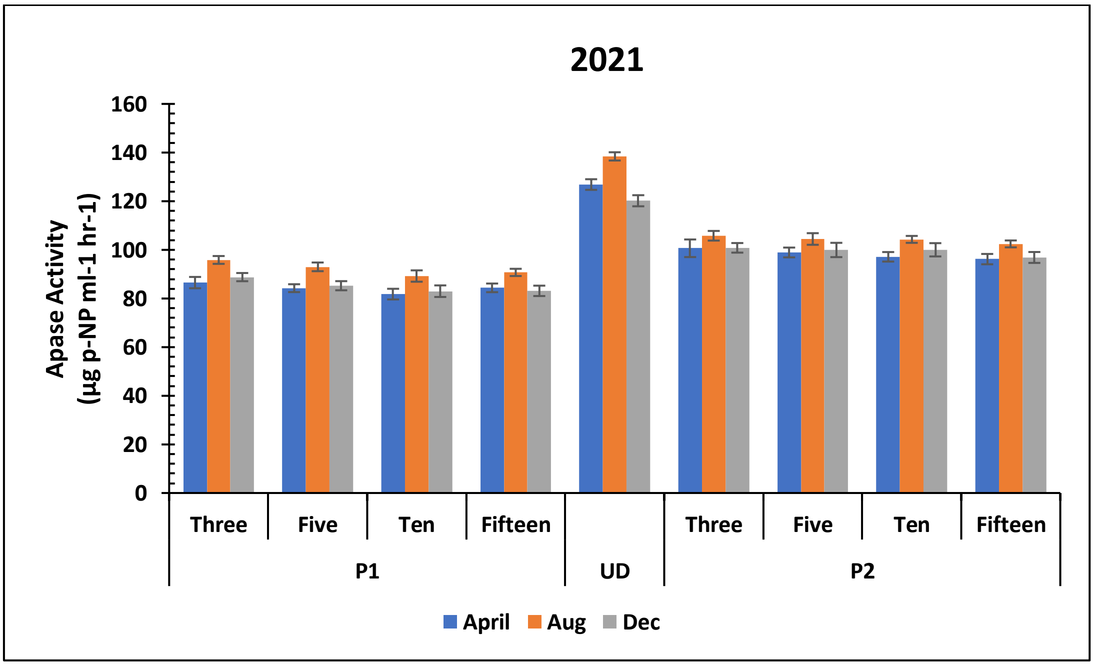

Figure 5.6: *Soil Apase activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in the year 2021. Each value were represented as mean ± SD (n=3)*

Table 5.3: One-way ANOVA on the level of Acid Phosphatase Activity (µg p-NP ml^{-1} hr^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Sl. No	Source of variation (P1 x Age x P1)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	657.605	.000*	232.913	.000*	321.823	.000*
2	3 X 5	15.248	.017*	9.888	.035*	23.079	.009*
3	5 X 10	85.742	.001*	48.479	.002*	22.257	.009*
4	10 X 15	48.460	.002*	6.527	.063 NS	.822	.416 NS
5	3 X 10	156.977	.000*	57.835	.002*	39.456	.003*
6	3 X 15	75.684	.001*	30.349	.005*	111.319	.000*
7	5 X 15	21.780	.010*	16.208	.016*	85.638	0.001*
8	3 X UD	651.274	.000*	213.166	.000*	502.037	.000*
9	5 X UD	907.042	.000*	298.146	.000*	694.729	.000*
10	10 X UD	1.492E3	.000*	369.146	.000*	451.694	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

Table 5.4: One-way ANOVA on the level of Acid Phosphatase Activity (μg p-NP ml^{-1} hr^{-1}) in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Sl. No	Source of variation (P2)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	413.889	.000*	143.230	.000*	247.295	.000*
2	3 X 5	22.029	.009*	5.687	.076^{NS}	7.691	.050*
3	5 X 10	9.737	.036*	.003	.959 ^{NS}	.032	.866 ^{NS}
4	10 X 15	.736	.439 ^{NS}	2.213	.211 ^{NS}	2.811	.169 ^{NS}
5	3 X 10	93.451	.001*	9.651	.036*	9.244	.038*
6	3 X 15	70.837	.001*	80.522	.001*	28.674	.006*
7	5 X 15	11.427	.028*	1.398	.302 ^{NS}	1.175	.339 ^{NS}
8	3 X UD	454.717	.000*	155.484	.000*	245.623	.000*
9	5 X UD	511.528	.000*	160.500	.000*	266.266	.000*
10	10 X UD	622.362	.000*	172.410	.000*	270.243	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

^{NS} Not significant

5.2.3 Urease Activity

The soil urease activity in different ages of oil palm plantation ranges from 29.78 to 54.9 µg NH_3 g dry soil^{-1} 2hr^{-1} at P1 site during the study period. At P2 site, it ranges from 48.71 to 61.93 µg NH_3 g dry soil^{-1} 2hr^{-1}. Soil sample in UD ranges from 66.98 to 79.49 µg NH_3 g dry soil^{-1} 2hr^{-1}. There is a lower level of urease activity in soil of all plantation age as compare with UD sample. A highly noticeable decrease was observed in 10 years among plantation age while there is little to no change in soil urease activity from 10 years to 15 years oil palm tree.

There is a variation in soil urease activity depending on season and also on plantation age. Significant difference was observed between different ages of plantation at both P1 and P2 site.. Highly consistent significant variation was reported between UD and different plantation ages at both P1 and P2. The significant difference level was high between 5 years and 10 years as compared to other age of plantation.

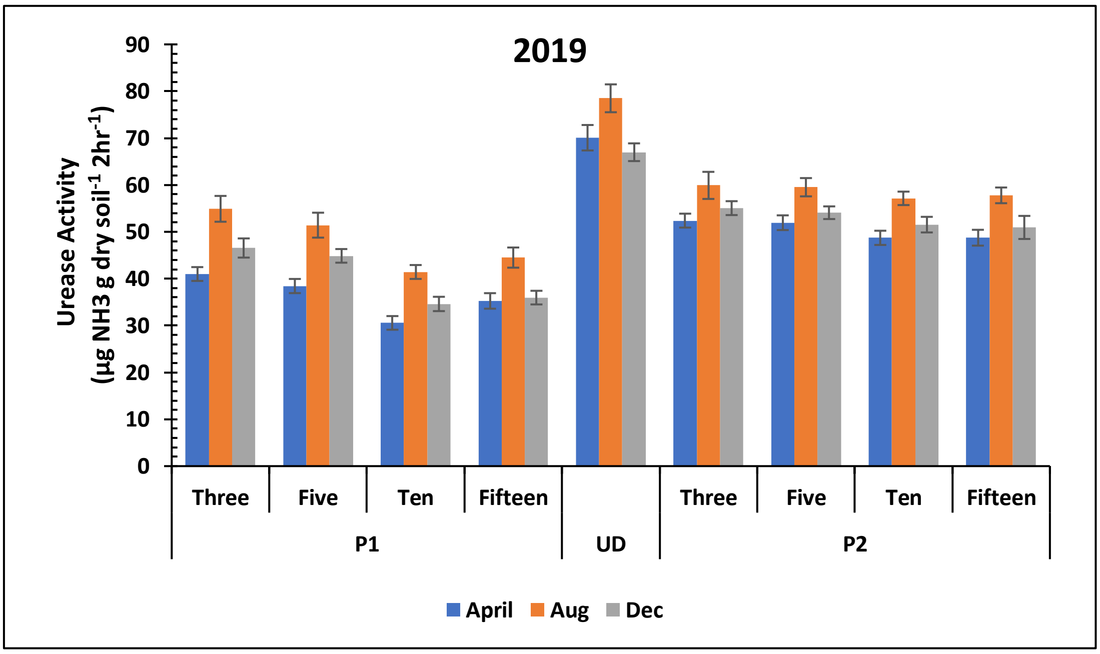

***Figure 5.7**: Soil urease activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3)*

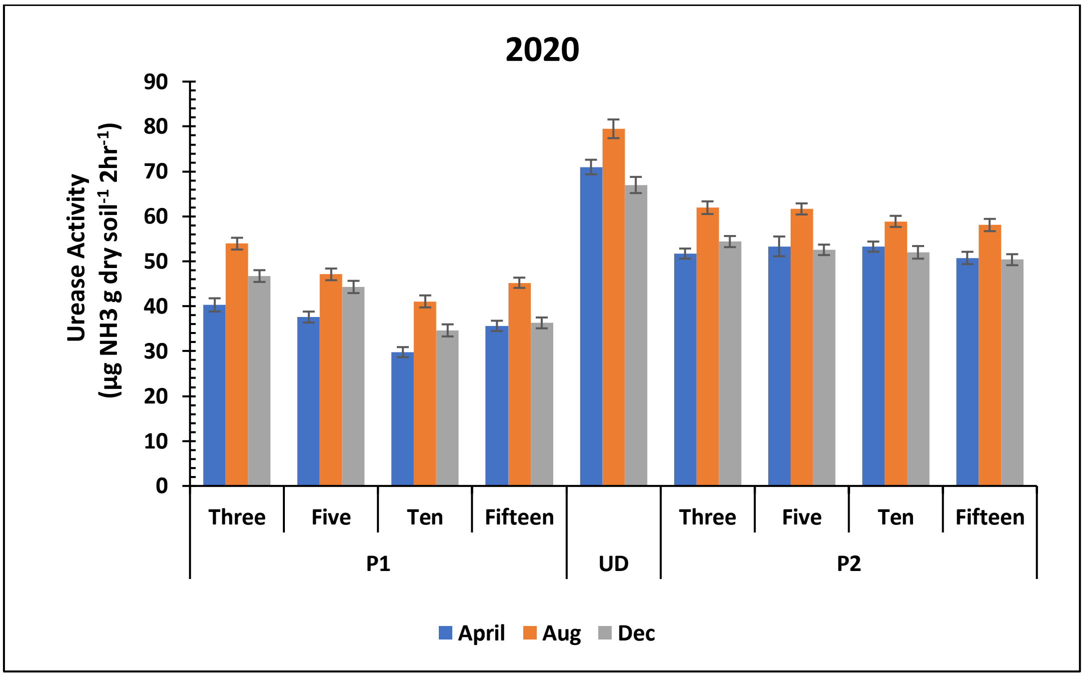

Figure 5.8: *Soil urease activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3)*

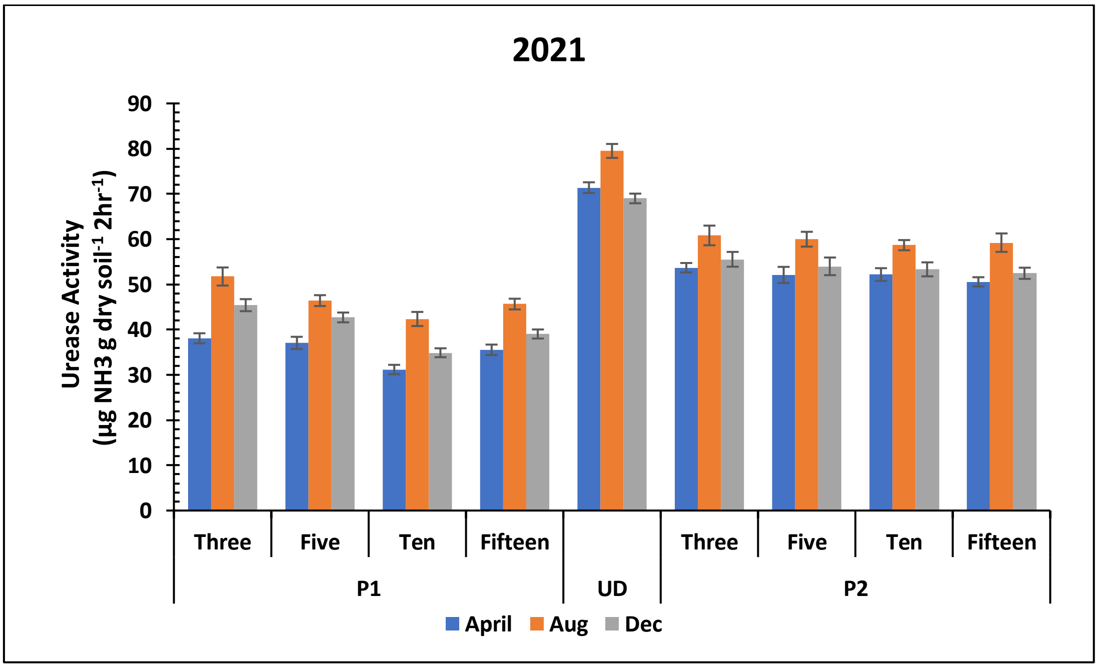

Figure 5.9: *Soil urease activity of different plantation age (3y, 5y, 10y and 15y) and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3).*

Table 5.5: One-way ANOVA on the level of Urease Activity µg NH_3 g dry soil^{-1} 2hr-^{1} in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Sl. no	Source of variation (P1 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	985.147	.000*	207.920	.000*	70.634	.000*
2	3 X 5	50.087	.002*	6.630	.062 NS	7.283	.054 NS
3	5 X 10	490.672	0.001*	107.795	.000*	801.692	.000*
4	10 X 15	123.484	.000*	20.243	.011*	14.035	.020*
5	3 X 10	940.161	.000*	176.044	.000*	349.398	.000*
6	3 X 15	180.061	.000*	78.892	.001*	290.543	.000*
7	5 X 15	52.227	.002*	37.800	.004*	727.889	.000*
8	3 X UD	858.486	.000*	145.879	.000*	35.668	.004*
9	5 X UD	1.006E3	.000*	197.637	.000*	42.772	.003*
10	10 X UD	1.592E3	.000*	472.351	.000*	91.498	.001*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

NS Not significant

Table 5.6: One-way ANOVA on the level of Urease Activity µg NH_3 g dry $soil^{-1}$ $2hr^{-1}$ in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Sl. no	Source of variation (P2 x Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	235.171	.000*	85.678	.000*	17.375	.000*
2	3 X 5	1.272	.323 NS	.110	.757 NS	10.367	.032*
3	5 X 10	8.264	.045*	15.926	.042*	41.550	.003*
4	10 X 15	9.514	.037*	2.284	.205 NS	.448	.540 NS
5	3 X 10	25.185	.007*	12.657	.0.48*	66.010	.001*
6	3 X 15	.405	.559 NS	1.011	.371 NS	23.354	.008*
7	5 X 15	1.735	.258 NS	1.353	.309 NS	14.195	.020*
8	3 X UD	316.504	.000*	86.944	.001*	12.434	.024*
9	5 X UD	323.872	.000*	115.561	.000*	14.603	.019*
10	10 X UD	388.218	.000*	143.101	.000*	20.753	.010*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

NS Not significant

5.2.4. Soil Microbial Biomass Carbon (C_{mic})

The highest microbial biomass carbon content was recorded at UD site (190.02 mg kg^{-1}) while the lowest (102.20 mg kg^{-1}) was recorded at 15 years oil palm tree in P1 region. It was shown that C_{mic} decreases as plantations age from 3 to 10 years. The decrease from 10 years to 15 years is very small in the first two years of the study period, and in 2021, they show the same level in both P1 and P2. Different plantation ages show a different range of C_{mic} content during the study period. Changes in C_{mic} content with seasonal variation were also observed, with August showing the highest content compared to April and December.

Undisturbed forest soil shows a higher significant C_{mic} content as compared to oil palm plantation soil. A significant difference in C_{mic} content was observed between UD and different ages of plantations during the study period. It can be seen from table 4.7 and 4.8 that August recorded a significant difference among all plantation sites at P1 and P2 sites. However, a few insignificant levels of variation were observed in April and December. A high significant level of difference was observed between the soil of 3 and 10 years palm tree and also between 5 and 10 years during the study period.

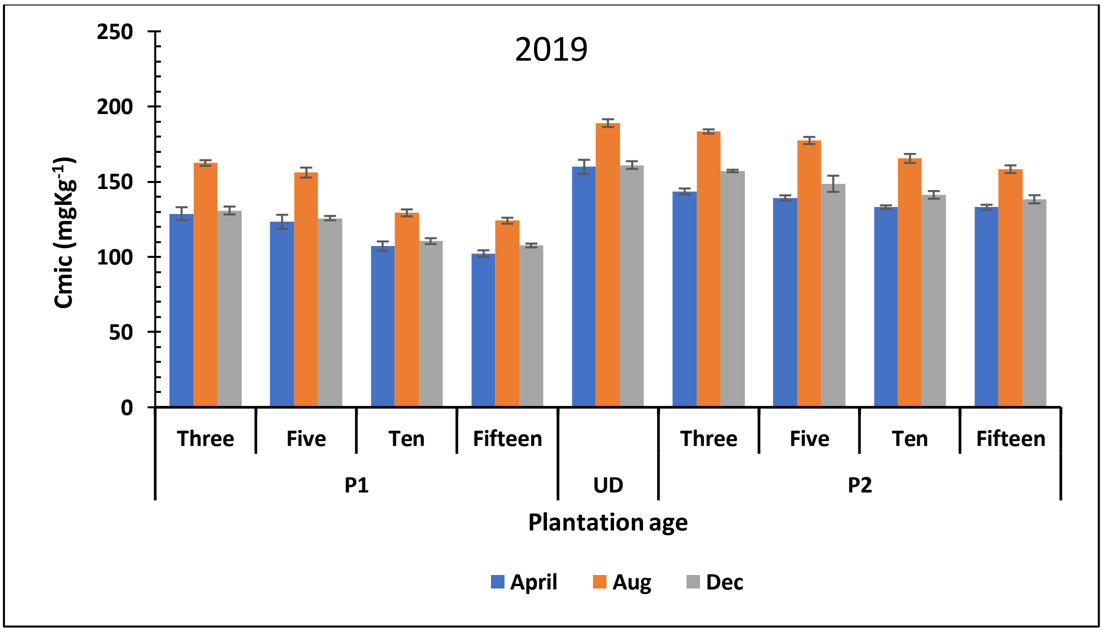

Figure 5.10: *Microbial Biomass Carbon (C_{mic}) in soil of different plantation age and undisturbed (UD) forest in 2019. Each value were represented as mean ± SD (n=3)*

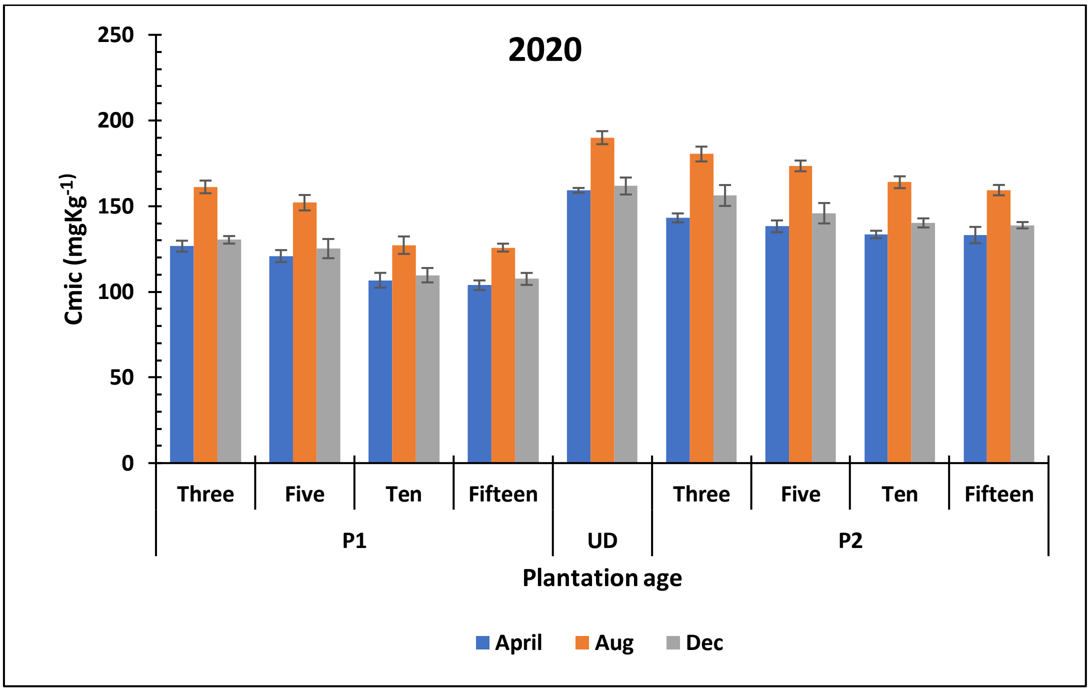

Figure 5.11: *Microbial Biomass Carbon (C_{mic}) in soil of different plantation age and undisturbed (UD) forest in 2020. Each value were represented as mean ± SD (n=3)*

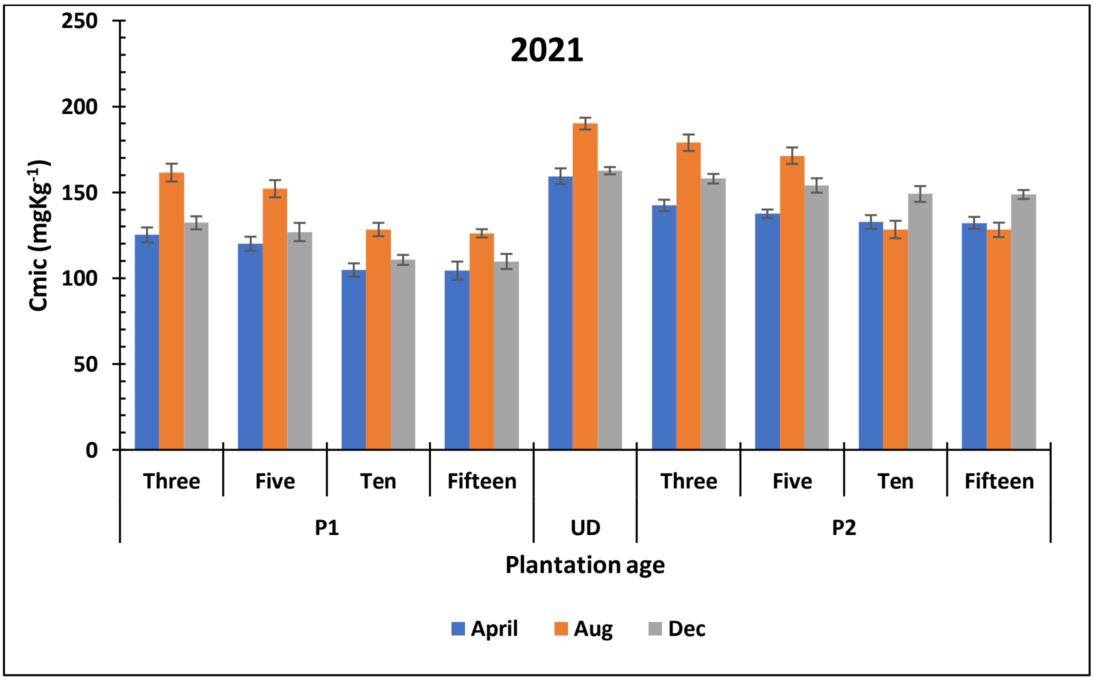

Figure 5.12: *Microbial Biomass Carbon (C_{mic}) in soil of different plantation age and undisturbed (UD) forest in 2021. Each value were represented as mean ± SD (n=3)*

Table 5.7: One-way ANOVA on the level of Microbial Biomass Carbon C_{mic} (mg kg^{-1})in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 1 (P1) and from undisturbed forest (UD).

Sl. no	**Source of variation (P1 x Age x UD)**	**April**		**August**		**December**	
		F-value	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**
1	3 X 5 X 10 X 15 X UD	190.817	.000*	4.675	.022*	328.400	.000*
2	3 X 5	6.941	.058 NS	8.383	.044*	8.631	.042*
3	5 X 10	95.272	.001*	158.947	.000*	120.145	.000*
4	10 X 15	11.829	.026*	21.576	.010*	4.785	.094 NS
5	3 X 10	207.208	.000*	630.200	.000*	117.219	.000*
6	3 X 15	204.780	.000*	597.659	.000*	190.981	.000*
7	5 X 15	113.392	.000*	204.513	.000*	266.686	.000*
8	3 X UD	105.890	.001*	208.656	.000*	203.905	.000*
9	5 X UD	137.708	.000*	183.245	.000*	432.576	.000*
10	10 X UD	356.879	.000*	1.276E3	.000*	749.424	.000*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

NS Not significant

Table 5.8: One-way ANOVA on the level of Microbial Biomass Carbon C_{mic} (mg kg^{-1})in different soil samples of plantation ages such as 3 years, 5 years, 10 years and 15 years at plot 2 (P2) and from undisturbed forest (UD).

Sl. no	Source of variation (P2 X Age x UD)	April		August		December	
		F-value	p-value	F-value	p-value	F-value	p-value
1	3 X 5 X 10 X 15 X UD	51.653	.000*	80.766	.000*	29.032	.000*
2	3 X 5	8.052	.052 NS	14.255	.020*	7.395	.053 NS
3	5 X 10	10.993	.030*	29.501	.006*	4.609	.098 NS
4	10 X 15	2.962	.160 NS	9.807	.035*	1.856	.245 NS
5	3 X 10	40.075	.003*	87.808	.001*	108.149	.000*
6	3 X 15	50.412	.002*	221.381	.000*	132.220	.000*
7	5 X 15	19.564	.011*	90.597	.001*	8.730	.042*
8	3 X UD	30.867	.005*	10.725	.031*	6.443	.044*
9	5 X UD	51.075	.002*	32.819	.005*	13.152	.022*
10	10 X UD	78.205	.001*	105.928	.001*	13.152	.022*
11	15 X UD	77.615	.001*	77.615	.001*	77.615	.001*

* Significant at $p \leq 0.05$

NS Not significant

5.3. Discussion

A decrease in soil dehydrogenase, acid phosphatase and urease enzyme activity has been observed at oil palm plantation sites as compared to undisturbed forest during the study period. The above findings show that oil palm plantations have a negative impact on the area's soil enzyme activity. The ageing of the crop also leads to a widespread decline in soil enzyme activity in monocultures. A plausible reason for this occurrence is that, like other monocultures, the process of growing oil palm requires the removal of native plants during the initial stages and the subsequent reduction of organic matter in the soil as the plants mature. This reduction in enzyme activity can be due to a decrease in the level of soil organic matter, which contributes to the substrate for soil enzymes (Blanchart et al., 2007). Analyzing enzyme activities is an effective method for assessing the extent of soil degradation due to various environmental factors (Rao et al., 2014). The decrease in soil enzyme activity as the age of palm trees increases may serve as a significant indication of the disruption caused by oil palm monoculture on the microbial soil community. There has been a significant reduction in soil enzyme activity in the soil of oil palm plantation sites as compared to undisturbed natural forest. This reduction is greater in the soil nearer to the tree and less in the soil further from the palm tree.

As reported in the soil physicochemical section, soil conversion results in modifications to soil structure and moisture content, among other soil physical properties. Consequently, this influences the activity of the enzyme. It is clear from the present study that there is a significant relationship between enzyme activities and physico-chemical properties in the soil of oil palm plantation site. The change in soil physical structure directly results in a reduction in pore spaces, and subsequent soil compaction may impede the accessibility of substrates and inhibit the mobility of enzymes (Wood et al., 2015). During the study period, changes in soil composition, organic matter concentration, and pH occurred in oil palm plantations. It's possible that these changes will have an direct or indirect effect on the activity of enzymes in the soil by changing the types of microorganisms that live there, the substrates that they can use, and how they interact with each other (Liao et al., 2016).

The decrease in overall soil enzyme activity before 15 years in the study can be hypothesised to be due to root exudate patterns during the developmental stage, particularly in the rhizosphere. The activity of soil enzymes can be either increased or decreased by root exudates, depending on their composition and the response of the microbial community. For example, certain exudate compounds can enhance the function of specific enzymes involved in nutrient cycling, while others may hinder enzyme activity (Cheng and Johnson, 1998). During the early phases of growth, specifically at the P1 location, it is hypothesised that root exudates play a significant role in the reduction of enzyme activity. Various types of exudates can contribute to the degradation of microbial properties, particularly in the rhizosphere. During the reproductive and developmental phases of oil palm trees, the patterns of root exudation may vary. Determinis et al. (2010) propose that changes in soil enzyme activity may be caused by changes in root exudates, which can potentially affect soil microbial communities and enzyme dynamics.

Soils at the 15 years plantation site experience little change in enzyme activity as compared to other ages of plantation, where there is a great reduction in enzyme activity. This is a remarkable observation during the study period. During the active growth phase of monocultures, such as oil palm, the plants consistently extract nutrients from the soil to support their development and growth. Therefore, carbon, nitrogen, and phosphorus, which are essential for microbial activity and the production of enzymes, gradually decrease in amount (Bunemann, 2006). The present research also observed a remarkable decline during this stage. However, when oil palm reaches 15 years, the activity of microbial enzymes shows little to no decrease. This could be attributed to the benefits of favourable conditions during the mature stage of the plant, as opposed to the active growing phase. The soil conditions in established oil palm plantations are more consistent than those in the initial stages of establishment. After the initial disturbance caused by land conversion and establishment, soil properties tend to become stable, leading to a gradual decrease in the variability of soil enzyme activity (Isbell, 2002). Over time, soil microbial communities in mature oil palm plantations acquire the ability to tolerate and adapt to the existing environmental conditions. However, this process does not happen during the early stages of development. The existence of consistent microbial communities in the soil of mature palm plantations could potentially play a role in maintaining a steady level of enzyme activity (Philippot, 2013).

It can be understood from the present study that due to variations in organic matter inputs and management practices, the soil dehydrogenase activity in oil palm plantations can typically be lower than that in undisturbed ecosystems. In comparison to oil palm plantations, forest ecosystems generally receive greater inputs of organic matter through litterfall, root turnover, and the decomposition of organic material. Elevated concentrations of organic matter in forest soils foster microbial activity, one of which is the existence of dehydrogenase enzymes. A reduction in organic matter inputs generally leads to diminished microbial activity and dehydrogenase activity in the soil of oil palm plantations (Lal, 2015; Wood et al., 2015). Dehydrogenases are indispensable enzymes that function as crucial indicators of the overall microbial activity in the soil environment. This research investigates the indicators that serve as measures of soil quality alterations in oil palm plantations. These changes in soil enzyme may be caused by environmental stressors or management strategies. Soil disturbance can result from the preparation, planting, and harvesting processes in oil palm plantations. This disruption can disrupt the microbial communities residing in the soil and subsequently diminish its biological activity, including that of dehydrogenase. On the other hand, natural forest ecosystems experience limited disturbances to the soil, thereby promoting the growth of soil microbial communities and maintaining high levels of enzyme activity (Six et al., 1999; Jha and Kumar, 2019).

Chapter 6

Principal Component Analysis of soil Physico-chemical properties, enzyme activities and soil microbial biomass carbon

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6.1. Introduction

Principal Component Analysis (PCA) was employed to identify a minimum dataset, following Tesfahunegn (2014) recommendation. This dataset, known as the Minimum Data Set (MDS), was selected based on its significant contribution to the total variance, as assessed by the performance of soil functions. A total of 11 potential Soil Quality (SQ) indicators, encompassing physical, chemical, and biological soil properties, underwent PCA to reduce the dimensionality of the dataset while retaining the variables that contributed significantly to the variance. PCA, as a method, relies on various statistical tools such as multiple correlation, factor analysis, and cluster analysis, ensuring objectivity and avoiding bias and data redundancy in the selection of the MDS through mathematical formulae (Wander and Bollero, 1999)

The primary objective of PCA is to reduce the dimensionality of the dataset containing numerous interrelated variables while preserving the variability inherent in the data. This is achieved by transforming the original variables into a new set of uncorrelated variables known as principal components (PCs). These PCs are ordered in such a way that the first few components capture most of the variation present in all the original variables (Malsawmtluanga et al., 2023). Hence, PCA was chosen as a data reduction tool to identify the most suitable indicator(s) for representing and estimating Soil Quality Index (SQI) (Navas et al., 2011). Moreover, employing SQI with PCA offers the advantage of predicting soil quality using a reduced dataset comprising a minimal number of soil parameters. This approach is predominantly objective, as the statistical procedure automatically selects a limited number of soil parameters necessary for calculating SQI based on the variances present in the entire dataset. Therefore, in the long term, particularly within specific soil/crop systems, SQI-PCA can be effectively utilized once it determines the most influential soil parameters required for assessing soil quality under particular soil, crop, or management conditions.

A principal component analysis (PCA) was performed to allow an integrated view of soil physico-chemical properties according to the age, study months and plots studied of oil palm. Analyses were performed in R version 4.1.2 (R Core Team 2021).

6.2. Result

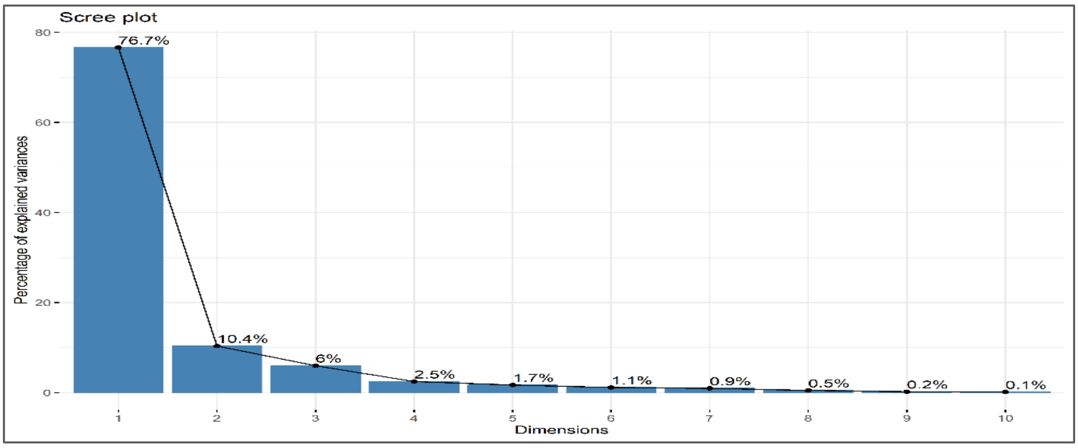
6.2.1. Soil physico-chemical properties across age of oil palm

To ascertain the optimal number of principal components, we assessed the variance percentages from the screen plot (Figure 5.1a). Ultimately, we chose to focus on the first two principal components in the PCA, which collectively accounted for 87.1% of the data variation; the first component explained 76.7%, while the second explained 10.4%. Eigenvalues of 8.43 and 1.14 were recorded (Table 6.1).

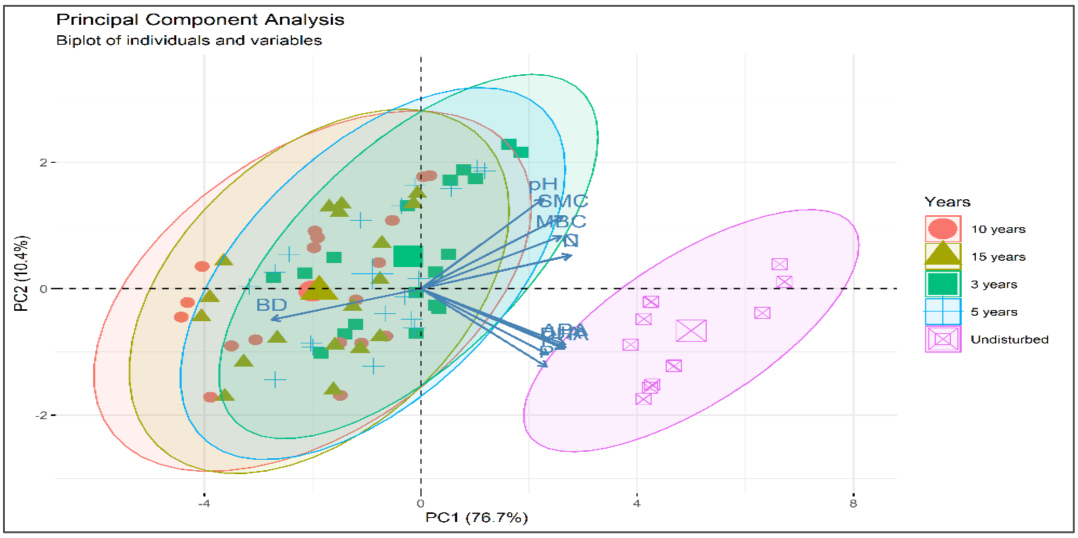
We observed distinct separation between undisturbed oil palm soils and those from 3, 5, 10, and 15 years of oil palm cultivation soils in the first component. Additionally, a partial differentiation among the soils from different cultivation periods was noted in the second component (Figure 6.1b).

In terms of variable correlations, the first component exhibited strong positive associations with N and C, followed by UA, APA, DHA, SMC, MBC, K, P, and pH, while a negative correlation was observed with BD. Conversely, the second component displayed direct relationships with P, K, DHA, UA, APA, and BD, with negative correlations observed for pH, SMC, MBC, C, and N (Table 6.2 & Figure 6.1b and 6.1c).

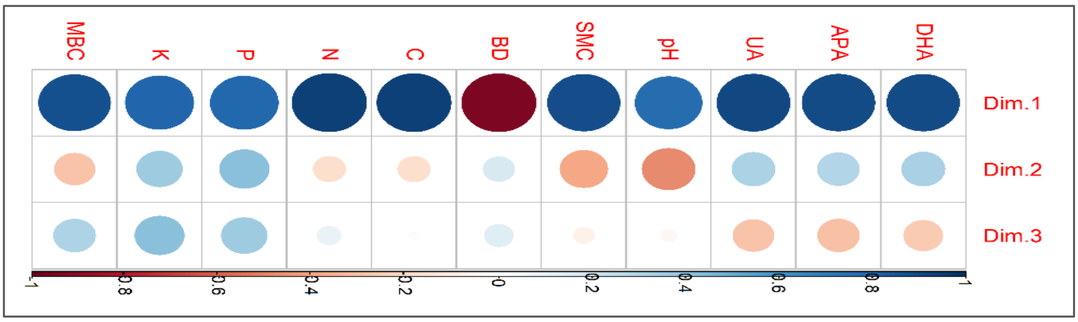
Among the variables, N made the highest contribution to the first component, whereas pH contributed the least. Conversely, in the second component, pH had the highest contribution among all variables, while BD had the lowest.



(a)



(b)



(c)

Figure 6.1: *Principal component analysis (PCA) for soil physico-chemical properties across oil palm age:* ***(a)*** *Contribution of each principal component to total variance* ***(b)*** *Biplot of individuals and variables (PC1 & PC2)* ***(c)*** *Principal components and their relation with variables.*

Table 6.1: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physico-chemical properties across oil palm age.

PCA	*Eigenvalue*	% of variance	cumulative %
1	8.43	76.65	76.65
2	1.14	10.36	87.01
3	0.66	5.97	92.98

Table 6.2: Variable correlations with principal component analysis (PCA) components for

Variables	PCA1	PCA2
DHA	0.893	0.321
APA	0.898	0.298
UA	0.904	0.314
pH	0.763	-0.479
SMC	0.889	-0.389
BD	-0.930	0.166
C	0.934	-0.179
N	0.938	-0.178
P	0.786	0.417
K	0.795	0.352
MBC	0.876	-0.280

6.2.2. Soil physico-chemical properties across study months of oil palm (April, August & December)

The results of the Principal Component Analysis (PCA) reveal insightful patterns in the soil physico-chemical properties across oil palm plantations during the study months. The Eigenvalues computed for PCA components indicate that the first principal component (PCA1) explains a substantial portion of the total variance, accounting for 82.27% of the variability observed, while the second principal component (PCA2) contributes an additional 8.79%. Collectively, PCA1 and PCA2 account for 91.06% of the total variance, underscoring their significance in capturing the underlying structure of the dataset (Table 6.3 & Figure 6.2a).

Upon examining the correlations between the original variables and the PCA components, it becomes evident that certain soil properties exhibit strong associations with the principal components (Table 6.4). Variables such as APA, UA, P, and K display positive correlations with both PCA1 and PCA2, indicating their substantial contributions to the variation explained by these components. Conversely, BD demonstrate negative correlations with PCA1 but positive correlations with PCA2, suggesting nuanced relationships with the principal components (Figure 6.2b & Figure 6.2c). Further analysis of the contribution of variables to the PCA components highlights the influential role of specific soil properties in shaping the observed patterns. Variables such as DHA, APA, UA, SMC, BD, C, N, and MBC significantly contribute to the variation captured by PCA1, indicating their pronounced impact on the overall soil physico-chemical profile. In contrast, pH, P, and K emerge as key contributors to the variation elucidated by PCA2, underscoring their importance in delineating distinct soil characteristics across the study months.

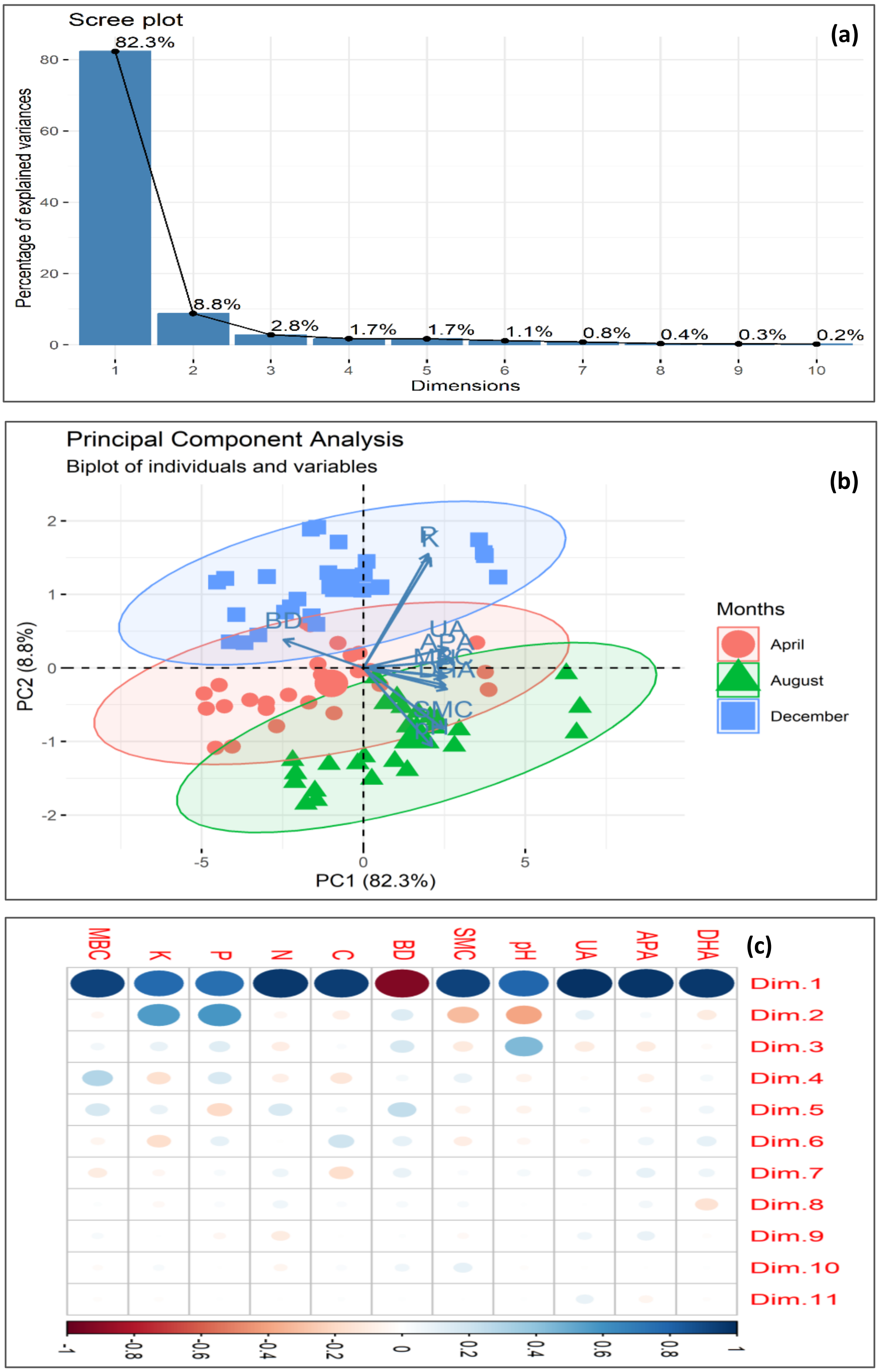


Figure 6.2. *Principal component analysis (PCA) for soil physico-chemical properties across study months of oil palm:* ***(a)*** *Contribution of each principal component to total variance* ***(b)*** *Biplot of individuals and variables (PC1 & PC2)* ***(c)*** *Principal components and their relation with variables.*

Table 6.3: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physico-chemical properties during study months of oil palm.

PCA	*Eigenvalue*	% of variance	cumulative %
1	9.05	82.27	82.27
2	0.97	8.79	91.06

Table 6.4: Variable correlations with principal component analysis (PCA) components for soil physico-chemical properties during study months of oil palm.

Variables	PCA1	PCA2
DHA	0.968	-0.108
APA	0.974	0.034
UA	0.980	0.101
pH	0.793	-0.399
SMC	0.92	-0.311
BD	-0.931	0.144
C	0.947	-0.087
N	0.965	-0.046
P	0.752	0.583
K	0.777	0.562
MBC	0.929	-0.042

6.2.3 Soil physico-chemical properties within Study plots (plot1 & plot2) of oil palm plantation

The Principal Component Analysis (PCA) yielded insightful findings regarding the soil physico-chemical properties within the study plots (plot1 and plot2) of oil palm plantations. The Eigenvalues computed for PCA components revealed that the first principal component (PCA1) accounted for a substantial proportion of the total variance, explaining 82.27% of the variability observed. Additionally, the second principal component (PCA2) contributed 8.79% to the total variance. Collectively, PCA1 and PCA2 cumulatively explained 91.06% of the total variance in the soil properties (Table 6.5 & Figure 6.3a).

Analysis of the correlations between the original variables and the PCA components unveiled distinct patterns. Positive correlations were observed between APA, UA, P, and K with both PCA1 and PCA2, indicating their significant contributions to the variation explained by these components. Conversely, DHA, pH, SMC, C, N and MBC exhibited a positive correlation with PCA1 but a negative correlation with PCA2, suggesting contrasting relationships with the two principal components. Similarly, BD displayed a negative correlation with PCA1 but a positive correlation with PCA2 (Table 6.6 & Figure 6.3c).

Further examination of the contribution of variables to the PCA components elucidated the influential role of specific soil properties. In PCA1, variables such as DHA, APA, UA, SMC, BD, C, N, and MBC demonstrated notable contributions, underscoring their pronounced impact on the overall variation in soil physico-chemical properties within the study plots. Conversely, in PCA2, variables such as P and K emerged as key contributors, highlighting their significance in delineating distinct soil characteristics (Table 6.6).

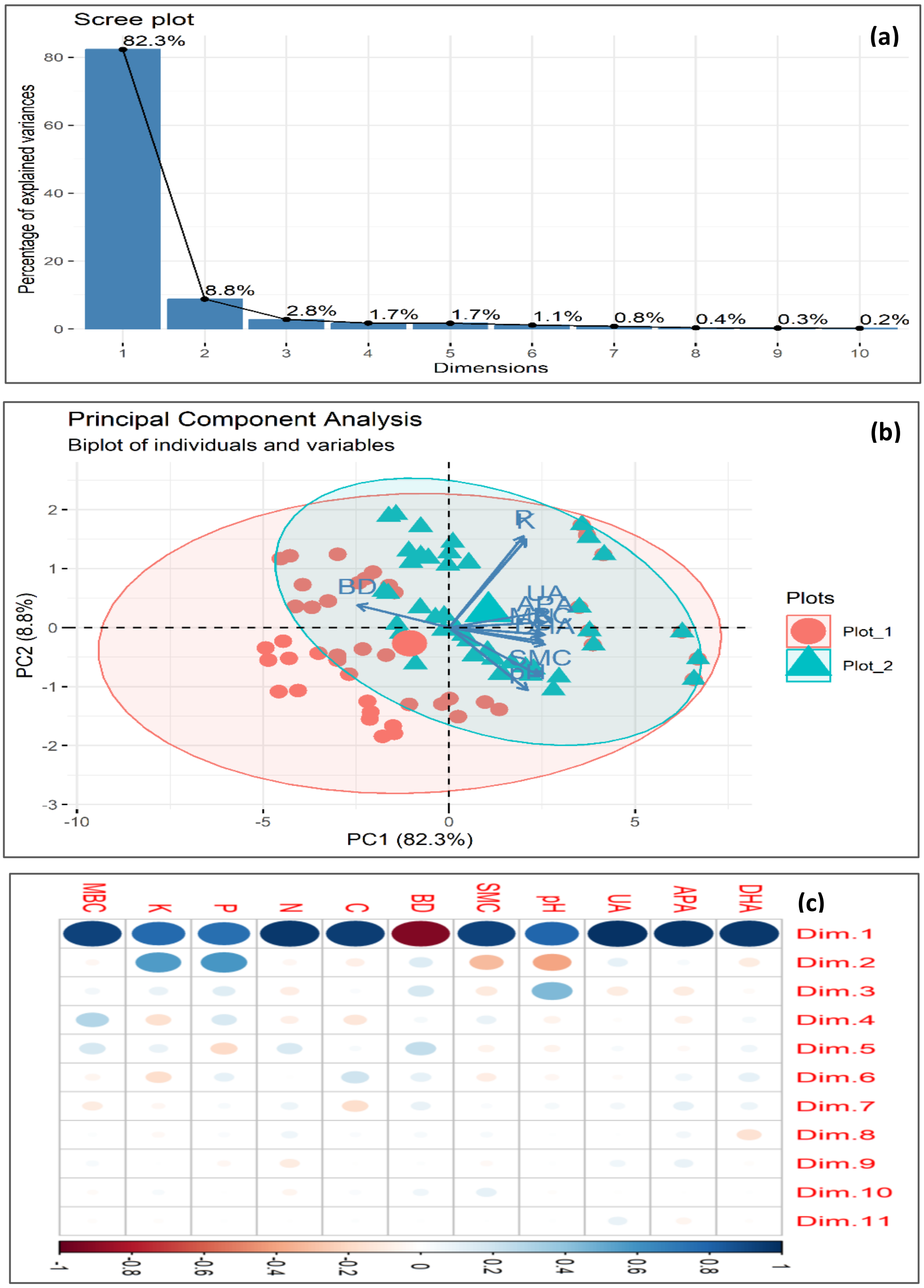


Figure 6.3. *Principal component analysis (PCA) for soil physico-chemical properties within study plots of oil palm:* ***(a)*** *Contribution of each principal component to total variance* ***(b)*** *Biplot of individuals and variables (PC1 & PC2)* ***(c)*** *Principal components and their relation with variables.*

Table 6.5: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for soil physico-chemical properties within study plots of oil palm.

PCA	***Eigenvalue***	***% of variance***	***cumulative %***
1	9.05	82.27	82.27
2	0.97	8.79	91.06

Table 6.6: Variable correlations with principal component analysis (PCA) components for soil physico-chemical properties within study plots of oil palm.

Variables	**PCA1**	**PCA2**
DHA	0.97	-0.11
APA	0.97	0.03
UA	0.98	0.10
pH	0.79	-0.40
SMC	0.92	-0.31
BD	-0.93	0.14
C	0.95	-0.09
N	0.97	-0.05
P	0.75	0.58
K	0.78	0.56
MBC	0.93	-0.04

6.2.4. Correlation coefficient of different soil qualities under different age of oil palm plantation and undisturbed forest.

The correlation table shows strong positive correlations between DHA, APA, UA, and various soil parameters like pH, Soil Moisture Content (SMC), and nutrient levels (C, N, P, K) during the study period. Notably, DHA and APA exhibit exceptionally high correlation coefficients, suggesting a strong relationship. Conversely, bulk density (BD) demonstrates strong negative correlations with most parameters, indicating an inverse relationship. These findings imply that soil organic matter (represented by DHA and APA) positively influences soil health and nutrient availability, while high bulk density may restrict nutrient uptake. The significance values (<.001) underscore the robustness of these correlations.

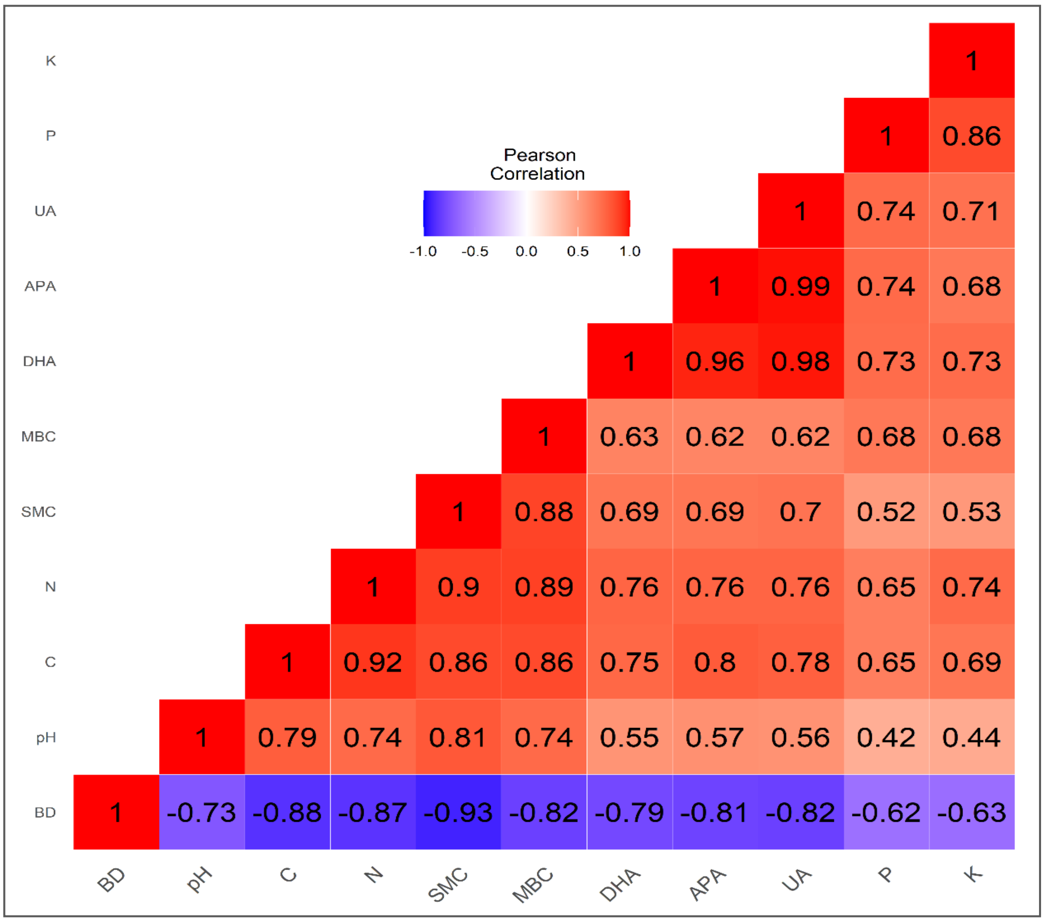


Figure 6.4: *Correlation heat map of different soil properties in oil palm plantation during the study period.*

6.3. Conclusion

In conclusion, the PCA analysis provided a comprehensive understanding of the factors driving variations in soil physico-chemical properties within oil palm plantations. The significant contributions of certain variables to the principal components highlight their importance in shaping soil characteristics. These findings have implications for agricultural management strategies aimed at optimizing soil quality, nutrient availability, and overall productivity in oil palm cultivation.

By leveraging the insights gained from PCA, stakeholders can develop targeted interventions to address specific soil-related challenges and promote sustainable agricultural practices. Future research efforts may focus on investigating the underlying mechanisms driving the observed patterns and exploring potential interactions between soil properties and other environmental factors. Ultimately, the integration of PCA into soil management practices can contribute to the long-term sustainability and resilience of oil palm plantations in diverse agricultural landscapes.

Chapter 7

Plant species diversity under oil palm plantation

7.1. Introduction

Diversity of species is an essential component of biodiversity. It denotes the extensive variety of species that inhabits a specific region. This is a collection of naturally occurring populations that are capable of or mate with one another, but are incapable of reproducing with other groups. Moreover, this concept is commonly known as taxonomic diversity or organismal diversity (Agrawal, 2002). Assessment of biodiversity generally involves an examination of the species diversity that is present. It is foundational to the diversity of higher taxonomic groups and the extensive array of ecological relationships that exist in biomes and communities (Kiester, 2001).

In 1998, Magurran introduced three distinct approaches for quantifying species diversity: species abundance, richness and taxonomic or phylogenetic diversity. The concept of species richness refers to the overall quantity of unique species that inhabit a given ecological community, region, or landscape. Species richness quantifies the quantity of distinct species that inhabit a particular region. The methodology exclusively emphasises species enumeration, neglecting to account for their abundance or distribution. In contrast, species evenness assesses the degree of uniformity in the abundance distribution of the species. Species diversity is a concept that encompasses the relative abundance of each species (evenness) as well as the number of distinct species present (species richness).

Mizoram covers an area of 21,081 square kilometres, accounting for only 0.64 percent of the country's total land area. Located in the Indo-Burma biodiversity hotspot, this region is teeming with a wide variety of plant and animal species, along with dense forests. Mizoram is characterised by valleys and rugged hill ranges, with a considerable portion of the population relying on forests for their livelihoods. This dependence on activities like fuelwood production, timber exploitation, and agriculture has led to the degradation of the ecosystem (Tripathi et al., 2017).

Area under oil palm plantation in Mizoram recently show significant increase from year to year. The total area under oil palm cultivation in Mizoram is estimated to be 26680 ha in 2021 where land under oil palm cover 6965 ha in Kolasib alone (https://agriculturemizoram.nic.in/). It is massive worldwide and studies examining the connection among ecosystem system and biodiversity services is highly significant.

One of the concerns raised about the development of oil palm plantations is its impact on biodiversity, particularly vegetation. The monopoly farming system, which enhanced species uniformity, may have been a contributing factor in the prevalence of weed species diversity and composition in oil palm plantations owned by smallholders. Other factors that may have played a role include management history-related factors. Due to the fact that the shading of the canopy has an effect on the composition of weeds, it appears that the prevalence of grass species increases in dominance as oil palms expand throughout the landscape (Ali et al., 2021)

Under the canopy of oil palm, the species richness of pteridophytes is greater as compared to the area's few forest species (Danielsen et al., 2009). In oil palm plantations, trees, lianas, epiphytic orchids, and native palms were entirely absent. Reduced soil productivity and fertility result from the restricted amount of light that reaches the land in OPP (Hanum et al., 2016). Oil palm also had a significantly lower species richness than disturbed (logged or secondary) forests (Fitzherbert et al., 2008).

One of the criticisms levelled against oil palm plantations is that they contribute to a decline in biodiversity, particularly as it pertains to vegetation. This statement requires empirical evidence from the field. Consequently, the purpose of this study is to compile an inventory of the plant species diversity on land undergoing conversion to oil palm plantation. Data and information obtained from this research will serve as one important source of information concerning the impact of oil palm plantation development on loss or gain of plant species diversity. The data will also serve as consideration for developing oil palm plantation and supports biodiversity conservation.

7.2 Result

According to the findings of the study, there are a total of 3269 individual plants that belong to 27 families and represent 43 species. During the course of the research, it became abundantly clear that the harvesting process of oil palm fruits causes a significant amount of disruption to the vegetation that is located beneath oil palm plantations. There is a large number of grass species, with *Cynodon dactylon* presenting the highest IVI (13.10). This is slightly higher than IVI of *Nephrolepis biseratta*, which is 13.06. With only three individual species recorded during the study, *Sterculia villosa* appears to have the lowest IVI as compared to other species.

Figure no. 7.1 makes it abundantly clear that the Asteraceae family is the one that has the greatest number of species types, followed by the Araceae family, and then the Poaceae family at that point. Of the families of plants, the Asteraceae family has six species, the Araceae family has four species, and the Poaceae family has three species combined. Over the course of the research, there are 18 families, each contributing only one species to the study area. Pteridophytes in general contribute five species, all of which are widely distributed in the area. *Thelypteris sp*. is found in abundance in the oil palm plantation field, providing a significant contribution to the overall diversity of the area.

Table 7.1: Distribution of species within oil palm plantation site.

Sl. no	Species	No.	Family	Density	Frequency	Abundance	IVI
1	*Acmella ciliata* (Kunth.) Cass.	MZUH000270	Asteraceae	68	10	680	7.46
2	*Ageratum conyzoides* Linn.	MZUH000281	Asteraceae.	152	28	542.9	11.42
3	*Amaranthus spinosus* L.	MZUH000282	Amaranthaceae	43	15	286.7	4.91
4	*Arisaema speciosum* (Wall.) Mart.	MZUH000283	Araceae	65	23	282.6	6.55
5	*Cheilocostus speciosus* (J.Konig) C.Specht	MZUH000272	Costaceae	27	17	158.8	3.89
6	*Chromolaena odarata* (L.) R.M.King & H.Rob.	MZUH000249	Asteraceae	65	17	382.4	6.42
7	*Colocasia esculenta* (L.) Schott	MZUH000248	Araceae	53	20	265	5.71
8	*Colocasia* Sp	MZUH000273	Araceae	38	10	380	4.71

9	*Crassocephalum crepidiodes* (Bent.) S. Moore	MZUH000264	Asteraceae	54	19	284.2	5.73
10	*Cyanthillium cinereum* (L.) H.Rob.	MZUH000250	Asteraceae	142	31	458.1	10.96
11	*Cynodon dactylon* (L.) Pers.	MZUH000274	Poaceae	181	23	787.2	13.1
12	*Davallia trichomanoides* Blume.	MZUH000260	Davalliaceae	32	13	246.2	4.08
13	*Derris robusta* (Roxb) Benth.	MZUH000268	Fabaceae	4	2	200	1.59
14	*Dicranopteris linearis* (Burm.f.) Underw.	MZUH000252	Gleicheniaceae	174	31	561.3	12.57
15	*Dioscorea bulbifera* L.	MZUH000266	Dioscoreaceae	27	12	225	3.68
16	*Diplazium maximum* (D. Don) C. Chr.	MZUH000265	Athyriaceae	134	24	558.3	10.46
17	*Drynaria quercifolia* (L.) J. Sm.	MZUH000261	Polypodiaceae	46	19	242.1	5.23

18	*Etlingera linguiformis* (Roxb.) R.M.Sm.	MZUH000257	Zingiberaceae	59	19	310.5	6.04
19	*Euphorbia hirta* L.	MZUH000284	Euphorbiaceae	112	27	414.8	9.29
20	*Homalomena aromatic* (Spreng.) Schott	MZUH000271	Araceae	18	4	450	3.78
21	*Imperata cylindrica* (L.) P.Beauv	MZUH000285	Poaceae	182	21	866.7	13.44
22	*Lindernia ruelloides* Colsm.	MZUH000269	Linderniaceae	63	21	300	6.35
23	*Lindsaea ensifolia* Sw.	MZUH000262	Lindsaeaceae	58	13	446.2	6.1
24	*Ludwigia octovalvis* (Jacq.) P.H. Raven.	MZUH000286	Onagraceae	41	17	241.2	4.82
25	*Lygodium* sp.	MZUH000253	Lygodiaceae	87	23	378.3	7.81
26	*Lygodium* sp.	MZUH000279	Schizaeaceae	51	23	221.7	5.75

27	*Microsorum* sp.	MZUH000278	Polypodiaceae	37	18	205.6	4.61
28	*Mikania micrantha* Kunth.	MZUH000256	Asteraceae	107	45	237.8	10.28
29	*Mussaenda roxburghii* Hook.f.	MZUH000263	Rubiaceae	20	8	250	3.12
30	*Nephrolepis biseratta* (Sw.) Schott	MZUH000287	Nephrolepidace-ae	185	29	637.9	13.06
31	*Oxalis* sp.	MZUH000255	Oxalidaceae	42	11	381.8	4.97
32	*Peperomia pellucida* Kunth.	MZUH000288	Piperaceae	178	28	635.7	12.78
33	*Peuraria Montana* (Lour.) Merr.	MZUH000275	Fabaceae	122	33	369.7	10.06
34	*Polygonum chinense* L.	MZUH000254	Polygonaceae	12	3	400	3.17
35	*Polygonum plebeium* R.Br.	MZUH000289	Polygonaceae	71	22	322.7	6.86
36	*Scoparia Dulcis* L.	MZUH000247	Plantaginaceae	102	9	1133.3	11.13

37	*Solanum indicum* L.	MZUH000251	Solanaceae	5	5	100	1.38
38	*Solanum nigrum* L.	MZUH000276	Solanaceae	133	25	532	10.4
39	*Spermacoce latifolia* Aubl.	MZUH000277	Rubiaceae	104	17	611.8	9.01
40	*Sterculia villosa* Roxb. ex Sm.	MZUH000267	Malvaceae	3	3	100	1.07
41	*Thelypteris sp.*	MZUH000259	Thelypteridaceae	172	25	688	12.47
42	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda	MZUH000258	Poaceae	59	17	347.1	6.02
43	*Urena lobata* L.	MZUH000290	Malvaceae	41	29	141.4	5.7

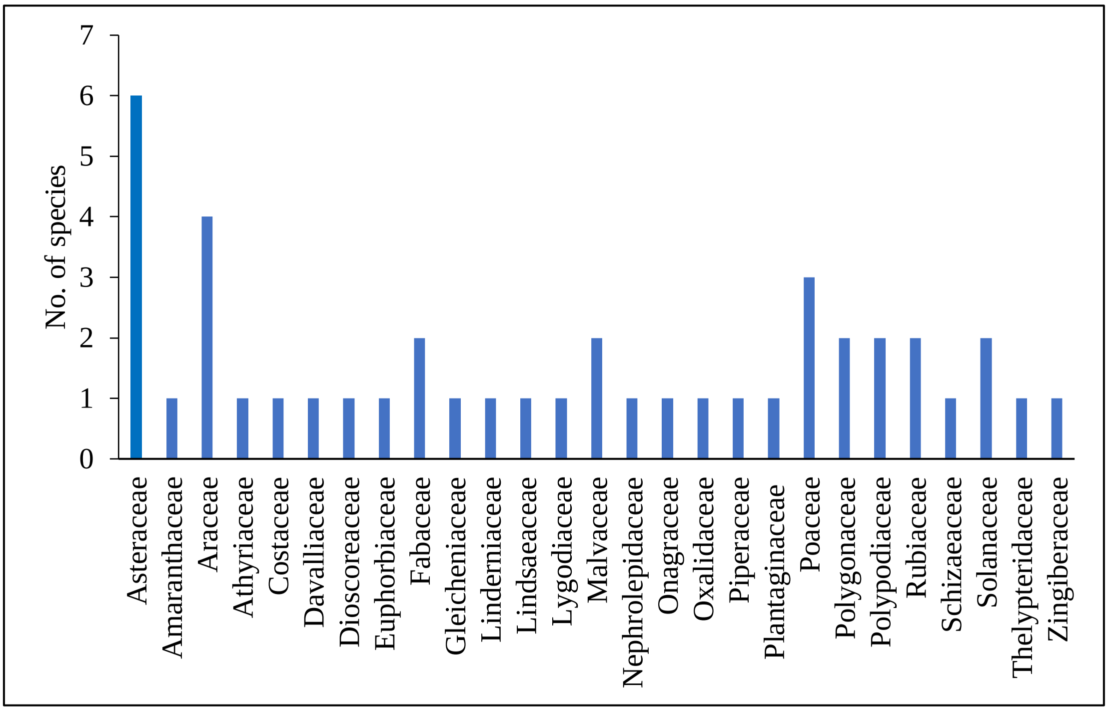


Figure 7.1: *Family distribution and number of species under oil palm plantation*

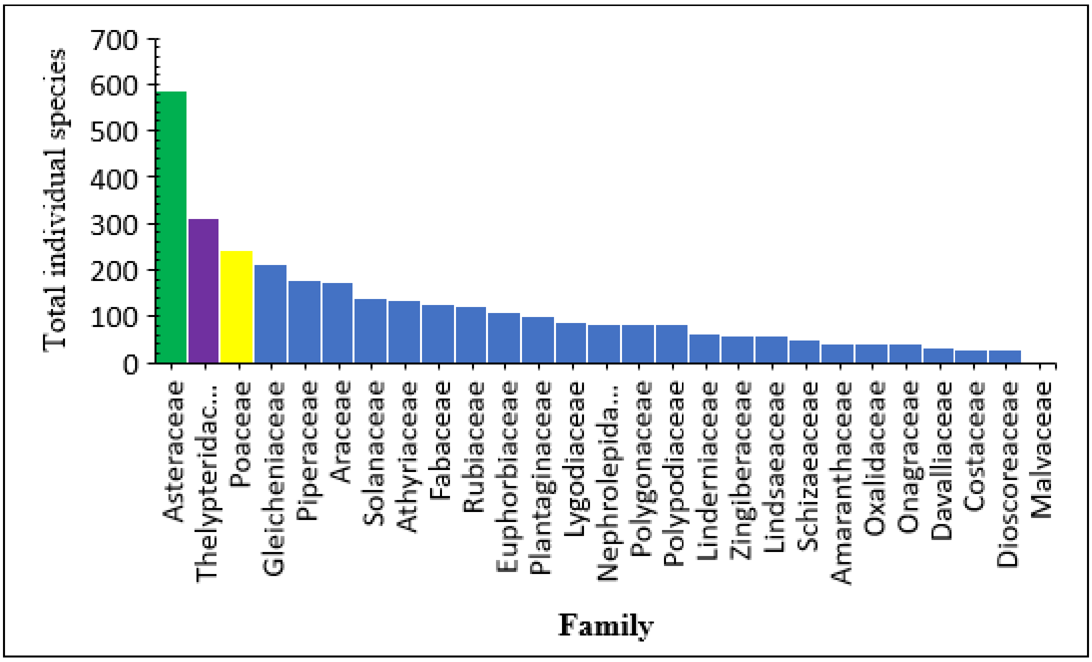


Figure 7.2: *Total number of individual species for each family*

Table 7.2: Diversity indices of plant species within oil palm plantation site

Index	Formula	Value
Shannon-Weiner (H')	$-\sum_{i=1}^{S} pi\ (\ln pi)$	3.194
Simpson's index of diversity (1-D)	$= \sum_{i=1}^{S} \frac{ni(ni-1)}{N(N-1)}$	0.971
Pielou's index {Evenness (E)}	$\frac{H'}{\ln(S)}$	0.677

Table 7.2 shows the species diversity indices observed in the study area. The Shannon-Weiner Diversity Index (H') reports a value of 3.194. The H' value of 3.194 in a tree monoculture plantation area like an oil palm plantation indicates a significant level of plant diversity, ranging from moderate to high. There is a significant amount of plant diversity present in the plantation area. During the study period, a Simpson's Index of Diversity value of 0.97 was observed. A Simpson's Index value close to 1 suggests a strong dominance of one or a few species within the plant community, leading to a relatively low diversity in the present study. An oil palm plantation area was found to have a Pielou's Index of Evenness value of 0.67, suggesting a moderate level of evenness in the distribution of individuals among species.

7.3. Discussion

It is evident from the results that the composition of species in the study area is influenced by the canopy. The distribution of plant species within the study area is impacted by the shade provided by the palm canopy, and pteridophytes appear to dominate as oil palms grow larger (Wan, 1987). Pteridophytes are present in an extensive range of habitats and constitute 20% of the total species population. In comparison to other monoplantations, the species richness of pteridophytes is higher in the oil palm plantation area under the canopy. Trees, lianas, epiphytic orchids, and native palms were entirely absent from the study area. The results clearly show that the canopy influences the species composition in the study area. The palm canopy's shade influences the composition of weeds, with pteridophytes appearing to dominate as oil palms grow larger (Wan, 1987).

Simpson's Index of Diversity value of 0.97 and Shanon diversity index value of 3.18 underscore the significance of preserving and improving biodiversity in monoculture plantation areas. Retaining native vegetation patches or implementing agroforestry practices are examples of management practices that can support the health and resilience of ecosystems by promoting the presence of a variety of plant species. Pielou's index quantifies the disparity in the distribution of individuals among species within a community. As a result, the current study's Pielou index value of 0.67 indicates that the distribution of individuals is somewhat even, but not as uniform as it could be. This implies that specific species within the monoculture plantation may be more abundant than others. The Simpson's indices results in the study area also suggest that the community is dominated by a small number of species, with fewer species contributing to the overall diversity.

This investigation underscores the importance of evaluating the impact of plantation management practices on the diverse array of animals and plants in the region. It emphasizes the importance of factors such as soil quality, climate, human activities, palm tree age and growth, and soil characteristics in determining the overall diversity of the local plant community. The study's findings are critical for long-term oil palm field planning and environmental preservation.

Chapter 8

Socio-economic impact of oil palm plantation

8.1. Introduction

Palm oil production boosts tropical economies. It promotes rural employment, raises farmers' living standards, and promotes economic growth. Bunyamin (2008) reports that oil palm farming increased provincial GDP and farmer incomes. Between 2010 and 2020, experts expect three to seven million hectares of oil palm plantations (OPP) for food and biofuel production (Gingold, 2010).

During 2004–2005, the Government of India, Ministry of Agriculture and Co-operation, approved oil palm cultivation under the Integrated Scheme of Oil Seeds, Pulses, Oil palm & Maize (ISOPOM), which began during the Xth Plan Period. The central and state governments shared oil palm cultivation (75:24). The first OPP reported in Mizoram occurred in 1999–2000 in Rotlang, Lunglei District, and Thingdawl, Kolasib District. In 2004, the Mizoram government enacted 'The Mizoram Oil Palm Regulation of Production and Processing Act. 2004' (Act No. 10 of 2004). The state government's strongly influenced farmers' decisions to switch from jhum to oil palm farming for subsistence. Initially, three companies Godrej Agrovet Ltd., Ruchi Soya Industries Ltd., and 3F signed an MOU under the act to buy FFB from farmers in Mizoram, but Ruchi Soya Industries Ltd. and 3F later withdrawn, and at present, Godrej Agrovet Ltd. is the sole buyer of FFB. Under this initiative, a small number of farmers in Aizawl, Kolasib, Mamit, Serchhip, Siaha, Lawngtlai, and Lunglei districts started OOP in 2005. However, OPP in Mizoram gained importance when the Department of Agriculture and Co-operation, Govt. of India, launched a special programme on Oil Palm Area Expansion (OPAE) under RKVY during 2011–12 and the National Mission on Oilseeds and Oil Palm (NMOOP) from 2014–2015.

The Government of Mizoram aims to implement an action programme with the objective of putting oil palm as a key component in the plan to generate employment, mitigate environmental degradation, and strengthen the process of oil palm development. OPP in Mizoram lowlands will boost farmer livelihoods and incomes (Lalzarliana, 2015). This policy therefore encourages and convinces many farmers to switch to OPP over other farming practices. The government and company also provide subsidies and free nursery distributions to attract farmers. The oil palm farmers received 4000 rupees as cultivation assistance each year during gestation (component-wise pattern for MM-II (Oil Palm) under NMOOP). Reddy (2004), the then Principal Scientist at the National Research Centre for Oil Palm (NRC-OP), studied Mizoram's agro-climatic and water conditions for oil palm cultivation. He concluded that southern Mizoram's gentle slope and low elevation are ideal for oil palm cultivation. In 2011, Mizoram had 16,71,700 ha (India State of Forest Report 2011) of forest cover. The Chadha Committee (2011) identified 61,000 ha of potential oil palm cultivation land, whereas the Rathinam Committee (2011) identified 40,000 ha. The main reason oil palm attracts farmers is that it earns over 50% more than conventional crops. OPP also promises rural agrarian development (Sati and Vangchhia, 2017).

Godrej Agrovet Ltd. recorded 500 active oil palm farmers in Mizoram (2020). Controversy and deliberation surround the OPP industry, with some farmers recently substituting it with another cash crop and still others on the brink of starting in several places in Mizoram. Thus, preliminary research and evaluation are necessary. The study examines farmers' socioeconomic status, rationale for adopting OPP, satisfaction, field challenges, and perceptions of OPP in relation to environmental concerns and marketing strategies.

8.2. Result

This chapter provides an account of the results and data analysis obtained during the survey. It examines the merits and demerits of oil palm cultivation in Kolasib District, as well as the positive impact and negative impact on the livelihood of local farmers. Each participant in this study is an individual from the Mizo community.

It is clear from figure 8.1 that there are 25% of farmers within the age group of 51-60 years, 55% of farmers are in the age group of 61-70 years which constitute the major group. There are 15% of farmers above 71 of age. The oldest farmer recorded was 74 years old from Kolasib town. According to the survey, 95% of oil palm farmers are male while only 5% are women. It was observed that most of the working groups are male and many of the started oil palm cultivation after their retirement.

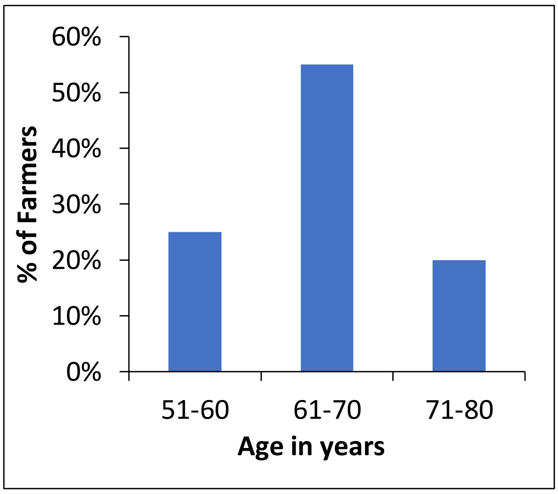


Figure 8.1: *Age distribution of oil palm farmers*

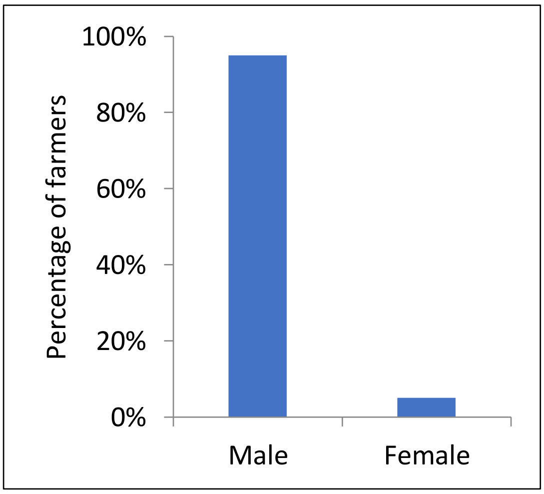


Figure 8.2: *Gender distribution of oil palm farmers*

The educational status in the survey was classified into three groups- up to elementary, secondary and till graduation. According to the survey, it is reported that most of the farmers have basic education in which 60% attain education up to elementary education, 30% Secondary and 10% graduation 60% respondents entered up to Elementary education, 30% of them entered secondary school and the other 10% finished their Graduation. The result shows that the oil palm farmers are literate. The main source of income among oil palm farmer is from their oil palm farming. In the study area, 65% of the farmers solely depend on oil palm cultivation for their financial income. However, 10% of the farmers get their main source of income from their government jobs. 25% of respondent get their main income from other source like fish pond, vegetable cultivation and areca nut cultivation. It is clear from the study that majority of the farmers relies on oil palm farming as the major source of income for their family. The educational status and source of income among the oil palm farmer has been presented in figure 8.3 and 8.4 respectively.

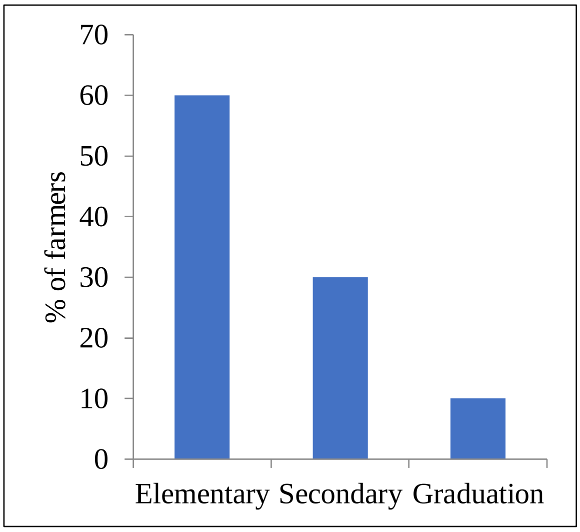


Figure 8.3: *Educational status of oil palm Farmers.*

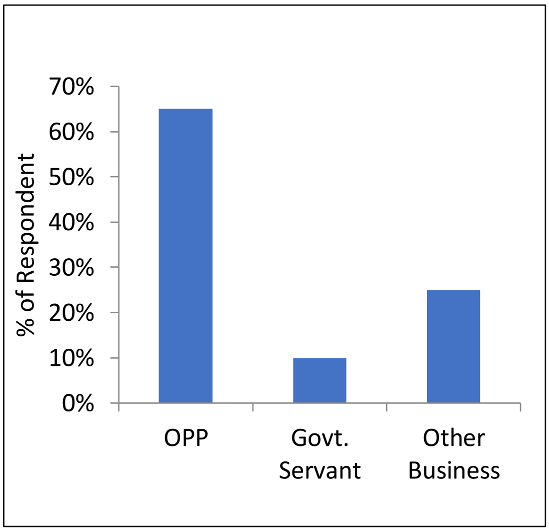


Figure 8.4: *Main source of income among farmers.*

OPP was promoted by the government of Mizoram from 2005 under its New Land Use Policy. Kolasib district was announced as the first oil palm district by the government of Mizoram. From the survey data it is also clear that all the farmer started oil palm farming after this policy. Majority of farmers in the study area, 55% started oil palm farming between 2004-2007,15% start their plantation during 2008-2011, 10% between 2009 and 2012 and 20% recently started oil palm farming in the year 2016-2019. It was also observed during the study that some oil palm farmers recently shift to Areca farming but they were not included in the survey as they are not active oil palm farmer at present. The reason for this shifting might be due to a higher income as compare to oil palm marketing. It is shown from figure 8.6 that most farmers choose to grow oil palm because of its potential for higher earnings and other benefits received as compare to other crop. It is clear that the government, in partnership with Godrej Agrovet Limited, effectively encouraged individuals to choose OPP over traditional jhum cultivation and other forms of cultivation. Only 20% of the farmers agreed that their land is suitable for oil palm farming. The present oil palm farmers are benefited with financial assistance, subsidies, seeds, water pipes, and other resources from the government. This allowed them to engage in cultivation without having to make any financial investments. A majority of the farmers 50% opted for this plantation because of its high profitability, while a smaller percentage 20% chose it because it is more compatible with their land compared to other crops and another 20% of the farmers report that oil palm cultivation can be easily managed as the palm tree do not need daily visit and not vulnerable to disease and pest as compare to other crop.

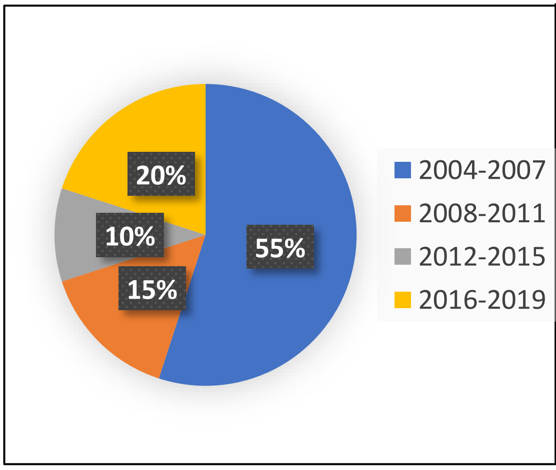


Figure 8.5: *Year of starting of oil palm plantation*

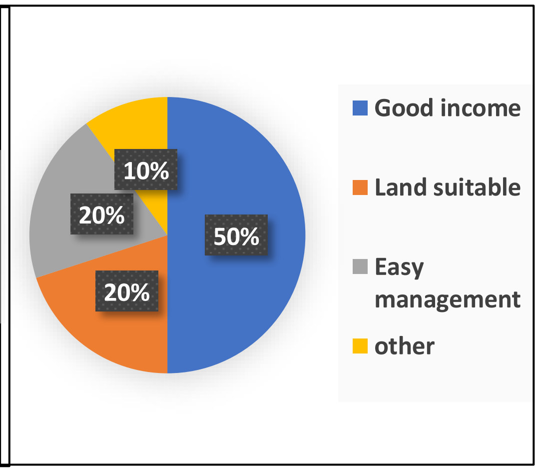


Figure 8.6: *Reason for choosing OPP by farmers*

Farmers sell their oil palm fruit to Godrej Agrovet Ltd. at a rate of Rs. 5.50 per kg, with the Department of Agriculture, Mizoram, contributing a matching additional 1 rupee. This rate has remained unchanged from June 2014 to the current survey, resulting in only 20% of farmers expressing satisfaction with their oil palm business, 20% expressing low satisfaction, and around 60% maintaining a moderate level of satisfaction. The study also revealed that 65% of the respondents expressed a desire to continue their current business, whereas 35% expressed a desire to cease oil palm farming and explore alternative options.

The majority of the farmers harvested more than 100 quintals in a year. Figure 8.8 reveals that 15% of farmers earn less than Rs. 50,000 annually from OPP. 30% of farmers earn between Rs. 50,000 and 100,000, while another 30% earn between Rs. 100,000 and 200,000 from OPP. According to the findings, 25% of farmers earn more than 200,000 rupees per year from OPP. According to the survey, the highest income earns 3.5 lakhs, but farmers expect more than this. Failure to achieve their expected annual income is mainly due to an improper link road to their oil palm field. This makes it difficult for farmers to carry their fruit to the main road, and they often remain unharvested during this season. In certain instances, farmers accumulate harvested FFB for nearly a week, leaving the crops vulnerable to pests and other microorganisms, leading to quality degradation and unsuitability for processing in the oil palm mill. Therefore, this situation prevents the achievement of the expected annual income.

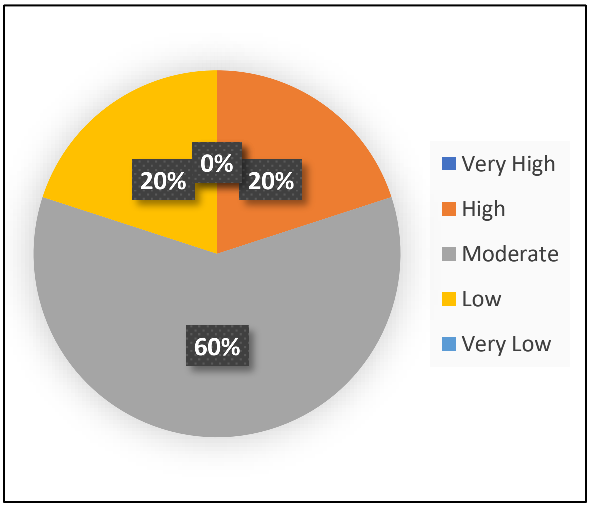


Figure 8.7: *Satisfactory level of farmers on OPP*

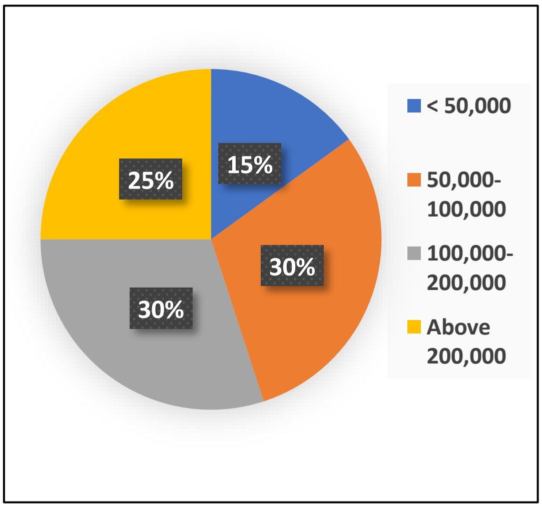


Figure 8.8: *Annual income of farmers from OPP*

One hectare of land can accommodate the planting of 150 oil palm trees. According to the survey results, the majority of farmers have 2-4 ha of land under OPP, while a few farmers have around 1 ha. It is shown from figure 8.9 that 50% of oil palm farmers shift from jhum cultivation to OPP. There are also 20% of cultivators who shift from rubber plantation to OPP. There are 10% of farmers who did not have any previous type of cultivation before OPP.

Figure 8.10 clearly demonstrates that clearing the secondary forest led to the establishment of the majority of the OPP area. In their field, farmers try to practice intercropping along with palm trees. However, most of them do not succeed, as this crop often produces low yields or remains unharvestable when cultivated between the palm trees. However, there are some species that grow wild in the plantation area. This plant is consumed by locals and is also in demand in the market.

Deforestation poses a significant challenge for the oil palm industry which is also a concern in the study. In the study area, a significant portion of the present oil palm land (70%) has been established in secondary forests and scrubland, while a small percentage (5%) has been transformed into an OPP area by clearing primary forest. 25% of the land has been converted from other existing cultivation to OPP.

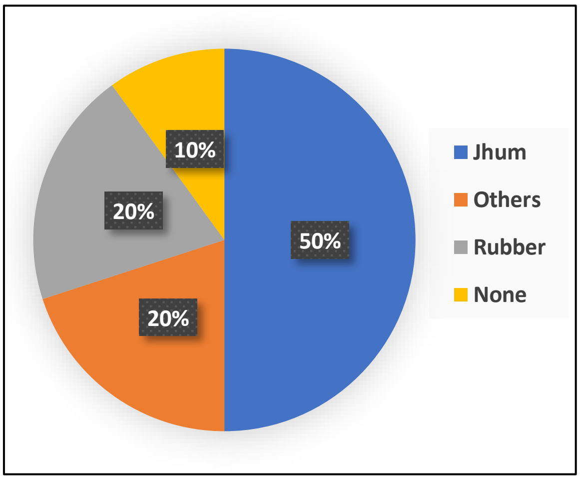


Figure 8.9: *Previous cultivation practice among farmers*

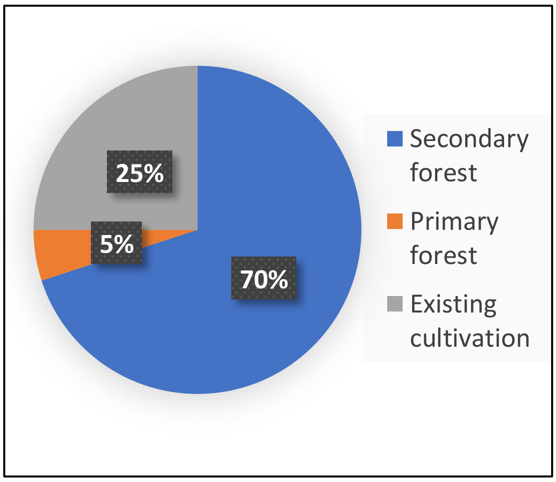


Figure 8.10: *Type of land before oil palm cultivation.*

8.3. Discussion

The study emphasises the socioeconomic consequences of oil palm cultivation in Kolasib district, Mizoram. The study observed that OPP has recently become the most extensively cultivated crop in Mizoram's tropical lowlands. Local farmers have conducted the plantation on a small scale, in contrast to many other OPP regions worldwide. Therefore, it is the responsibility of the government and companies to assist independent farmers in the sustainable and productive cultivation of oil palm. It is evident that OPP enhances the income of farmers and further contributes to the economic development of numerous farmers.

The number of female farmers is significantly lower than expected because, in the sample community, women are primarily considered to be responsible for household chores. The farmers in the study area also think that the oil palm plantation, its management, and harvesting are not a woman's job, as they require heavy labour during this process. Therefore, oil palm farming is not suitable for households where male workers are absent. Mizoram is the third most literate state in the country; the survey result also shows a high literacy rate among the oil palm farmers. Few of the respondents from the first group mentioned that they could not continue school because of poverty and the absence of an accessible school at that time. Overall, it is clear that the majority of farmers in the study area rely heavily on oil palm farming for financial stability. While some supplement their income with government jobs, others diversify their earnings by engaging in other forms of agriculture, such as fish ponds and vegetable cultivation. This demonstrates the importance of oil palm cultivation in the local economy but also highlights the need for farmers to explore alternative sources of income to ensure financial security.

The survey results showed that the current lack of a proper, well-maintained link road to their oil palm fields is a major hindrance for farmers in reaching their expected annual income. This obstacle not only makes it challenging for farmers to transport their fruit to the main road, but also results in unharvested crops, quality degradation, and unsuitability for processing in the oil palm mill. Addressing this issue is critical to improving the livelihoods of these farmers and helping them achieve their desired financial goals. The observation clearly showed that farmers' attempts at intercropping with palm trees have not yielded significant success. Despite this, some wild species, such as *Solanum nigrum* and *Arisaema speciosum*, thrive in the plantation area, attracting local consumption and market demand, thereby offering a potential source of income for farmers in the region.

Deforestation remains a pressing issue for the oil palm industry, with a large portion of current oil palm land established in secondary forests and scrubland. This raises concerns about environmental sustainability in the study region. Efforts to balance economic growth with conservation efforts are critical for the oil palm industry's long-term viability in this area. Oil palm farming has led to mixed levels of satisfaction among farmers. While the majority feel moderately satisfied with their oil palm business, there is a significant portion of farmers who wish to cease their current oil palm farming and are considering exploring alternative options.

Chapter 9

Summary and Conclusion

Assessing and analysing the impact of OPP on soil is crucial because oil palm trees are highly vulnerable to environmental stresses, which have the potential to disrupt soil fertility. This study explores the variations in soil quality between an oil palm plantation-occupied area and an undisturbed forest. The study also analyses the impact of different ages of oil palm plantations on the soil's physical and chemical properties, plant biodiversity, soil microbial biomass and enzyme activities, socio-economic factors, and land use in the study area. Kolasib district is chosen as a study site primarily because oil palm trees thrive in tropical lowlands at lower elevations. Moreover, the southern region of Buhchangphai in Kolasib district provides a favourable topography for cultivating oil palm. In the study, soil samples were collected during the months of April, August, and December for three consecutive years, from 2019 to 2021. Soil quality was studied at both undisturbed forest and plantation sites, which represented ages of three, five, ten, and fifteen years. The soil physico-chemical screening involved analysis of soil pH, soil moisture content, bulk density, water holding capacity, soil organic carbon, total nitrogen, available phosphorus, and exchangeable potassium. The study also examined the soil microbial biomass carbon content and three soil enzyme activities: dehydrogenase, phosphatase, and urease activities. These enzymes serve as dependable indicators that promptly react to variations in environmental conditions, changes in land utilisation, and adjustments in soil management techniques. Quantitative data were collected for the study of plant diversity in an oil palm plantation field, and species diversity indices were measured accordingly. The present study employed a quantitative approach to investigate the socio-economic effects of oil palm cultivation on farmers.

Soils in oil palm plantations show diminished physical characteristics as compared to undisturbed forest. Thus, it suggests that oil palm plantations have a large negative impact on the physical properties of soil. The compacted soil in these plantations restricts root growth and water infiltration, leading to decreased water holding capacity and increased susceptibility to erosion. Additionally, the loss of organic matter and soil structure in oil palm plantations further exacerbates these issues, ultimately resulting in degraded soil health and reduced overall productivity of the land. It is crucial to implement sustainable land management practices in oil palm plantations to mitigate these negative effects and preserve the long-term health of the soil.

There is a difference in soil physico-chemical characteristics among different plantation age where 10 years show the greatest decrease in soil physical quality. It is further important to understand these differences in soil characteristics among different plantation ages as it is crucial for implementing effective soil management practices to maintain soil health and productivity in forestry systems.

The soil sample from core zone and buffer zone in plantation area shows variation. The core zone(P1) shows greater decrease in soil physico-chemical quality as compare with buffer zone(P2) and undisturbed forest. In conclusion, the soil quality in the core zone of the plantation area has significantly decreased compared to both the buffer zone and undisturbed forest. This indicates that the impact of plantation activities on soil physico-chemical properties is more pronounced in the core zone. Further studies are needed to understand the specific factors contributing to this difference and to develop strategies for mitigating soil degradation in plantation areas. CNPK value in soils of oil palm plantation show decrease level as compared to undisturbed forest showing that this plantation results in reduced soil fertility of the area. Thus, negatively impact the soil quality. This decrease in CNPK value can lead to poor nutrient availability for plant growth and may result in lower crop yields. Additionally, the reduced soil fertility can also contribute to increased erosion and soil degradation, further impacting the overall health of the ecosystem. Therefore, it is important for oil palm plantations to implement sustainable practices to mitigate these negative effects on soil quality and ensure the long-term productivity of the land.

Soil enzyme activity in oil palm plantation greatly decrease in plantation site as compared to undisturbed forest. Thus, oil palm plantation negatively impact soil enzyme activity in an area. Diminishing microbial biomass carbon, soil enzyme activity and organic carbon in oil palm plantation has indicate that oil palm plantation negatively impact microbial community in an area. The age of oil palm tree also had a significant impact on the health and productivity of the soil in plant in the area. As oil palms age, soil disturbance from various plantation activities can disrupt microbial communities and decrease biological activity. The highest disturbance is mostly observe in soil of 10 years plantation. This decline in microbial activity can lead to decreased soil fertility and productivity, ultimately affecting the overall health of the ecosystem. Without a diverse and thriving microbial community, essential nutrient cycling processes may be disrupted, further exacerbating the negative impacts of oil palm plantations on the environment. It is crucial to implement sustainable land management practices that support and enhance microbial diversity in order to maintain the long-term health and productivity of oil palm plantations.

Plant species diversity in oil palm plantation has been adversely affected by the palm tree leading to comparatively less number of abundant species in the area. The findings of the research suggest that the presence of oil palm plantations has a notable impact on the diversity and composition of the vegetation in the area. The dominance of certain grass species and the varying IVI values of different plant species highlight the effects of oil palm fruit harvesting on the surrounding ecosystem. Further studies may be needed to better understand the long-term implications of these disruptions and to explore potential conservation strategies for maintaining biodiversity in oil palm plantation landscapes. This indicates that while there is a high level of plant diversity in the plantation area, the distribution of individuals among species is not evenly spread out. Certain species are dominating the plant community, leading to a lower overall diversity. Despite this, the presence of a variety of plant species in the area highlights the importance of maintaining biodiversity in agricultural landscapes. Efforts to promote greater evenness in species distribution could help support a more balanced and resilient ecosystem within the plantation.

In conclusion, the establishment of oil palm plantations in secondary forests and scrublands raises significant concerns about the environmental sustainability of the study region. It is crucial for the oil palm industry to find a balance between economic benifits and conservation efforts in order to ensure its long-term viability. While many farmers feel moderately satisfied with their oil palm business, a notable portion is looking to explore alternative options due to low or moderate levels of satisfaction. The mixed levels of satisfaction among farmers also highlight the need for further research and support for those who are looking to explore alternative options to oil palm farming. It is evident that there is a growing interest among some farmers to move away from oil palm cultivation, indicating a shift in attitudes towards more sustainable agricultural practices. Overall, it is imperative that stakeholders work together to address these challenges and implement strategies that promote both economic prosperity and environmental protection in the oil palm industry. While previous intercropping practices with palm trees has not proven successful in terms of yield, the presence of wild edible plant species like *Solanum nigrum* and *Arisaema speciosum* in the plantation area presents a promising opportunity for farmers. These plants are both consumed locally and in high demand in the market, which would be an additional source of income for farmers in the region. It is clear that exploring alternative crops that thrive in this environment could be beneficial for agricultural productivity and economic sustainability in the area.

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https://vikaspedia.in/agriculture/crop-production/package-of-practices/oilseeds/oil-palm

Photo plate: *Oil palm plantation site at Buhchangphai*

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Examination	Board	Year	Division	Percentage	Achievement
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NET(Environmental Sc.)	UGC	2017			
NET(Education)	UGC	2021			
MA (Education)	IGNOU	2021	I	64.00	
M.Sc (Botany)	MZU	2012	I	69.4	
B.Ed	IGNOU	2015	I	68.00	
B.Sc (Botany)	MZU	2009	I	68.5	
HSSLC	MBSE	2006	II	57	
HSLC	MBSE	2004	I	71	

Ph.D. Registration No. and Date : MZU/Ph.D./1282 of 06.09.2018

Department Botany : Botany

Title of Research : Ecological impact of oil palm (*Elaeis guineensis* Jacq.) plantation in Kolasib district, Mizoram

Supervisor : Dr. F. Lalnunmawia

Joint supervisor : Dr. H. Lalruatsanga

List of publications (UGC-Care journals):

1. Lalawmpuia, H. Lalruatsanga2, F. Lalnunmawia, Lalbiakdika and Elizabeth Vanlalruati Ngamlai (2023). Oil Palm Plantation: Carbon Sequestration Potential and Effective carbon Management within Serchhip, Mizoram. *Ecology, Environment and Conservation.* 29 (1): 96-101.

2. Lalawmpuia and H. Lalruatsanga(2021). Enumeration of Plant Species Inhabiting Oil Palm trees (*Elaeis guineensis*) at Zawlpui Plantation Site, Serchhip District, Mizoram. *Science and Technology Journal*. 9(1): 32-35

3. Lalawmpuia and H. Lalruatsanga(2021). Impact of plant age on dehydrogenase activity of soil in Oil Palm (*Elaeis guineensis* Jacq.) plantation sites of Buhchangphai, Mizoram, India. *Ecology, Environment and Conservation*. 27 : 236-238.

List of Seminar and Workshop attended (Paper presented):

1. International conference on conservation of biodiversity in Genomic era held at Pachhunga University College during 22nd -23rd March, 2024.

2. National level research methodology workshop held on 17th -18th January, 2024 at Pachhunga University College, Aizawl. Organised by Research and Development Cell PUC & IQAC,PUC.

3. International Seminar on Recent Advancement in Science and Technology (ISRAST) held during 16th – 18th November, 2020. organised by Department of Botany, Mizoram University.

4. International Conference on Recent Advancement in Animal Science (ICRAAS) held at Pachhunga University College during 6th -8th November, 2019. Organised by Department of Zoology, PUC

PARTICULARS OF THE CANDIDATE

NAME OF CANDIDATE	: Lalawmpuia
DEGREE	: Ph.D.
DEPARTMENT	: Botany
TITLE OF THESIS	: Ecological impact of oil palm (*Elaeis guineensis* Jacq.) plantation in Kolasib district, Mizoram.
DATE OF ADMISSION	: 06.09.2018

APPROVAL OF RESEARCH PROPOSAL

1. DRC	: 02/05/2019
2. BOS	: 03/05/2019
3. SCHOOL BOARD	: 17/05/2019
4. MZU REGISTRATION NO.	: 204 of 2006-07
5. Ph.D REGISTRATION No. & DATE	: MZU/Ph.D./1282 of 06.09.2018
6. EXTENSION	: Nil

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ABSTRACT

ECOLOGICAL IMPACT OF OIL PALM (*Elaeis guineensis* Jacq.) PLANTATION IN KOLASIB DISTRICT, MIZORAM

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

LALAWMPUIA

MZU REGISTRATION NO: 204 of 2006-07

Ph.D. REGISTRATION NO: MZU/Ph.D./1282 OF 06.09.2018

DEPARTMENT OF BOTANY

SCHOOL OF LIFE SCIENCES

JULY, 2024

ECOLOGICAL IMPACT OF OIL PALM (*Elaeis guineensis* Jacq.)

PLANTATION IN KOLASIB DISTRICT, MIZORAM

BY

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SUBMITTED

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN BOTANY OF MIZORAM UNIVERSITY, AIZAWL

Abstract

Oil palm (*Elaeis guineensis* Jacq.) is the world's most versatile and economical oil producing crop at present. However, it is also one of the most environmentally controversial crop. The National Mission on Oilseeds and Oil Palm (NMOOP) aims to promote the growth of oil palm farming in India, with a specific focus on Mizoram. Mizoram's northern region is characterised by several small rivers and a gently sloping topography, making it suitable for OPP. Numerous farmers in the Kolasib district cultivate oil palm continuously throughout the year as an important source of income, allowing small-scale land owners to participate in the industry. Due to the rising demand for palm oil, numerous local farmers have transitioned from jhumming to cultivating oil palm since it offers greater profitability and reliability. There is a pressing concern arising from the introduction of oil palm plantations in Mizoram and its plans for future expansion where the economical viability has been weighed with the ecological aspect.

The study examines the influence of varying ages of oil palm plantations on the physical and chemical qualities of the soil, biodiversity of plants, micro communities and enzymes in the soil, socio-economic aspects, and land usage in the defined area. The proposition to extend the plantation underscores the necessity of scrutinising its repercussions in one of the oil palm focal districts in northeast India. The abundance of conflicting accounts is a significant challenge that requires scientific investigation and inquiry in the Kolasib environment. The Mizoram state's lack of authentic publications or documentation of environmental impact assessments necessitates a thorough study and evaluation. These studies are expected to identify potential risks and offer necessary evidence for the cultivation of the area.

Soil sample was collected from UD site and different plantation ages: 3y, 5y, 10y and 15y. Plantation site was located at Buhchangphai (24019'69"N 92038'81"E), Kolasib district. Soil under palm tree is collected from two distinct locations or plots, denoted as Plot 1 and Plot 2, respectively. Samples for Plot 1 is collected from the core

zone at 1.5 m from the main trunk within the weeded circle and and Plot 2 is collected from buffer zone at 4 m from the main trunk within the palm avenues. Soil samples were collected on April, August, and December for three consecutive year between 2019 - 2021. Soil physico-chemical properties such as soil pH, SMC, WHC, BD, SOC, TN, Available P and exchangeable K were measured in the study. Soil microbial biomass and soil enzyme activities for Dehydrogenase, phosphatase, and urease were measured during the study. These enzymes are selected as they are reliable indicators that quickly respond to changes in environmental conditions, modifications in land use, and alterations in soil management practices. Principal component analysis was perform for various soil properties studied during the research period. Species diversity under oil palm plantation was also studied to determine the impact of OPP on plant community of an area. Both quantitative and qualitative analysis was done in the study. The quantitative approach (Bryman, 2012) was used for the study of socio economic impact of OPP among farmers within Kolasib district.

The study finds out that soils in oil palm plantation shows a diminished physico-chemical properties as compared to undisturbed forest. The SMC level at the UD site ranges from 19.26% to 27.36% during the study period while it was only 11.13% at 10 years plantation site in December 2020. This difference between UD and plantation site was also observed in soil pH and WHC where all plantation ages of oil palm soil shows a lesser level respectively. However, BD of soil is greater in plantation site as compared to UD site. Highest soil bulk density 1.42 gcm^{-3} was recorded in 10 years during the month of December 2020. Among different age of plantation, 3 years showed the lowest bulk density. The soil bulk density consistently increases from 3 years till 10 years plantation. Unlike bulk density, when comparing different age of plantation 10 years show maximum decrease value of Soil pH, SMC, WHC. It was observed from the findings that the soil's physical quality deteriorated mainly after 5 years of plantation. Significant difference at $p \leq 0.05$ was observed mostly between different soil properties of plantation ages and undisturbed forest during the study period.

This study also reports that the soils at OPP sites contain less organic carbon as compared to UD. Soil NPK also show similar trend. This study reveals that the rate of decrease in NPK is greater at younger plantations especially from 5 years to 10 years. The age of oil palm tree also had a significant impact on the CNPK level of the soil in the area. Nitrogen, Phosphorus and Potassium decreases progressively from 3 years to 10 years, later changes marginally at fifteen years. UD forest has significantly high level of NPK as compared to plantation site. Carbon, Nitrogen and Potassium record highest level during August while Phosphorus show highest in December.

DHA in soils of oil palm plantation site were significantly lower in comparison to soil of undisturbed forest. As the plantation ages, there is a decline in the levels of DHA. There was a substantial drop in DHA from 3 years, 5 years to 10 years, but minimal decrease was observe from 10 years to 15 years. The study reported a consistent decrease in soil Apase and Urease activity as the age of the plantation increased, however, reaching its lowest point at 10 years. Although there is minimal disparity between 10 years and 15 years plantation, 15 years show slightly higher value. Highest Cmic level was recorded at UD site (190.02 mg kg^{-1}) where lowest (102.20 mg kg^{-1}) was recorded in soil of 15 years plantation. It was shown that C_{mic} decreases remarkably as plantation ages from 3 years to 10 years. However, a marginal decrease was observed from 10 years to 15 years.

The soil sample from core zone and buffer zone in plantation area shows variation. The core zone(P1) shows greater decrease in soil physico-chemical quality, soil enzyme activity and microbial biomass carbon as compare with buffer zone(P2) and undisturbed forest.

Principal Component Analysis of soil physico-chemical properties, microbial biomass carbon and soil enzyme activities observed that there is distinct separation between undisturbed oil palm soils and those from 3, 5, 10, and 15 years of oil palm cultivation soils in the first component. Strong positive correlation between different soil physico-chemical properties, microbial biomass carbon and enzyme activity was observed during the study period.

According to the findings on the study of plant diversity under oil palm plantation, there are a total of 3269 individual plants that belong to 27 families and represent 43 species recorded during the study period. Asteraceae family has the greatest number of species types, followed by the Araceae family, and then the Poaceae family. The Shannon-Weiner Diversity Index (H') reports a value of 3.194, Simpson's Index of Diversity value of 0.97 and Pielou's Index of Evenness value of 0.67. In comparison to other mono plantations, the species richness of pteridophytes is higher in the oil palm plantation area under the canopy. Trees, lianas, epiphytic orchids, and native palms were entirely absent from the study area. Plant species diversity in oil palm plantation has been adversely affected by the palm tree leading to comparatively less number of abundant species in the area. The findings of the research suggest that the presence of oil palm plantations has a notable impact on the diversity and composition of the vegetation in the area.

The study also investigates the socioeconomic impact of oil palm cultivation in Kolasib district, Mizoram. The study observed that OPP has recently become the most extensively cultivated crop in Mizoram's tropical lowlands. It is evident from the study that OPP enhances the income of farmers and further contributes to the economic development of numerous farmers. A majority of the farmers 50% opted for this plantation because of its high profitability, while a smaller percentage 20% chose it because it is more compatible with their land compared to other crops and another 20% of the farmers report that oil palm cultivation can be easily managed as the palm tree do not need daily visit and not vulnerable to disease and pest as compare to other crop. The majority of the farmers harvested more than 100 quintals in a year. In the study, 15% of farmers earn less than Rs. 50,000 annually from OPP. 30% between Rs. Rs 50,000 - 100,000, while another 30% earn between Rs. 100,000 and 200,000 from OPP. According to the findings, 25% of farmers earn more than 200,000 rupees per year from OPP. While many farmers feel moderately 60% satisfied with their oil palm business, a notable portion is looking to explore alternative options due to varying levels of satisfaction. The mixed levels of satisfaction among farmers also highlight the needs for further research and support for those who are looking to explore alternative options to oil palm farming. It is evident that there is a growing interest among some farmers to move away from oil palm cultivation, indicating a shift in attitudes towards more sustainable agricultural practices.

The decline in soil physico-chemical properties, soil enzyme activities and microbial biomass carbon under oil palm plantation during the study period shows the negative impact of oil palm plantation. As compared to undisturbed forest, there is a reduce soil fertility and plant diversity which also ultimately affect the overall health of the ecosystem. Without a diverse and thriving microbial community, essential nutrient cycling processes may be disrupted, further exacerbating the negative impacts of oil palm plantations on the environment. It is crucial to implement sustainable land management practices that support and enhance microbial diversity in order to maintain the long-term health and productivity of oil palm plantations. The result of the present research underlines the criticality of effective agronomic management of oil palm in order to mitigate its adverse effects on the soil. While the current study did not assess the management practices, it is hypothesised that a proper land management system could enhance soil quality through the implementation of measures such as reducing disturbance during harvesting, incorporating leguminous plant into the understory and avoiding intensive hand weeding.