# EFFECTS OF *Eucalyptus* PLANTATION ON THE PHYSICO-CHEMICAL PROPERTIES AND LITTER DECOMPOSITION PROCESSES IN SOIL

**A THESIS**
**SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF PHILOSOPHY IN BOTANY, UNIVERSITY OF DHAKA**


**SUBMITTED BY**
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**SESSION: 2013-2014**
**REG. NO.: 194**
**EXAM ROLL: 01**

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**SEPTEMBER 2019**

**DEDICATED**

**TO**

**MY FAMILY AND TEACHERS**

# *CERTIFICATE*

*This is to certify that the research work embodying the result of the thesis entitled "**Effects of Eucalyptus plantation on the physico-chemical properties and litter decomposition processes in soil**" was carried out by the author herself in the Ecology and Environment Laboratory, Department of Botany, University of Dhaka, under our supervision and the style and contents of this thesis is suitable for the partial fulfillment of the Degree of Master of Philosophy in Botany.*


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# ACKNOWLEDGEMENT

Having completed this study, I am grateful to my supervisor Mohammad Zabed Hossain (Ph.D., UGAS, Iwate University, Japan; Post-Doctorate, SLU, Uppsala, Sweden), Professor, Department of Botany, University of Dhaka, for his constant support, guidance, supervision, encouragement and co-operation during the time of my research work. I am also thankful to my co-supervisor Dr. Ashfaque Ahmed, Professor, Department of Botany, University of Dhaka for his valuable suggestion and endless encouragement during the period of my research.

I feel proud to express my sense of gratitude to the Chairman, Professor Dr. Rakha Hari Sarker and at the same time to the former Chairman Professor Dr. Moniruzzaman Khondker and Professor Dr. M A Bashar of the Department of Botany, University of Dhaka for providing all laboratory facilities during the study period.

I am indebted to Dr. Sirajul Hoque, Professor, Department of Soil, Water and Environment, University of Dhaka for his kind help in chemical analysis of soil samples. I am also grateful to Mrs. Kishwar Jahan, Assistant Professor and Mr. Saiful Islam, Lecturer, Department of Botany, University of Dhaka for their kind help in taking spectrophotometer reading.

I would like to send my love to my lab mates Nur Jahan apu, Habib bhai, Ataur bhai, Moshidul bhai, Ritu, Shaila, Rasel, Nabila, Jake, Pranty, Pragga, Sydul and Suraiya for their co-operation and encouragement. Specially I am thankful to Kashem, Mehedi and Tropa who stood behind me whenever I needed. They should be aware of that they will not be forgotten ever.

I am also thankful to my parents for their strong encouragement and my brothers for their understanding and endless love. I would like to remember my grandparents late Akhil Chandra Sarker and late Binodini Rani Sarker. I am grateful and would like to express my heartfelt gratitude to my husband Suvashish Bose for his encouragement and support.

Finally, I express my heartiest gratitude to God who has enabled me to complete this work.

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# ABSTRACT

Plantation of *Eucalyptus* has been increasing worldwide for the multiple benefits including fast growth, massive biomass production and quick economic returns. However, plantation with *Eucalyptus* has created debate from ecological concerns such as loss of biodiversity and degradation of soil quality including loss of soil water and nutrients. The general aim of the research was to investigate the ecological effects of plantation with the introduced species *Eucalyptus* to improve understanding about the plantation, afforestation and management of sustainable forestry program by using this tree species in Bangladesh. Soil and plant materials were collected from different sites such as Tangail, Dinajpur and Dhaka where there were plantations of this species was done along with other tree species such as Acacia (*Acacia auriculiformis*), Jarul (*Lagerstroemia speciosa*) and teak (*Tectona grandis*). Soil was collected at different distance from the tree trunk and depths along the soil column in order to study the physical and chemical properties. At the Madhupur site where Eucalyptus plantation was done beside the plantation with Acacia, pH was significantly (P = 0.0399) affected by depth but not by plantation and their interactions. Electrical conductivity was significantly affected by plantation (P = 0.0001) but not by depth and their interactions. Total P (%) was significantly affected by both plantation (P = 0.0310) and depth (P = 0.0211) but not by their interactions. At the Dinajpur site where *Eucalyptus* plantation was done beside the plantation with Jarul. Moisture content (P = 0.0001) and organic carbon were significantly (P = 0.03) affected by plantation but not by depth and their interactions. Soil pH was significantly affected by both plantation (P = 0.0001) and depth (P = 0.0029) but not by their interactions. Total phosphorous was significantly affected by both plantation (P = 0.0015) and depth (P = 0.0241) but not by their interactions. N:P was significantly affected by only plantation

(P = 0.0494). At the Dr. Muhammad Shahidullah Hall Campus site where *Eucalyptus* plantation was done beside the plantation of teak, three-way ANOVA statistics showed that pH value was significantly affected by plantation (P = 0214), distance (P = 0.0001) and depth (P = 0.0103) but not by their interactions. Organic carbon content was significantly affected only by the interaction of distance and depth (P = 0.0457) but not by other factors such as plantation, distance and depth. Total P (%) (P = 0.0001) and N:P (P = 0.0047) were significantly affected only by plantation. Litter decomposition study conducted for 12 months showed that mass loss rate of Mahagony (*Swetenia mahogoni*) was significantly affected by litter type (P = 0.023) and time (P = 0.075) but not by their interactions. In case of teak, mass loss rate was significantly affected by time (P = 0.002) and between time and litter type (P = 0.017) but not by litter type. In case of Axonopus (*Axonopus compressus*), highly significant (P = 0.001) difference was found between time and litter type (P = 0.035) but not in their interactions. Soil N content was significantly (P = 0.000) affected only by time in teak and only by interaction between time and litter type (P = 0.019) in Mahogony. Litter type effects on N release was absent for each species. Overall, the results of the present study indicated that plantation with *Eucalyptus* might had potential influence in altering decomposition rate of an ecosystem through mixing of its litter with that of the other plant pecies.

# INTRODUCTION

## 1.1 Background

Plantation of *Eucalyptus* has been increasing worldwide for the multiple benefits including fast growth, massive biomass production and quick economic returns (Youngfang 1992). Over 13 million ha of area now are estimated to be under cultivation with *Eucalyptus* worldwide and the area is increasing (Davidson 1988). The general findings of studying environmental effects of *Eucalyptus* plantation is that although people have the perception that cultivation of this plant has negative effects they like to grow this plant for quick economic return (Poore and Fries 1987). Due to its nature of fast growth, various species of *Eucalyptus* have become one of the most popular throughout the world for plantation. However, since it requires more water and nutrients from soil due to its fast growing nature there have been concerns over the effects of *Eucalyptus* plantation on water and nutrient status and litter decomposition processes in soil.

Bangladesh is one of the most densely populated countries in the world with limited total land area and forest area. Increased population, rapid industrialization and urbanization have been creating pressure on the natural forest ecosystems. In order to meet the demand of timber and other forest products as well as to implement reforestation program, the Department of Forestry, Government of Bangladesh has introduced *Eucalyptus* as fast growing plant species. However, plantation with *Eucalyptus* has created debate

from ecological concerns such as loss of biodiversity and degradation of soil quality including loss of soil water and nutrients. Although this species has a great potential to be a wonderful timber species against rapid diminishing of forest there has been no substantial scientific data on the ecological effects of plantation of *Eucalyptus* in Bangladesh soil condition. Hossain *et al*. (2010) reported significant effects of plantation with exotic species on the Sal forest soils in Bangladesh. However, there is a lack of scientific investigation on the ecological effects of the plantation of *Eucalyptus*, although such information is relevant for the proper afforestation, plantation and management of the sustainable forestry program in Bangladesh.

*Eucalyptus* is the most popular plantation tree over the world because of their fast growth and high adaptation power. But plantation of *Eucalyptus* has created enormous concerns about its socio-economic and environmental impacts (Calder *et al*. 1997, Poore and Fries 1987). *Eucalyptus* was introduced in Bangladesh in early 19th century but systematic selection and growth trial was established only in mid1980's. *Eucalyptus camaldulensis, E. tereticornis* and *E. brassiana* were recommended for large scale plantation programs in Bangladesh by Bangladesh Forest Research Institute (BFRI). Though growing of *Eucalyptus* in Bangladesh is still a controversial and critical topic, plantations are increasing day by day. Individual people and farmers are planting *Eucalyptus* in their homesteads, marginal, wastelands and crop fields. It is very difficult to draw conclusion whether a plantation is good or bad for environment. But it depends on the selection of species, species-site

interactions, ecological interference, and end uses. The ecological success of a plant species in a specific environment depends on its abundance and use purpose. Though BFRI recommended *Eucalyptus* through elimination trial, provenance trial, and growth trial under different ecosystems of Bangladesh but more study is needed to understand the ecological impacts of plantation with *Eucalyptus*.

## 1.2Taxonomy and systematics of *Eucalyptus*

*Eucalyptus*, under the family Myrtaceae, is a genus that contains more than 600 species distributed throughout the world (Poore and Fries 1987).Members of the genus dominates the tree flora of Australia. Of these species, at least 40 have been widely grown outside their natural geographical origin. These are grown from the equatorial tropics through the sub-tropics to arid, Mediterranean and warm temperate climates, from sea level to about 4000 meters altitude in the Andes, and on a very wide range of sites and soils (Poore and Fries 1987). This feature of adaptability of this genus with a wide range of environmental conditions makes it difficult to generalize their feature. The high adaptation capability has made the species popular among people. *Eucalyptus* trees are the world's most widely planted hardwood species. Nearly all *Eucalyptus* are evergreen, but some tropical species lose their leaves at the end of the dry season. The leaves on a mature *Eucalyptus* plant are commonly lanceolate, petiolate, apparently alternate and waxy or glossy green and scented. The most readily recognizable characteristics of *Eucalyptus* species are the distinctive flowers and fruit (capsules or "gum nuts"). The flower petals

cohere to form a cap when the flower expands. The fruit is surrounded by a woody, cup-shaped receptacle. Fruit contains numerous minute seeds. Possibly the largest fruits—from 5 to 6 centimeters (2 to 2.5 inches) in diameter and found in *E. macrocarpa*, also known as the mottlecah, or silver leaf *Eucalyptus*. Several *Eucalyptus* species are among the tallest trees in the world. The growth rate and height of the *Eucalyptus* plant mostly depend on the soil properties of that area.

## 1.3 Distribution of *Eucalyptus*

There are approximately 600 species of *Eucalyptus*, 37 of these species are of interest for the forest industry while only 15 are used for commercial purpose. However, all species have great environmental values. Currently, *Eucalyptus* is planted over 90 countries of the world. For the first time, *Eucalyptus* started to planting outside its natural distribution over 200 years ago in Europe. European botanists described the genera and its main species. The first reference in the Iberia Peninsula dates from 1829 – in Portugal. The first *Eucalyptus* in Europe (*Eucalyptus obliqua*) was planted in the greenhouses of the Royal Botanic Gardens, Kew (Kew Gardens) in 1774 from seed donated by Captain Tobias Furneaux, whereas the first *Eucalyptus* (*Eucalyptus robusta*) to be planted outdoors was in the English Garden of the Royal Palace of Caserta (Italy) in 1792 by Johann Andreas Graefer, probably with seeds donated by Sir Joseph Banks. Deforestation and forestation is a continuous process though their rate is not same. Forest plantations covered 187 million ha in year 2000 of which Asia accounted for 62%, 124 million ha was in 1995 (FRA 2000). *Eucalyptus* is

most dominating plantation tree over the world. Globally 48% of the forest plantation estate is for industrial end-use and *Eucalyptus, Hevea, Acacia* and *Tectona* are considered as main genera of plantation in the tropical and sub-tropical area.

## 1.4 Uses of *Eucalyptus* species

### 1.4.1 Use of *Eucalyptus* as timber

*Eucalyptus* is prized for its straight tall grain, strength and stable qualities. *Eucalyptus* is used for all types of construction, fine as well as utilitarian, light and heavy. It is often made into flooring or objects (such as bowls) are created from *Eucalyptus* logs that have been hollowed out by termites. It is very easy to saw, sand, plane and polish. *Eucalyptus* timber takes paint very well. For this reason, it is often used for tongue-and-groove flooring. For all interior uses, such as decorate, cabinets and wood working and lacquer is the best finish for *Eucalyptus*. Lacquer dries fast, seals permanently and is easy to use. It is user friendly and resists runs, reddish and orange peel. The wood is heavy which should be taken into consideration when shaping it into furniture and others. Currently, the major market for *Eucalyptus* wood is the pulp and paper industry. The major product classes being newsprint from cold soda pulping or fine writing and photocopy paper from kraft pulping. In recent years, there has been increasing interest in using plantation. *Eucalyptus* timber is also used in producing sawn timber, veneers and reconstituted wood products. Breeding objectives have been developed from unbleached kraft pulp not for solid or reconstituted wood products. *Eucalyptus* has been acclaimed to have economic

and ecological benefits (Lemenih 2010, Kebebew and Ayele 2010, Bekele 2015). Farmers are continuing planting *Eucalyptus* converting their farm plots mainly its positive economic benefits (Mekonnen *et al.* 2007; Adimassu *et al.* 2010).

### 1.4.2 Industrial uses of *Eucalyptus*

Biomass is waste material from plants or animals that is not used for food or feed. Biomass contains stored chemical energy from the sun. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels. It is used in various industrial processes, such as energy production or raw materials for manufacturing chemicals (Ur-Rehman *et al.* 2015). The biomass of *Eucalyptus* is mainly used as fuel. It gives high amount of cellulose which is a fundamental raw material for the paper and cardboard industry. In steel industry, charcoal is used to control the quality of steel by improving the quality of pig iron. *Eucalyptus* is used as worldwide source of charcoal. Biomass production of a plant depends on the age and the variety of that plant. For example, Kamaljit *et al.* (2005) proved that biomass production is high at younger plantation of any plant rather than older plantations, and more than three times greater in older plantations of Dalbergia compared to *Eucalyptus* plantations.

### 1.4.3 *Eucalyptus* in soil improvement

*Eucalyptus* may also improve soil characteristics when planted on degraded or deforested site. Soil improvement may be caused by improving the structure of the surface soil, by penetrating relatively impermeable layers of sub soil and by drawing up nutrients from depth (Poore and Fries 1987). In the swampy areas, time to time *Eucalyptus* have been used to lower water tables, either to dry out the soil or to control mosquitos. It is frequently planted as shelter belts and provides some protection against wind erosion. *Eucalyptus* is also used to control surface run-off. The proportion of surface run-off from the *Eucalyptus* and Acacia was similar to that from the shola (sub-montane evergreen forest) (Chinnamani *et al.* (1965).

## 1.5 Ecological concerns of *Eucalyptus* plantation

Plantation of *Eucalyptus* has created enormous concerns about its socio-economic and environmental impacts (Calder *et al.* 1997, Poore and Fries 1987). Because of its rapid growth and wide range of conditions in which the various species can grow, the genus has been a popular choice for introduction especially in the warmer parts of the world. Plantation of this genus has been strongly criticized in some quarters because they are alleged to cause adverse effects on soil and hydrology.

Criticisms on *Eucalyptus* plantation are varied. It is said that *Eucalyptus* is poor habitat of birds because of their canopies and fruits type. *Eucalyptus* has high

demand of water, strong absorption of nutrients, desertification of the area, soil erosion and so on. Some of them would apply equally to any other plantation species; for example that monocultures are more prone than mixed forests to the depredations of pests and diseases. Yet other criticisms are common to all introduced or exotic species, that they are unpalatable to indigenous animals and introduce a discordant note in the landscape. According to the IUCN, the biggest threats to biodiversity are those related to human activity. Of those threats, introduced species are a significant cause of biodiversity loss. Introduced species, also referred to as "exotic species", include organisms that are brought to a region where they previously had never been found. Introduced species are often dangerous to native species because they have not evolved together and therefore compete for food and shelter. Introduced species may also compete with native species for resources, causing populations of the native species to decline (Dice 1945).

### 1.5.1 Soil moisture and nutrient uptake

The quality and the texture of soil depend on its moisture and nutrient content. Soil quality includes soil physical, chemical and biological properties, as well as soil processes and their interactions (Andrews and Carroll 2001). The presence and availability of nutrients in soil are directly dependent on its moisture content. On the other hand, these are the plant growth controller. Sufficient presence of these enhances the plant growth rate. It is normally accepted concept that plant with high yield rate absorbs much moisture and nutrient for its high growth. The high growth rates and biomass stocks of

plantation compared with previous vegetation types can also lead to higher demand for soil nutrients (Mendham *et al.*2003, Merino *et al.* 2004). Fast growing and short rotation tree plantations uptake high amounts of nutrients from the soil in comparison to slow-growing species (Dessie *et al.* 2011, Heilman *et al.* 1997). Chanie *et al.* (2013) found that *Eucalyptus* decreased both soil nutrients and crop (maize) yield up to 20 m away from the *Eucalyptus* trees. *Eucalyptus* trees also take up a great amount of water from the soil and this can affect water availability, competing with crops and other vegetation for water and depleting the water table (Dessie *et al.* 2011, Jagger *et al.* 2003, Palmberg 2002). Degradation of soil quality is a serious problem (Miao *et al.* 2012, Zhao *et al.* 2013). *Eucalyptus* is considered to consume higher water and nutrients and it has allelopathic effect on undergrowth vegetation (Nigatu and Michelsen 1993, Fikreyesus *et al.*2011, Chanie *et al.* 2013).

### 1.5.2 Effects on vegetation composition

By definition, biological diversity means "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (United Nations 1992). Bio-diversity is the asset of any country and it plays very important role in the ecological system of that geographical zone. The change in bio-diversity cause change in nature and ultimate consequences affect the surroundings. Habitat changes, exotic species, over exploitation, nutrition cycle are the main causes of the bio-diversity losses or vegetation change.

Vegetation plays a key role in soil development due to its influence on nutrient cycling, hydrological processes and soil erosion (de la Paix *et al.* 2013, Zhao *et al.* 2013). Degradation of soil quality is a serious problem (Miao *et al.* 2012, Zhao *et al.* 2013). Invasive alien species have been a major cause of extinction. Introduction of exotic species in the tropics has occurred extensively for commercial timber production through replacing local species with fast growing species, as well as for the perceived superior aesthetic value of certain plant varieties (Hossain and Pasha 2001, Bhagwat *et al.* 2012, Mukul *et al.* 2006). Such a practice has been evident since the colonial period and has rendered many native and unique ecosystem exposed to invasion by exotic species (Simberloff 2005, Underwood *et al.* 2004, Bhagwat *et al.* 2012). Other factors that have also influenced dissemination of exotics were their efficient dispersal capacities, large reproductive output, and greater tolerance to broad range of environmental conditions than local endemic species (Campbell 2005). Exotic species have also proved problematic for high conservation value areas due to their detrimental effects that can potentially threaten the persistence of native flora and fauna (Biswas *et al.* 2007, Stinson *et al.* 2006). Due to global environmental change, development processes, and ever-increasing population pressures, tropical forest ecosystems are now more vulnerable to anthropogenic pressures and influences than they have been in the past (Randall *et al.* 2008, Vila *et al.* 2011, Watt 1998). A better understanding of the processes that promote the establishment of exotic species, their mode of introduction, and their bio-geographic profile could be

useful for the control and management of exotic (and invasive) species in forest ecosystem as well as in high value conservation areas (Hierro *et al.* 2005, Hill *et al.* 2005, Leung *et al.* 2009, Sliva and Smith 2004).

Ahmed *et al.* (2007) reported that *Eucalyptus* plants of above 10-years old had the most adverse effect on the crop yield as it caused 15% reductions on an average under its canopy while plants within the age of 7-10 years and 5-7 years old causes yield reduction about 12% and 8% respectively in the existing agro-forestry system of Sitakunda upazila, Bangladesh, but in the same region *Eucalyptus* below 5 years old had insignificant or very little effect on the crop yield. It has been debated internationally whether the fast-growing *Eucalyptus* plantations cause local biodiversity to increase or decrease (IFS, 1989, Tang *et al.* 2007). The density of plants (no. of plants per hectare) in young *Dalbergia* plantations was double that of same age *Eucalyptus* plantations and more than four times that of old *Eucalyptus* plant (Kamaljit *et al.* 2005).

## 1.6 Litter decomposition and nutrient cycle

Nutrient cycle is one of the most important ecological key processes of an ecosystem. Nutrient cycle is the cycle of biological and chemical elements and compounds in specific patterns through substances in an ecosystem; the uptake, use, release and storage of nutrients by plants and their environments. Nutrient cycles in the nature include carbon cycle, nitrogen cycle, water cycle, sulfur cycle, phosphorus cycle and oxygen cycle. Nutrients, especially N and P, are cycled from forest trees to the surface soil and litter layer in combination with large amounts of photo-synthetically fixed carbon. These nutrients are then

made available again for uptake by the processes of decomposition and mineralization. These processes have a key role in regulating nutrient availability and hence the rate of forest growth (Attiwill *et al.* 1993). In many ecosystems, plant productivity depends largely on this recycling of nutrients, since the amount of essential nutrients entering an ecosystem each year is often low (Aber and Melillo 1991, Schlesinger 1997).

### 1.6.1 Role of litter quality in nutrient cycling

Litter quality defines how beneficial the litter is to the microbial community as an energy or nutrient source. Litter nutrient concentration (Millar *et al.* 1948, Merrill and Cowling 1966, Berg and Staaf 1980, Schlesinger and Hasey 1981, Gallardo and Merino 1993, Berg *et al.* 1996) and the concentration of carbon fractions (e.g., lignin) (Fogel and Cromack 1977, Meentemeyer 1978, Stohlgren 1988) have been identified as indicators of litter quality due to their influence on microbial activity and litter decay rates. The ratio between carbon (or carbon fractions) and nutrients is another measure of litter quality (Melillo *et al.* 1982).

Decomposition is one of the important factors of the terrestrial ecosystems that connect many aboveground and belowground processes. The decomposition of dead leaves and roots is one of the major pathways by which carbon (C) fixed during photosynthesis is returned to the atmosphere (Couteaux *et al.* 1995) and changed into soil organic matter (SOM). Plant detritus and SOM are the largest carbon pools in the terrestrial biosphere (Moore and Braswell 1994).

Understanding litter decomposition processes and the factors controlling litter decomposition is important for studying nutrient cycling.

### 1.6.2 Factors controlling litter decomposition rates

Litter decomposition plays role in global carbon cycle. It accounts for most of the heterotrophic soil respiration and results in formation of more stable soil organic carbon (SOC) which is the largest terrestrial carbon stock (Lal 2005). Litter decomposition is a key process in terrestrial ecosystems, releasing nutrients, returning $CO_2$ to the atmosphere, and contributing to the formation of humus. Litter decomposition is strongly controlled both by climate and by litter quality. Litter decomposition rates are a function of litter quality, biota and microclimate as well as edaphic properties (Heneghan *et al.* 1983).

In decreasing order of importance, the key factors regulating decomposition are commonly assumed to be climate, litter quality (e.g. N content, C/N ratio, lignin content etc) and decomposer communities (e.g. bacteria, fungi and soil macro- and micro fauna) (Meentemeyer 1984). Fungi and bacteria are the most common decomposers (Wardle 2002). Many studies (Couteaux *et al.* 1995, Aerts 1997, Moorhead *et al.* 1999, Gholz *et al.* 1995, Silver and Miya 2001) have concluded that the combination of climate (e.g. mean annual temperature, actual evapotranspiration, mean annual precipitation etc.) and litter quality (N content, C/N ratio, lignin content) are the primary factors controlling litter decomposition.

Decomposition is often inhibited during the dry season compared with the wet season in tropical seasonal forests (Swift and Anderson 1989, Swift *et al.* 1979). Lignin and holocellulose in the litter structure are major energy source available to decomposer organisms, constituting 70-80% of fresh organic matter (Swift *et al.* 1979). Plant species differ greatly in the decomposability of their litter (Cornelissen 1996, Grime *et al.* 1996). This decomposition process is largely influenced by the quality of its substrate, which in turn is determined mostly by its chemical composition (Wardle *et al.* 2003, Bardgett 2005). High levels of nitrogen and phosphorus enhance rates of microbial decomposition of litter and its mineralization (Enriquez *et al.* 1993) because such litter contains nutrients in quantities surplus to what microbes require. Lignin, decomposition products may form stable nitrogenous compounds making nitrogen less readily available to decomposer organisms (Berg 1988).In contrast, anti-herbivore chemicals such as phenolic compounds and tannins slow down the decomposition (Hättenschwiler and Gasser 2005, Hättenschwiler and Vitousec 2000) because they block the action of decomposing enzymes. Besides litter quality, the rate of decomposition is also affected by microbial communities (Hector *et al.* 2000). Orwin *et al.* (2006) showed experimentally that sources of carbon in the substrate and their diversity alter the structure of the soil bacterial community which in turn can influence litter decomposition rate.

Effects of litter chemistry on the temporal pattern of decomposition were also observed in some studies (Hossain and Sugiyama 2008) indicating that effects of litter quality on litter decomposition is related to time during the

decomposition process. Therefore, litter quality influences decomposition process not only through its direct effects as substrate quality but also through its indirect effects of changes in structure and function of decomposer community (Hector *et al.* 2000, Hossain *et al.* 2010). Effects of litter chemistry on the temporal pattern of decomposition were also observed in some studies (Hossain and Sugiyama 2008) indicating that effects of litter quality on litter decomposition is related to time during the decomposition process.

## 1.7 Plantation of *Eucalyptus* in Bangladesh

### 1.7.1 History of introduction of *Eucalyptus*

Bangladesh is one of the most densely populated countries in the world with limited total land area and forest area. Increased population, rapid industrialization and urbanization have created pressure on the natural forest ecosystem. In order to meet the demand of timber and other forest products as well as to implement reforestation program, the Department of Forestry, Government of the People's Republic of Bangladesh has introduced a number of fast growing plant species including *Eucalyptus* sp. (Kashem *et al.* 2015).

Forest plantation in Bangladesh started with teak (*Tectona grandis*) from 1871 and till to date it is the dominant species in plantation forests but the species is limited in the plantation forests of Forest Department and the Jothlands of Chittagong Hill Tract (CHT). To fulfill the huge demand of the forest produces, initiatives were taken in the late seventies to find out the fast growing plant species of exotic and indigenous ones. Acacia and *Eucalyptus* were the most

successful plants for providing biomass within a short period. Species elimination trial, provenance trial and growth trial of *Eucalyptus* species proved successful in wider range of research centers of Bangladesh Forest Research Institute (BFRI). However, the questions of large scale mono-culture of *Eucalyptus* became a concern among the researchers, policy makers, growers and environmentalists. Media played a significant role about negative environmental impacts of *Eucalyptus* in Bangladesh and the neighboring countries. Bangladesh Government took a decision of banning the species from further plantation programs without having strong scientific findings of the species. In some case, the established *Eucalyptus* plantations were also failed, but the farmer and individual growers are still planting the species; even *Eucalyptus* is becoming a dominant species in some districts such as Rangpur, Dinajpur, Nilphamari and Lalmonirhat. The people of northern part of Bangladesh, face a defective circle of poverty. They like to plant a fast growing species for quick returns. *Eucalyptus* in house-hold, cultivation field, road side is a common scenario there because of its short rotation, fast growth, free from grazing animals and required less space. *Eucalyptus* seeds are available at a low price. The species is significantly contributing in the wood products of the country and people prefer the species for its faster growth rather than environmental hazards.

### 1.7.2 Plantation of *Eucalyptus* in the forest areas

*Eucalyptus* is an important tree species for afforestation in tropical and subtropical regions and has been introduced to many countries around the

world. About 10% of the total forest land of Bangladesh is covered by tropical Sal forests. Until the beginning of the 20th century, dry and moist deciduous forests existed as a continuous belt from Cumilla to Darjeeling in Indian sub-continent. The present notified area of this forest is largely honeycombed with rice fields (FAO 1995). Champion *et al*. (1965) classified Sal forest as tropical moist deciduous forests. FAO (2000) divided Sal forest into two subtypes, pure Sal and mixed Sal, basis on the soil type and tree canopy. Sal (*Shorea robusta*) forest is a largest and threatened ecosystem in Bangladesh. The tropical moist deciduous Sal forest ecosystem of central Bangladesh is currently facing a critical situation. Destructive anthropogenic and natural impacts along with over exploitation of forest resources have caused severe damage to the forest ecosystem. Sal is usually harvested for the purposes of construction works, fuel wood, timbers, tannins, pillars, and furniture making. The Bangladesh government is trying to reforest the area with some fast growing exotic plants such as Akasmoni (*Acacia auriculiformis*) and *Eucalyptus* (*Eucalyptus camaldulensis*). The Madhupur Sal forest is an example; out of 18,623.48 ha, 3,157.89 ha were pass out for rubber cultivation (Gain 2005) and another 40,000 hectares of Sal forests were planned for woodlots and agroforestry plantations under the Forestry Sector Project. However, introduction of several exotic species in plantation forestry is one of the biggest threats to the biodiversity of natural Sal forest. Invasion of exotic plant species may cause major loss of biodiversity and species extinction either due to direct replacement by the exotics or indirect effects on the ecosystem. The Sal forests

have decreased drastically over the last forty years, due to new plantations with exotic species, which contempt the principles of silvicultural systems and the impacts of the invasive exotic species on the Sal forest ecosystem. The most extensively planted exotic species in Sal forest area are: *Acacia auriculiformis* (26.1%), *Eucalyptus camaldulensis* (24.6%) and *Acacia mangium* (18.7%). The remaining 30% of the area is occupied with all other species including Sal. Sal is the original climax species in these areas and represents only 12% of the plantation programs.

Although this genus has a great potential to be a wonderful timber species there has been no substantial data on the ecological effects of *Eucalyptus* plantation in the condition of Bangladesh. Limited studies are available on the ecological effects like soil moisture and nutrient status of plantation with *Eucalyptus*. Plantation with exotic species such as Acacia sp. and *Eucalyptus* sp. has been found to alter the properties of soil in the Sal forest of Bangladesh (Kashem *et al.* 2015, Hossain *et al.* 2010a).

### 1.7.3 Agroforesty with *Eucalyptus*

The interaction of agriculture and trees is defined as agroforestry. It includes the agricultural use of trees, trees on farms and in agricultural landscapes, farming in forests and along forest margins and tree-crop production. Interactions between trees and other components of agriculture may be important at a range of scales. The scales are fields where trees and crops are grown together, on farms where trees may provide fodder for livestock, fuel, food, shelter or income from products including timber and landscapes where

agricultural and forest land uses combine in determining the provision of ecosystem services. Agroforestry is good for agro-biodiversity and sustainability, and it provides good economic rate of return.

By the end of the nineteenth century, establishing forest or agricultural plantations had become an important objective for practicing agroforestry. *E. camaldulensis* has been planted in degraded areas as well as in the agroforestry programmes for the development of socio-economic condition of the rural people for a long time. Davidson and Das (1985) reported that *E. camaldulensis* proved superior in production of yield and biomass. Recent barrier on *Eucalyptus* plantation in Bangladesh is the outcome of media rather than on the basis of experimental results. Studies on the allelopathic effects of *Eucalyptus* is greatly controversial (Willis 1991).

It is found that less vegetation exists under *Eucalyptus* canopy than local trees (Luo 2005). Recent study showed that water, ethanol, or acetone extracts from *Eucalyptus urophylla* also have allelopathic effect on *Pisolithus tinctorius*, a common fungus in South China (Lin *et al.* 2003). Though many works are being done all over the world on allelopathy, it is very new in Bangladesh (Uddin *et al.* 2000, Hossain *et al.* 2002, Hoque *et al.* 2003). Traditional agriculture in the Northern part of Bangladesh is unsustainable, it keeps farmers in a vicious circle of poverty. Agroforestry is a promising alternative, which is considered as one of the very few options to elevate people out of the poverty cycle. Here, agroforestry protect the existing forest as well as improves environmental sustainability.

## 1.8 Challenges in studying ecological impacts of plantation

### 1.8.1 Time consuming experiment

*Eucalyptus* is a perennial timber plant. For its longer life span, study of total activities is very difficult and time consuming. This genus has a vast area of root system and different growth rate in different species. Long term study may influence by different external effects such as climate change, natural disaster and introduced flora and fauna.

### 1.8.2 Lack of comparable species

Finding out the effect of tree plantations on biodiversity is not possible. The size and direction of the effect, whether the plantation influences positive or negative changes in biodiversity, depends on the vegetation that is being replaced and on the location of the plantation within the landscape. Additionally, it is important to differentiate between the scales of biological diversity. There were no any specific plant species to compare the ecological effects of *Eucalyptus* as exotic. There was no any plant species of which total nutrient uptake information is determined and fixed. Each and every plant species has some ecological effects and these were depended on ecosystem of that area.

## 1.9 Objectives of the study

The main objective of the present study was to understand the ecological effects of *Eucalyptus* plantation. The specific objectives of the study were to

- examine whether *Eucalyptus* uptakes more water and nutrients than other plant species by collecting field data.
- find out the effects of *Eucalyptus* litter on the mass loss rate and nutrient (N) release of other plant species.

# MATERIALS AND METHODS

## 2.1 Effects of *Eucalyptus* plantation on soil properties

### 2.1.1 Description of the study sites

Three different sites located in three different geographical areas were selected for conducting this study in order to examine whether the effects of plantation vary with soil types. The sites were situated in the districts of Tangail, Dinajpur and Dhaka (Fig 2.1).

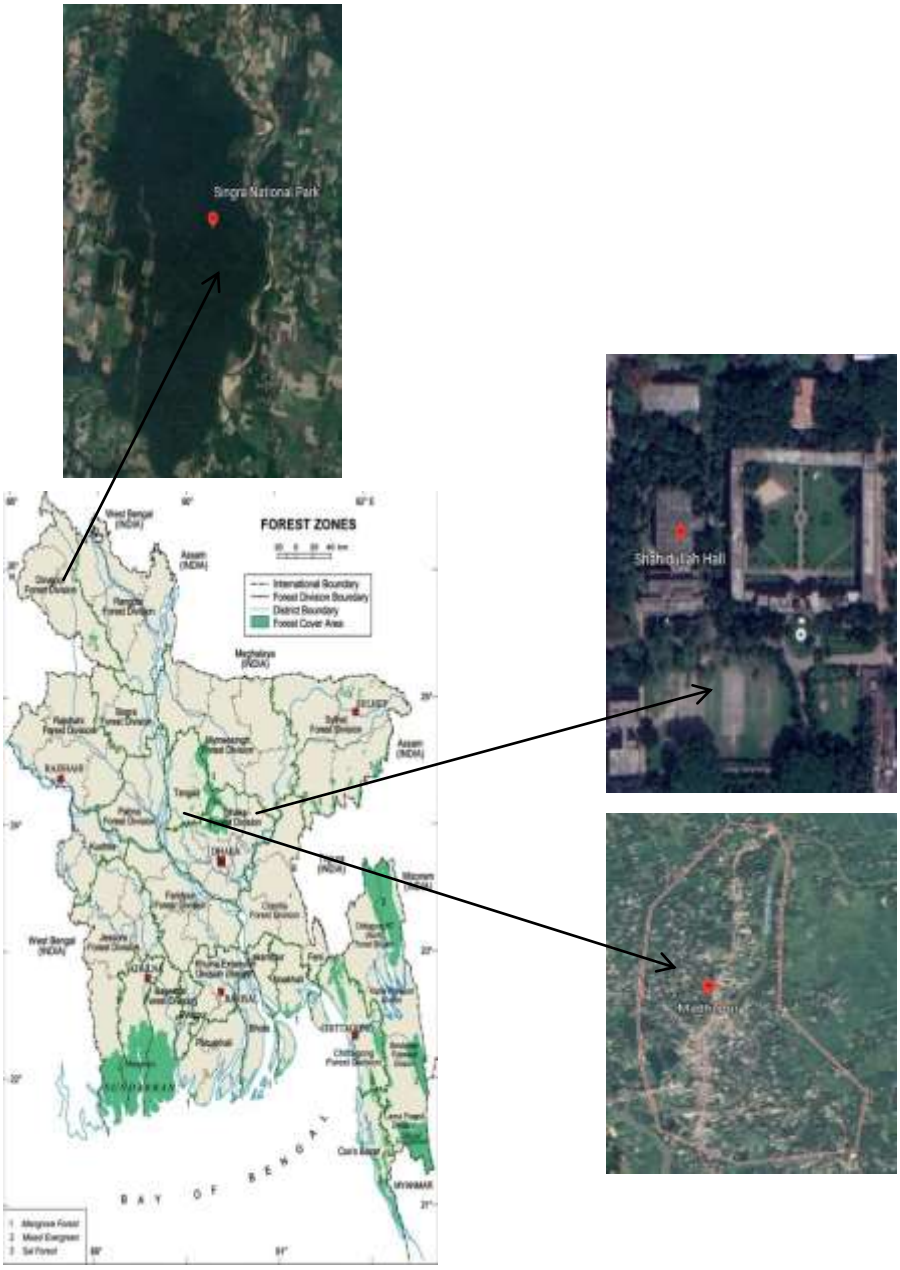


**Fig. 2.1.** Location of three study sites- Tangail site near Madhupur forest, Dinajpur site near Singra forest and Dhaka site at the Dr. Muhammad Shahidullah Hall play-ground, Dhaka University campus.

**Tangail site**

There are two kinds of Sal forests in Bangladesh: moist deciduous and dry deciduous. Moist deciduous are distributed in Madhupur, Tangail (Hossain *et al.* 2010b). Madhupur forest is commonly known as Sal (*S. robusta*) forest because the dominant plant of this forest is Sal. Though Sal is the dominant plant in this forest, mix-culture is also familiar in this area. Compared to other forests in Bangladesh, Sal forests are known as one of the richest ecosystems. Changes in land-use such as crop cultivation and plantation with introduced species *Eucalyptus* and Acacia in the Sal forest as part of the plantation program by the Government of Bangladesh have taken place over the decades (Hossain *et al.* 2010).

Madhupur forest area, Tangail experiences a tropical climate. In summer, there is high rainfall and much less in winter. The annual rainfall of the area is *ca.* 1800 mm. Nearly 90% of which (rainfall) occurs in the period of May through October. The average temperature in Tangail is $25.5^0$C. The district Tangail is situated between 24° 01′ and 24° 47′ north latitudes and between 89° 44′ and 90° 18′ east longitudes.

Site of *Eucalyptus* plantation in the Madhupur area, Tangail was selected in an area where plantation of *Eucalyptus* and Acacia was done in two plots situated side by side. Both of them are exotic and timber yielding plants. This site was near moist deciduous Sal forest and in between Sal forest and agricultural land.

From this site (Madhupur, Tangail), soil was collected from three different locations selected randomly at the distance of 10 m from each other along a transect. Then, soil was collected at the three different depths 0-10 cm, 10-20 cm and 20-30 cm in each location. Thus, a total of 18 soil samples (2 plantation x 3 depths x 3 replicates) were collected from this area (Fig. 2.2).

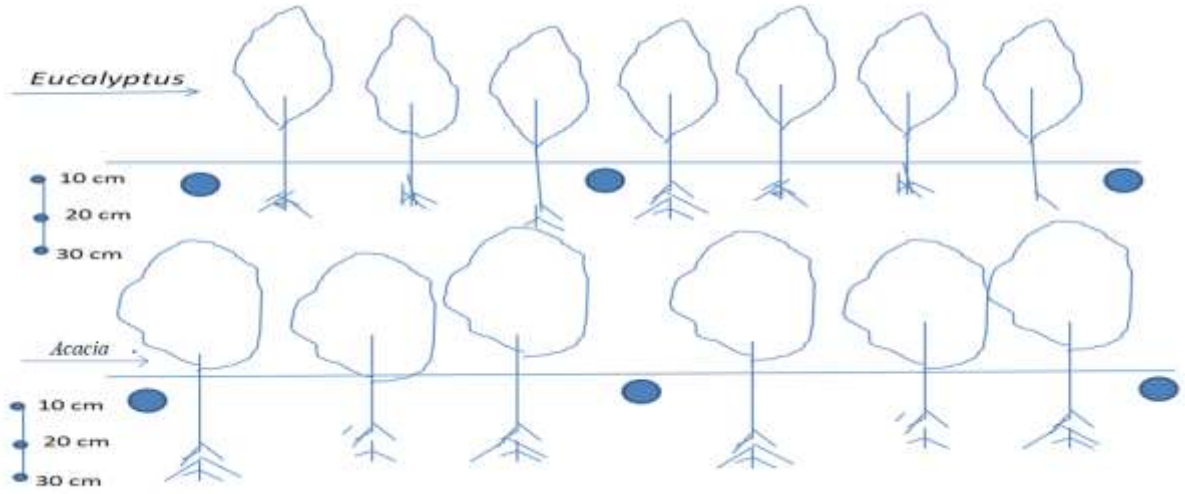


**Fig. 2.2.** Experimental design for soil collection from Tangail site.

**Dinajpur site**

This study site was situated near the Singra forest, Dinajpur. Dinajpur has a hot, wet and humid tropical climate. The average annual temperature of this area is $25^0$C, highest in August ($29^0$C) and lowest in January ($18^0$C). Annual rainfall of this area is 140.60 mm. The geographical location of this area is $25.63^0$N and $88.65^0$E.

Site of *Eucalyptus* plantation near the Singra forest, Dinajpur was selected in an area where plantation of *Eucalyptus* and Jarul (*Lagerstroemia speciosa*) was planted in two plots situated side by side. The plantation pattern was as like as Madhupur area (*Eucalyptus* and Acacia). Jarul is also a timber yielding plant cultivated in this area.

Soil was collected from three different locations selected randomly at the distance of 10 m from each other along a transact. Then, soil was collected at the three different depths 0-10 cm, 10-20 cm and 20-30 cm in each location. This design helped to clarify the effects of *Eucalyptus* plantation on the soil properties. Thus, a total of 18 soil samples (2 plantation x 3 depths x 3 replicates) were collected from this area.

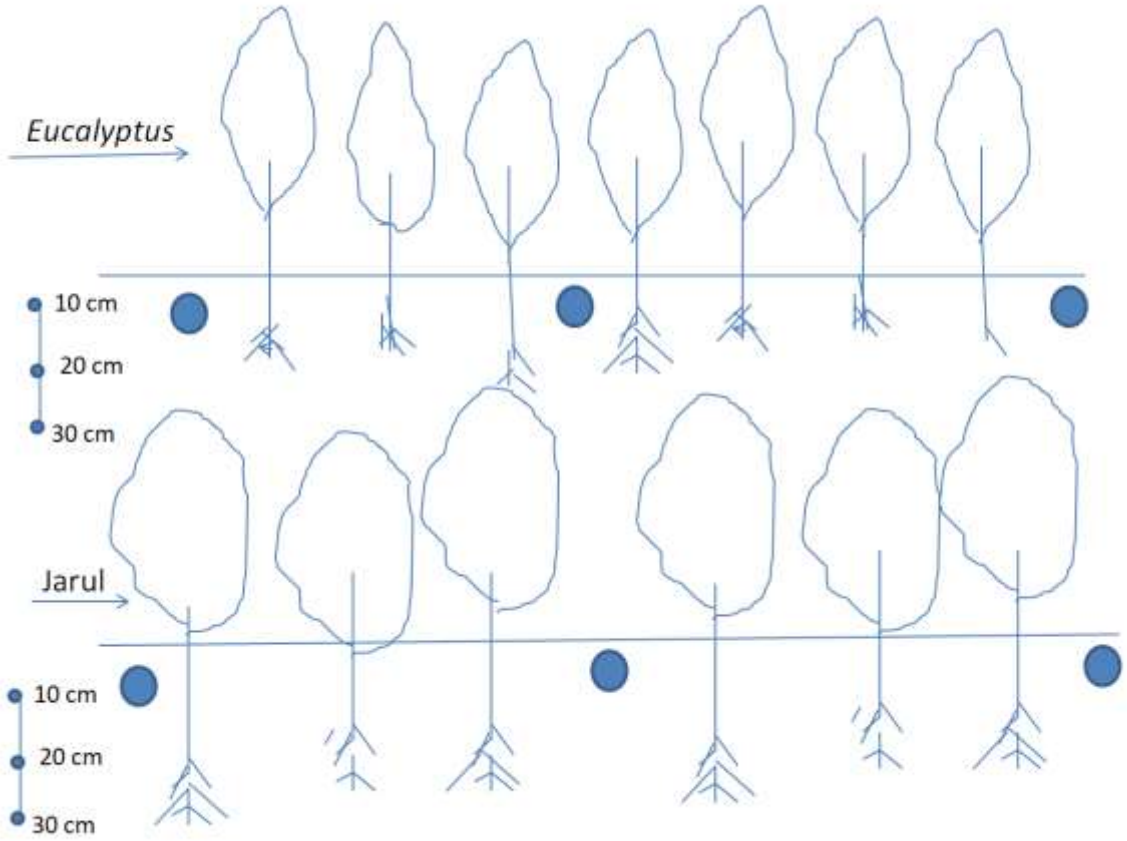


**Fig. 2.3.** Experimental design for soil collection from the Dinajpur site.

**Fig. 2.4(a).** Plantation with *Eucalyptus* in the rural areas of Bangladesh.

**Fig. 2.4(b).** Plantation with *Eucalyptus* in the rural areas of Bangladesh.

**Dhaka Site**

The geographical location of this study area is $23^0 42^{'}$ N and $90^0 24^{'}$ E. Dhaka experiences a tropical wet and dry climate. It has a distinct monsoonal season. The annual average temperature of this area is 25°C. In January, temperature becomes low and average temperature is 18°C. Temperature becomes high in August and this time average temperature is 18°C. During the monsoon season, around 80% of the annual average rainfall of 1,854 millimeters occurs which lasts from May until the end of September.

Site of *Eucalyptus* plantation in the Dhaka University campus was selected from the Dr. Muhammad Shahidullah Hall playground where *Eucalyptus* has been planted in a row where teak (*Tectona grandis*) was planted on the other side of the same row. This site was selected because plantation with both plant species was done in the same geographical area and same soil type. Both plantation experiences nearly same age and both are perennial timber yielding plants. Therefore, soil should be of similar properties and if there is any difference in soil moisture content and nutrients then that difference should be attributable to the effects of plantation.

The soil samples were collected at three different depths 0-10 cm, 10-20 cm and 20-30 cm at the distance of 1 ft, 3 m and 6 m from the base of the tree trunk. From each plantation, four plants about 10 ft away from each other, were selected as replicates to collect soil samples at different three horizontal

distances and three vertical depths. Thus, a total of 72 soil samples (2 plantation × 3 horizontal distance × 3 vertical depths × 4 plants) were collected from this field. This three-factorial experimental design helped to elucidate the effects of plantation, horizontal distance from the plant, vertical depth and their interactions on the soil moisture content and nutrients.

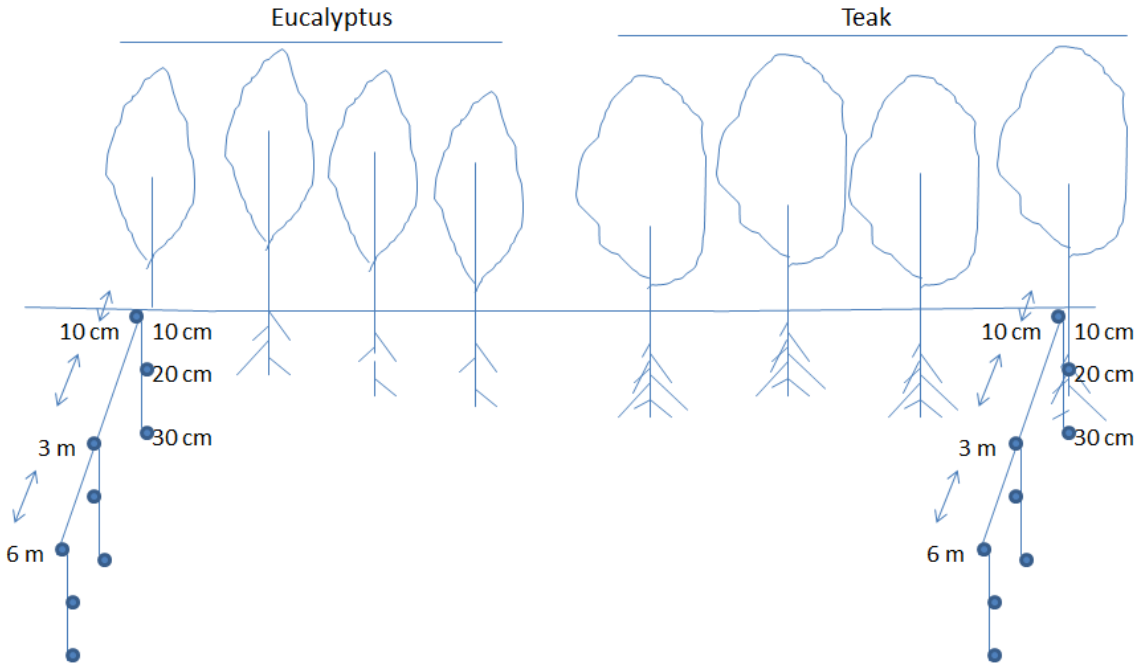


**Fig. 2.5.** Experimental design for soil collection from the Dr. Muhammad Shahidullah Hall playground, Dhaka University campus.

### 2.1.2 Soil sample collection

Soil samples were collected with the help of auger and then kept within the polythene bags immediately after collection. The bags were tighten properly to preserve the exact soil content and marked with a permanent marker carefully for avoiding any further hazard. Different soil properties such as soil moisture, soil pH, electrical conductivity, and nutrients (nitrogen, phosphorus, organic carbon) were measured as soon as possible.


**Fig.2.6.** Plantation with *Eucalyptus* (left side) and Teak (right side) (a), root base of *Eucalyptus* (b) and root base of Teak (c) in Dr. Muhammad Shahidullah Hall playground, Dhaka University campus.

### 2.1.3 Analysis of soil properties

**Determination of soil moisture content**

For the determination of soil moisture content, 10g fresh soil was taken into a cup made with aluminum foil and then kept in an oven at $105^0$C temperatures for 24 hours. Soil moisture content was determined by the following formula:

Soil moisture content (%) = $\frac{F-D}{D} \times 100$

Where, F= Weight of fresh soil

D= Weight of dry soil.

**Determination of soil pH**

Soil pH was recorded in the laboratory within 24 hours after collection from the field. Soil pH was determined in suspension with distilled water (1:2, w: v). 10 g soil was taken in a beaker and then 20 ml distilled water was added to make a suspension by shaking well. The suspension was kept for a while for settling down of the particles. The pH meter (Hanna pH meter, pHeP) was calibrated with known pH. Then, the pH values were recorded for each of the soil sample.

**Determination of soil electrical conductivity**

Soil conductivity was recorded in the laboratory within 24 hours after collection from the field. Soil electrical conductivity was determined in suspension with distilled water (1:5, w: v), however the value was expressed under the consideration of saturation extract. 10 g soil was taken in a beaker and then 50 ml distilled water was added to make a suspension by shaking well. The suspension was kept for a while for settling down of the particles. The conductivity meter was calibrated with known conductivity.

**Determination of soil organic carbon**

Organic carbon of the soil was determined by the method of Walkley and Black (1934). For the determination of soil organic carbon, 2.0 g soil which was passed through 2 mm sieve was weighted and transferred to a 500 ml clean dry conical flask. 10 ml of normal potassium dichromate solution was added. Then 10 ml conc. $H_2SO_4$ was added and mixed thoroughly. The flask was allowed to cool on a sheet of asbestos with occasional shaking for half an hour. After changing the color into green, an additional 10 ml $K_2Cr_2O_7$ was added. After half an hour when the flask was cool, approximately 150 ml distilled water, 10 ml phosphoric acid and 0.2 g of sodium fluoride was added. Then, 3 ml of diphenylamine indicator was added. The color of the solution was deep violet. The excess of chromic acid left in the flask was titrated with the help of normal ferrous sulfate solution. At the end point the color of the solution was

changed to deep bottle green. A blank experiment was done in the same way with all reagents except soil.

**Calculation:**

1000 ml of N $K_2Cr_2O_7$ = 3 g of C (eq. wt. of C = 12/4= 3).

Or, 1 ml of N $K_2Cr_2O_7$ solution = 0.003 g of C

$$\% \text{ of organic carbon (\% OC)} = \frac{(B-T)\times f \times 0.003 \times 100}{W}$$

Where,

B = Amount in ml of N $FeSO_4$ solution required in this experiment

T = Amount in ml of N $FeSO_4$ solution required in experiment with soil

f = Strength of N $FeSO_4$ solution (from blank experiment)

W = Weight of soil.

**Determination of soil available nitrogen**

Available nitrogen in soil was determined by following the Kjeldahl method (1883). For determination of available nitrogen, 5 g soil was taken in a 100 ml plastic bottle. 50 ml 1N KCl solution was added to it and shaken for 1 hour with a shaker SSeriker at 480 rpm and then it was left for 1 hour. Then the samples were filtered with Whatman filter paper. Then, 10 ml of extract was distilled with 10 ml of 10%NaOH using micro Kjeldahl distillation apparatus.

0.2 g Devarda's alloy was added into the funnel where sample and 10% NaOH were given. The distillate was collected in 10 ml 2% $H_3BO_3$ until the volume was about 50 ml. About 60 ml volume of distillate (ammonium borate) was collected in a 125 ml conical flask containing 10 ml of boric acid with mixed indicator. Then, the distillate was titrated against the standard $H_2SO_4$. The end point was indicated by pink color of the solution. A blank experiment was done simultaneously using all the chemicals except soil.

**Calculation:**

1000 ml 1N $H_2SO_4$ = 1000 ml normal nitrogen = 14 g nitrogen.

Or 1 ml of 1N $H_2SO_4$ = 0.014 g N

$$\% \text{ of available nitrogen} = \frac{(T-B)\times f\times .014\times 100\times 100}{W\times \text{volume of extract used}}$$

Where,

B = Amount in ml of N/100 $H_2SO_4$ required in titration of the blank experiment.

T = Amount in ml of N/100 $H_2SO_4$ required in titration of the experiment with soil.

f = Normality factor of N/100 $H_2SO_4$ (=0.0112 N).

W = Weight of soil.

**Determination of phosphorus content of soil**

Soil phosphorus was determined by Vanadomolybdophosphoric Yellow Color method as described by Jackson 1973. For the determination of soil phosphorus content, 1g finely powdered soil was taken in a beaker. 10 ml $HNO_3$ was added to it and dried. Then, 5 ml $HClO_4$ was added to it and dried again. Little amount of distilled water was added and filtrated. 4 ml of this solution was taken into a 25 ml volumetric flask. 5 ml coloring reagent was added and finally made volume up to 25 ml in volumetric flask with distilled water. A blank experiment was done simultaneously using all the chemicals except soil. 5 standard solutions were prepared by using all chemicals and phosphorus of known concentration 0, 0.5, 1.0, 1.5, 2.5 instead of soil. Absorbance was determined using a spectrophotometer at 440 nm. By using the absorbance of 5 concentrations standard curves was drawn and from this standard curve concentration of sample phosphorus was determined.

**Calculation:**

% P was calculated by using following formula:

$$\% \text{ P} = \frac{\text{ppm} \times 25 \times 50 \times 100}{\text{Vol. taken for color} \times \text{wt of soil} \times 10^6}$$

## 2.2 Effects of *Eucalyptus* litter on the decomposition and nutrient release of other plant species.

### 2.2.1 Leaf sample collection

Four plant species named *Eucalyptus* (*Eucalyptus camaldulensis*), *Axonopus* (*Axonopus compressus*), Mehogoni (*Swietenia mahagoni)*, and Teak (*Tectona grandis*) leaves were collected from Dr. Muhammad Shahidullah Hall play-ground, Dhaka University area. Leaves were fully expanded and fresh and matured. All leaves were kept in an oven at $60^0$C temperature for 24 hours. After drying, the leaves of each species were cut into 2 cm × 2 cm size for decomposition purpose except *Axonopus*, rest of the leaves were preserved for further chemical composition (total P %, total N %, phenolic compounds and Tannin) analysis.

### 2.2.2 Soil collection

Soil for the decomposition process was collected from the garden of Botany Department, University of Dhaka. This was done to kept the soil properties same to all types of leaf litter during decomposition process.

### 2.2.3 Leaf chemical analysis

**Determination of total nitrogen (%)**

Total nitrogen of leaf was determined by following the Kjeldahl method (Black 1965). For determination of total nitrogen, 0.2 g of finely powdered leaf was taken in a 500 ml clean Kjeldahl flask. 2 ml of distilled water was added to it and shaken and then it was left for 20 minutes. 10 ml of conc. $H_2SO_4$ was added to it and mixed thoroughly. The flask was heated over a low flame in a digestion chamber for 15 minutes. When white fumes of $H_2SO_4$ appeared, the flask was removed from the heater and 3 g of catalyst (digestion mixture) was added to raise the boiling temperature of $H_2SO_4$ digestion to accelerate the reaction. Then the flask was placed over the heater and temperature was raised. The digestion was kept for 4 hours till the liquid was clear. When the digestion was cold it was diluted with distilled water and finally made volume up to 100 ml in a volumetric flask with distilled water.

Then 10 ml of extract was distilled with 10 ml of 40% NaOH using micro Kjeldahl distillation apparatus with equal volume of NaOH. The distillate was collected in 10 ml 2% $H_3BO_3$ until the volume was about 50 ml.

About 60 ml volume of distillate (ammonium borate) was collected in a 125 ml conical flask containing 10 ml of boric acid with mixed indicator. Then the distillate was titrated against the standard $H_2SO_4$. The end point was indicated by pink color of the solution. A blank experiment was done simultaneously using all the chemicals except soil.

**Calculation:**

1000 ml 1N $H_2SO_4$ = 1000 ml normal nitrogen = 14 g nitrogen.

Or 1 ml of 1N $H_2SO_4$ = 0.014 g N

$$\% \text{ of total nitrogen} = \frac{(T-B)\times 0.014\times 50\times 100}{W\times \text{volume of extract used}}$$

Where,

B = Amount in ml of N/100 $H_2SO_4$ required in titration of the blank experiment.

T = Amount in ml of N/100 $H_2SO_4$ required in titration of the experiment with soil.

F = Normality factor of N/100 $H_2SO_4$ (=0.00915 N).

W = Weight of soil.

**Determination of total phosphorus (%)**

Phosphorus content was determined using colorimetric method with ammonium - molybdate - ascorbic acid as reagent. The leaves were cut into small pieces. 0.2 g leaf was taken in a 200 ml clean and dry Kjeldahl flask. Five ml $H_2SO_4$ was added to it. The flask was heated over a low flame in a digestion unit for 15 minutes. After 15 minutes, the flask was removed from the digestion unit and allowed to cool down. When the digestion was cooled, 2 ml of $H_2SO_4$ +$HClO_4$ (95:5 digest) was added to it. The flask was heated until the sample became colorless. The flask was removed from the heater and

allowed to cool down. After cooling the digestion, it was diluted with 20 ml water. The solution was filtered and transferred into a 50 ml volumetric flask and finally made volume up to 50 ml with distilled water.

An aliquot (0.5 ml digests) was transferred into 25 ml volumetric flask. Small amount of water was added. The pH of the sample was adjusted to 5.2 by adding indicator (5% NaOH) drop by drop. When the color was changed into yellow 0.1N $H_2SO_4$ was added drop by drop until the sample become colorless. Then 5 ml coloring reagent (ammonium - molybdate - ascorbic acid) was added. The flask was shaken and finally the volume was made up to 50 ml with distilled water.

A blank experiment was done simultaneously using all the chemicals except soil. 5 standard solutions were prepared by using all chemicals and phosphorus of known concentrations 0, 0.5, 1.0, 1.5 and 2.5 instead of soil. Absorbance was taken using a spectrophotometer at 440 nm. By using the absorbance of 5 concentrations, standard curve was drawn and from this standard curve concentration of sample phosphorus was determined. Three replicates were analyzed for the determination of phosphorus in each leaf litter type.

**Calculation:**

Percent of total phosphorous (P %) was calculated by using following formula-

$$\% \text{ P} = \frac{\text{ppm} \times 25 \times 50 \times 100}{\text{Vol. taken for color} \times \text{wt of soil} \times 10^6}$$

**Determination of phenolic compounds**

Phenolics were determined by following standard method (Graça and Bärlocher 2005). A stock solution was prepared with 25 mg tannic acid and 100 ml 70% acetone. This solution was used to make different 6 (six) tannic acid concentrated sample. 0ml, 0.2 ml, 0.4 ml, 0.6 ml, 0.8 ml and 1ml stock solution was taken in six Eppendrof tube along with 1 ml, 0.8 ml, 0.6 ml, 0.4 ml, 0.2 ml and 0 ml distilled water. 5 ml of 2% $Na_2CO_3$ in 0.1 N NaOH was added to each tube and mixed properly and kept for 5 minutes. Then, 0.5 ml of folin-ciocalteu reagent was added to it and mixed properly.

After two hours, absorbance was measured at 760 nm using a spectrophotometer. Tannic acid concentration was plotted against absorbance. A linear relationship was found by plotting the absorbance against tannic acid concentration.

0.1 g dry leaf from each sample was taken and grinded to powder using liquid nitrogen. Grinded leaf powder (Phenolic extract) was taken in 5 ml of 70% acetone and kept for 60 minutes at $4^0$C. Then, the extract was centrifuged at 13000 rpm for 15 minutes. 0.5 ml of the supernatant was taken and volume was made up to 1 ml with distilled water. 0.5 ml of the supernatant was taken and volume was made up to 1 ml with distilled water. Then, 5 ml 2% $NaCO_3$ in 0.1N NaOH added to it and mixed properly and kept for 5 minutes.

After 120 minutes, absorbance was measured at 760 nm using a spectrophotometer. Based on standard curve tannic acid equivalent per mg of

leaf powder was determined. Three replicates were analyzed for the determination of phenolics in each leaf litter type.

**Determination of tannin**

For the determination of tannin content, standard protocol was followed (Graça and Bärlocher 2005). Leaves were dried and grinded to powder which passes through a 0.5 mm mesh screen with liquid nitrogen. Then, 0.1 g powdered leaf was taken in a 50 ml Eppendorf tube and 5 ml extraction solution (50% methanol) was added. Tannins were extracted for 30 minutes at $4^0$C. 300 µl of sample was taken in a test tube by micropipette. 200 µl distilled water was added to adjust total volume to 500 µl. Then 7 ml solution 2 ($FeSO_4.7H_2O$ + HCl) was added to it and vortexed. A control experiment was done simultaneously using all the chemicals except leaf.

Absorbance was measured using a spectrophotometer at 550 nm. Tubes were placed in water bath at $95^0$C and incubated for exactly 50 minutes. Then the tubes were cooled at room temperature before measuring absorbance again at 550 nm. Absorbance was calculated due to the acid butanol reaction by subtracting the absorbance before heating from that after heating. Three replicates were analyzed for the determination of tannins in each leaf litter type.

## 2.3 Leaf litter decomposition and nutrient mineralization analysis

### 2.3.1 Experimental set up

Microcosm experimental design was followed to study litter decomposition rates (Hossain and Sugiyama 2008). At first, 0.5 kg garden soil are taken in a pot and then kept 1 g dry leaf for control and 0.5g dry leaf for mixed with Eucalyptus. The leaves were mixing well with soil using forceps. Then, the pot was covered with a polythene bag and kept for incubation in the growth room. Triplicate replications were used for each species. Water was added in such a way that all pot received similar moisture content. These leaves are collected from pot at four month interval and washed with distilled water and, dried and weighted. Decomposed soil samples were used to determine the release of nitrogen from litter into soil.

### 2.3.2 Determination of litter mass loss rate

On day after completion of 4 months, 8 months and 12 months during the period of incubation, the leaf litter that had not decomposed was collected destructively and rinsed thoroughly with distilled water to remove soil. Litter was then oven-dried for 24 h at $60^0$C. The mass loss rate was then calculated using the following formula and expressed as a percentage of initial mass before incubation:

$$\text{Mass loss rate (\%)} = \frac{W0 - Wt}{W0} \times 100$$

Where $W_0$ refers to dried leaf litter weight before incubation and $W_t$ refers to dried leaf litter weight after 4 months, 8 months and 12 months of incubation.


**Fig. 2.7(a).** Pots prepared as control for incubation for 4 months (a), 8 months (b) and 12 months (c).

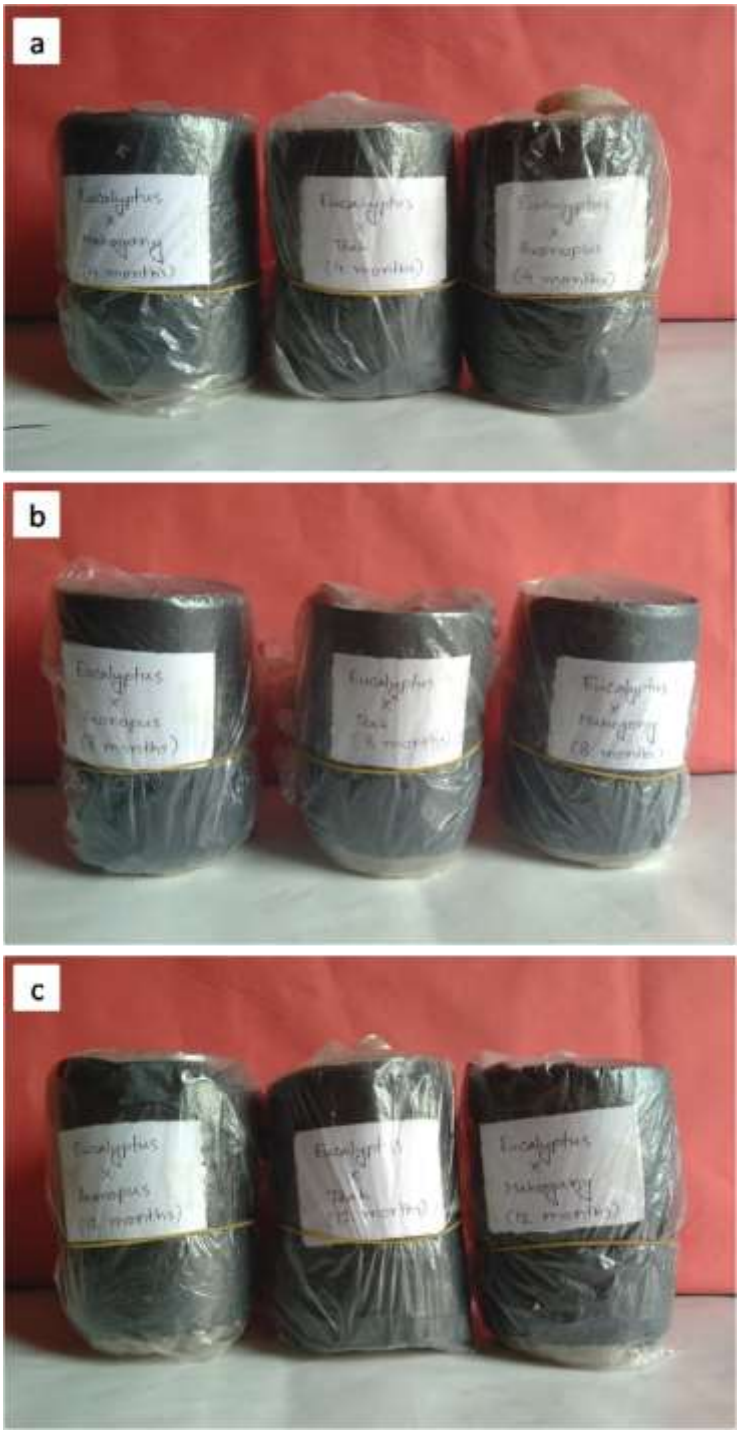


**Fig. 2.7(b).** Pots prepared for treatment before incubation for 4 months (a), 8 months (b) and 12 months (c).

### 2.3.3 Determination of mineralized nitrogen in soil

Soil nitrogen content after incubation was determined by following the Kjeldahl method (Black 1965). For determination of available nitrogen, 5 g soil was taken in a 100 ml plastic bottle. 50 ml 1N KCl solution was added to it and shaken for 1 hour with a shaker at 480 rpm and then it was left for 1 hour. Then the samples were filtered with Whatman filter paper. Then, 10 ml of extract was distilled with 10 ml of 10%NaOH using micro Kjeldahl distillation apparatus. 0.2 g Devarda's alloy was added into the funnel where sample and 10% NaOH were given. The distillate was collected in 10 ml 2% $H_3BO_3$ until the volume was about 50 ml. About 60 ml volume of distillate (ammonium borate) was collected in a 125 ml conical flask containing 10 ml of boric acid with mixed indicator. Then, the distillate was titrated against the standard $H_2SO_4$. The end point was indicated by pink color of the solution. A blank experiment was done simultaneously using all the chemicals except soil.

**Calculation:**

1000 ml 1N $H_2SO_4$ = 14 g nitrogen.

Or 1 ml of 1N $H_2SO_4$ = 0.014 g N

% of available nitrogen $= \frac{(T-B)\times f\times .014\times 100\times 100}{W\times \text{volume of extract used}}$

Where,

B = Amount in ml of N/100 $H_2SO_4$ required in titration of the blank experiment.

T = Amount in ml of N/100 $H_2SO_4$ required in titration of the experiment with soil.

f = Normality factor of N/100 $H_2SO_4$ (=0.0112 N).

W = Weight of soil.

# RESULTS

## 3.1. Effects of *Eucalyptus* plantation on soil properties

### Tangail site

Two-way ANOVA statistics on the effects of plantation, depth and their interactions on soil properties shown in Table 3.1.1.Soil moisture was not significantly affected by plantation, depth and their interactions. pH was significantly affected by depth (P = 0.0399) but not affected by plantation and their interactions. Electrical conductivity was affected by plantation (P = 0.0001) but not by depth and their interactions. Total phosphorous was significantly affected by both plantation (P = 0.0310) and depth (P = 0.0211) but not by their interactions. Organic C, available N and N:P ratio were not significantly affected by plantation, depth and their interactions.

**Table 3.1.1. Two-way ANOVA statistics on the effects of plantation, distance, depth and their interactions on the properties of soil collected from Tangail site**

| Soil properties | Source of variations | df | F ratio | P value |
|---|---|---|---|---|
| Moisture (%) | Plantation | 1 | 3.0276 | 0.1074 |
| | Depth | 2 | 0.2858 | 0.7564 |
| | Plantation × Depth | 2 | 0.4763 | 0.6323 |
| pH | Plantation | 1 | 0.1935 | 0.6678 |
| | Depth | 2 | 4.2634 | 0.0399 |
| | Plantation × Depth | 2 | 0.1452 | 0.8664 |
| Electrical | Plantation | 1 | 267.7825 | 0.0001 |
| Conductivity | Depth | 2 | 19.716 | 0.0483 |
| (µS/cm) | Plantation × Depth | 2 | 7.272 | 0.2719 |
| Available N (%) | Plantation | 1 | 2.4854 | 0.1409 |
| | Depth | 2 | 0.2354 | 0.7938 |
| | Plantation × Depth | 2 | 0.1481 | 0.8639 |
| Total P (%) | Plantation | 1 | 5.9701 | 0.0310 |
| | Depth | 2 | 5.4179 | 0.0211 |
| | Plantation × Depth | 2 | 1.9851 | 0.1800 |
| Organic C (%) | Plantation | 1 | 0.2426 | 0.6312 |
| | Depth | 2 | 0.4455 | 0.6507 |
| | Plantation × Depth | 2 | 0.1372 | 0.8732 |
| N:P | Plantation | 1 | 0.1511 | 0.7043 |
| | Depth | 2 | 1.0810 | 0.3701 |
| | Plantation × Depth | 2 | 0.6198 | 0.5544 |

Table 3.1.2 shows mean values of different soil physical and chemical properties such as moisture, pH, electrical conductivity, percent of organic carbon (% OC), percent of available N (%N), per cent of P (%), nitrogen-phosphorus ratio (N:P). The highest moisture content was found at 10 cm depth (15.63 ± 1.50%) and the lowest value was at 30 cm depth (12.85 ± 0.24%) in *Eucalyptus* plantation. For Acacia plantation, the highest moisture content was recorded at 30 cm depth (11.81 ± 2.53%) and at 10 cm depth (11.33 ± 1.85%) moisture content was lowest. The highest pH value was found at 30 cm depth (6.40 ± 0.10) and the lowest at 20 cm depth (5.77 ± 0.09) in *Eucalyptus* plantation. Highest pH value (6.23 ± 0.28) at 30 cm depth and lowest pH value at 20 cm depth (5.8 ± 0.21) ware recorded in Acacia plantation.

In *Eucalyptus* plantation, highest soil electrical conductivity (µS/cm) was recorded at 30 cm depth (157.65 ± 44.35) and lowest at 10 cm depth (126 ± 11.15). Highest conductivity (365 ± 33.8) at 20 cm depth and the lowest conductivity at 10 cm depth (244.35 ± 7.35) ware recorded in Acacia plantation. Highest percent of organic carbon (% OC) was found at 10 cm depth (0.32 ± 0.01%) and lowest at 20 cm depth (0.26 ± 0.04%) in *Eucalyptus* plantation. Highest per cent of OC (0.33 ± 0.27%) at 10 cm depth and lowest organic carbon at 30 cm depth (0.14 ± 0.08%) was recorded in Acacia plantation. In *Eucalyptus* plantation, highest percent of available nitrogen was recorded at 30 cm depth (0.016 ± 0.002%) and lowest at 20 cm depth (0.014 ± 0.004%). Highest percent of available nitrogen (0.0197 ± 0.001%) at 30 cm

depth and lowest was found at 10 cm depth (0.017 ± 0.005%) was recorded in Acacia plantation.

Highest value of phosphorus (%P) was found at 30 cm depth (0.0073 ± 0.0%) and lowest at both 10 cm and 20 cm depth (0.0057 ± 0.0%) in *Eucalyptus* plantation. Highest P (0.011 ± 0.002%) was recorded at 30 cm depth and lowest value (0.0053 ± 0.0015%) at 10 cm depth in Acacia plantation. Nitrogen phosphorus ratio (N:P) was recorded highest at 10 cm depth (2.67 ± 0.48) and lowest at 30 cm depth (2.31 ± 0.37) in *Eucalyptus* plantation. In Acacia plantation, highest N:P was found at 10 cm depth (4.21 ± 2.14) and lowest at 30 cm depth (1.9 ± 0.4).

**Table 3.1.2. Mean values with standard error mean of the physico-chemical properties of soil measured at different depths (10 cm, 20 cm and 30 cm) of *Eucalyptus* plantation and Acacia plantation at Tangail study site.**

| Soil properties | Replicates | Eucalyptus | Acacia |
|---|---|---|---|
| Moisture (%) | 10 | 15.63 ± 1.50 | 11.33 ± 1.85 |
| | 20 | 13.38 ± 0.62 | 11.38 ± 2.29 |
| | 30 | 12.85 ± 0.24 | 11.81 ± 2.53 |
| pH | 10 | 6 ± 0.10 | 5.93 ± 0.23 |
| | 20 | 5.77 ±0.09 | 5.8 ± 0.21 |
| | 30 | 6.4 ± 0.10 | 6.23 ± 0.28 |
| Electrical | 10 | 126 ± 11.15 | 244.35 ± 7.35 |
| conductivity | 20 | 151.85 ± 33.25 | 365 ± 33.8 |
| (µS/cm) | 30 | 157.65 ± 44.35 | 350 ± 27.05 |
| Organic C | 10 | 0.32 ± 0.01 | 0.33 ± 0.27 |
| (%) | 20 | 0.26 ± 0.04 | 0.23 ± 0.06 |
| | 30 | 0.27 ± 0.13 | 0.14 ± 0.08 |
| Available N | 10 | 0.015 ± 0.002 | 0.017 ± 0.005 |
| (%) | 20 | 0.014 ± 0.004 | 0.019 ± 0.001 |
| | 30 | 0.016 ± 0.002 | 0.0197 ± 0.001 |
| P (%) | 10 | 0.0057 ± 0.000 | 0.0053 ± 0.002 |
| | 20 | 0.0057 ± 0.000 | 0.009 ± 0.001 |
| | 30 | 0.0073 ± 0.000 | 0.011 ± 0.002 |
| N:P | 10 | 2.67 ± 0.48 | 4.21 ± 2.14 |
| | 20 | 2.46 ± 0.61 | 2.25 ± 0.27 |
| | 30 | 2.31 ± 0.37 | 1.9 ± 0.4 |

**Dinajpur site**

Table 3.1.3 shows Two-way ANOVA statistics on the effects of plantation, depth and their interactions of Dinajpur study site. Moisture content was significantly affected by both plantation (P = 0.0001) and their interactions (P = 0.0477). Organic carbon (P = 0.0268) was significantly affected by plantation but not affected by depth and their interactions. Soil pH was significantly affected by both plantation (P = 0.0001) and depth (P = 0.0029) but not by their interactions. Total phosphorus was significantly affected by both plantation (P = 0.0015) and depth (P = 0.0241) but not by their interactions. Nitrogen-phosphorus ratio (N:P) was significantly affected by only plantation (P = 0.0494). Electrical conductivity and available N were not affected by plantation, depth and their interactions.

**Table 3.1.3. Two-way ANOVA statistics on the effects of plantation, depth and their interactions on properties of soil collected from Dinajpur study site.**

| Soil properties | Source of variations | df | F ratio | P value |
|---|---|---|---|---|
| Moisture (%) | Plantation | 1 | 234.9589 | 0.0001 |
| | Depth | 2 | 1.7589 | 0.2138 |
| | Plantation × Depth | 2 | 3.9620 | 0.0477 |
| pH | Plantation | 1 | 32.6454 | 0.0001 |
| | Depth | 2 | 9.8804 | 0.0029 |
| | Plantation × Depth | 2 | 1.7491 | 0.2155 |
| Electrical | Plantation | 1 | 0.495 | 0.7584 |
| Conductivity | Depth | 2 | 10.336 | 0.1693 |
| (µS/cm) | Plantation × Depth | 2 | 3.988 | 0.4729 |
| Available N | Plantation | 1 | 0.2558 | 0.6222 |
| (%) | Depth | 2 | 0.6164 | 0.5561 |
| | Plantation × Depth | 2 | 0.1100 | 0.8967 |
| Total P (%) | Plantation | 1 | 16.6667 | 0.0015 |
| | Depth | 2 | 5.1667 | 0.0241 |
| | Plantation × Depth | 2 | 0.1667 | 0.8484 |
| Organic C (%) | Plantation | 1 | 6.3651 | 0.0268 |
| | Depth | 2 | 2.7540 | 0.1037 |
| | Plantation × Depth | 2 | 0.7294 | 0.5024 |
| N:P | Plantation | 1 | 4.7783 | 0.0494 |
| | Depth | 2 | 0.0851 | 0.9190 |
| | Plantation × Depth | 2 | 0.5717 | 0.5792 |

Mean values of soil properties such as moisture content, pH, soil electrical conductivity (µS/cm), percent of organic carbon, percent of available nitrogen, percent of phosphorus, nitrogen-phosphorus ratio at three different depths shown in table 3.1.4.

In case of *Eucalyptus* plantation, the highest moisture content was found at 10 cm depth (4.65 ± 0.37%) and the lowest at 30 cm depth (3.30 ± 0.98%). Moisture content was highest at 30 cm depth (20.82 ± 1.27%) and lowest at 20 cm depth (16.14 ± 0.62%) in Jarul plantation. Highest pH value was found at 30 cm depth (5.45 ± 0.13) and lowest at 20 cm depth (5.06 ± 0.08) in *Eucalyptus* plantation. Highest pH value (5.12 ± 0.11) at 30 cm depth and lowest pH value at 20 cm depth (4.62 ± 0.11) was recorded in Jarul plantation.

In *Eucalyptus* plantation, the highest soil electrical conductivity value was recorded at 10cm depth (844.15 ± 630.65) and the lowest at 30 cm depth (118 ± 14.35). Highest conductivity (565.65 ± 124.6) at 20 cm depth and the lowest conductivity at 30 cm depth (200.5 ± 30.45) ware recorded in Jarul plantation. Highest percent of organic carbon was found at 10 cm depth (0.40 ± 0.05) and lowest at 20 cm depth (0.32 ± 0.02%) in *Eucalyptus* plantation. Highest OC (0.52 ± 0.08%) at 10 cm depth and lowest OC at 30 cm depth (0.36 ± 0.02%) ware recorded in Jarul plantation. Highest percent of available N (0.0147 ± 0.004%) at 10 cm depth and the lowest at 30 cm depth (0.0130 ± 0.002%) was recorded in *Eucalyptus* plantation. In Jarul plantation, the highest value of available N was recorded at 10 cm depth (0.0150 ± 0.002%) and the lowest at

20 cm and 30 cm depth (0.0113 ± 0.0045%) and (0.0113 ± 0.001%), respectively.

Highest amount of phosphorus was found at 10 cm depth (0.0037 ± 0.000%) and the lowest at 30 cm depth (0.0027 ± 0.0%) in *Eucalyptus* plantation. Highest P (0.0047 ± 0.0%) was recorded at 10 cm, 20cm depth and the lowest (0.0037 ± 0.0%) at 30 cm depth in Jarul plantation.

The ratio between nitrogen and phosphorus (N:P) was recorded the highest at 20 cm depth (4.70 ± 0.78) and the lowest at 30 cm depth (3.86 ± 1.02) in *Eucalyptus* plantation. In Jarul plantation, highest N:P was found at 10 cm depth (3.38 ± 0.73) and lowest at 20 cm depth (2.60 ± 0.87).

**Table 3.1.4. Mean values with standard error mean of the physico-chemical properties of soil measured at different depths (10 cm, 20 cm and 30 cm) of *Eucalyptus* plantation and Jarul plantation at Dinajpur site.**

| Soil properties | Replicates | Eucalyptus | Jarul |
|---|---|---|---|
| Moisture (%) | 10 | 4.65 ± 0.37 | 16.64 ± 1.95 |
| | 20 | 3.92 ± 0.73 | 16.14 ± 0.62 |
| | 30 | 3.30 ± 0.98 | 20.82 ± 1.27 |
| pH | 10 | 5.06 ± 0.08 | 4.65 ± 0.05 |
| | 20 | 5.30 ± 0.12 | 4.62 ± 0.11 |
| | 30 | 5.45 ± 0.13 | 5.12 ± 0.11 |
| Electrical | 10 | 844.15 ± 630.65 | 565.65 ± 124.6 |
| conductivity | 20 | 169.5 ± 24.3 | 574 ± 155.5 |
| (µS/cm) | 30 | 118 ± 14.35 | 200.5 ± 30.45 |
| Organic C (%) | 10 | 0.40 ± 0.05 | 0.52 ± 0.08 |
| | 20 | 0.32 ± 0.02 | 0.47 ± 0.07 |
| | 30 | 0.33 ± 0.03 | 0.36 ± 0.02 |
| Available N (%) | 10 | 0.0147 ± 0.004 | 0.015 ± 0.002 |
| | 20 | 0.0133 ± 0.002 | 0.0113 ± 0.004 |
| | 30 | 0.0130 ± 0.002 | 0.0113 ± 0.001 |
| P (%) | 10 | 0.0037 ± 0.000 | 0.0047 ± 0.000 |
| | 20 | 0.0033 ± 0.000 | 0.0047 ± 0.000 |
| | 30 | 0.0027 ± 0.000 | 0.0037 ± 0.000 |
| N:P | 10 | 3.86 ± 1.02 | 3.38 ± 0.73 |
| | 20 | 4.70 ± 0.78 | 2.60 ± 0.87 |
| | 30 | 4.68 ± 0.70 | 3.14 ± 0.38 |

**Dhaka site**

Three-way ANOVA statistics on the effects of plantation, depth, distance and their interactions are shown in Table 3.1.5. pH was significantly affected by plantation (P = 0.0214), distance (P = 0.0001), and depth (P = 0.0103) but not by plantation versus depth, plantation versus distance and their interactions. Organic carbon was significantly affected only by the interaction of distance and depth (P = 0.0457) but not by plantation, depth, distance, plantation versus depth, plantation versus distance and their interactions. Total phosphorus was significantly affected by plantation (P = 0.0001), distance (P = 0.0227), and depth (P = 0.0095) but not by plantation versus depth, plantation versus distance and their interactions. Nitrogen-phosphorus ratio (P = 0.0047) was significantly affected only by plantation.

Moisture content, electrical conductivity, available N, and nitrogen versus phosphorus ratio (N:P) did not show any significant difference on the effects of plantation, depth, distance and their interactions.

**Table 3.1.5. Three-way ANOVA statistics on the effects of plantation, distance, depth and their interactions on soil moisture (%), pH, electrical conductivity, organic C, available N (%), P (%) and nitrogen versus phosphorus (N:P) ratio.**

| Soil properties | Source of variations | df | F ratio | P value |
|---|---|---|---|---|
| Moisture (%) | Plantation | 1 | 0.0058 | 0.9397 |
| | Distance | 2 | 0.9474 | 0.3941 |
| | Depth | 2 | 2.4336 | 0.0973 |
| | Plantation × Distance × Depth | 4 | 25.9936 | 1.7046 |
| | Plantation × Distance | 2 | 0.0173 | 0.9829 |
| | Distance × Depth | 4 | 0.2384 | 0.9154 |
| | Plantation × Depth | 2 | 0.7557 | 0.4746 |
| pH | Plantation | 1 | 5.6124 | 0.0214 |
| | Distance | 2 | 10.4502 | 0.0001 |
| | Depth | 2 | 4.9895 | 0.0103 |
| | Plantation × Distance × Depth | 4 | 0.6965 | 0.5977 |
| | Plantation × Distance | 2 | 1.8855 | 0.1616 |
| | Distance × Depth | 4 | 0.3932 | 0.8126 |
| | Plantation × Depth | 2 | 0.0960 | 0.9086 |
| Electrical conductivity (µS/cm) | Plantation | 1 | 0.05 | 0.9206 |
| | Distance | 2 | 5.7655 | 0.3233 |
| | Depth | 2 | 2.3615 | 0.6261 |
| | Plantation × Distance × Depth | 4 | 0.697 | 0.9669 |
| | Plantation × Distance | 2 | 9.411 | 0.1621 |
| | Distance × Depth | 4 | 0.6625 | 0.9698 |
| | Plantation × Depth | 2 | 0.3765 | 0.9276 |
| Organic C (%) | Plantation | 1 | 1.9325 | 0.1702 |
| | Distance | 2 | 1.9779 | 0.1483 |
| | Depth | 2 | 0.1256 | 0.8822 |
| | Plantation × Distance × Depth | 4 | 1.3814 | 0.2526 |
| | Plantation × Distance | 2 | 0.5327 | 0.5901 |
| | Distance × Depth | 4 | 2.6072 | 0.0457 |
| | Plantation × Depth | 2 | 0.8852 | 0.4185 |
| Available N (%) | Plantation | 1 | 2.9737 | 0.0903 |
| | Distance | 2 | 0.1025 | 0.9028 |
| | Depth | 2 | 0.3052 | 0.7382 |
| | Plantation × Distance × Depth | 4 | 0.5888 | 0.6721 |
| | Plantation × Distance | 2 | 0.0026 | 0.9974 |
| | Distance × Depth | 4 | 0.3587 | 0.8369 |
| | Plantation × Depth | 2 | 0.0342 | 0.9664 |
| P (%) | Plantation | 1 | 20.0643 | 0.0001 |
| | Distance | 2 | 4.0643 | 0.0227 |

| | | | | |
|---|---|---|---|---|
| | Depth | 2 | 5.0795 | 0.0095 |
| | Plantation × Distance × Depth | 4 | 0.4437 | 0.7764 |
| | Plantation × Distance | 2 | 0.8359 | 0.4390 |
| | Distance × Depth | 4 | 1.7204 | 0.1589 |
| | Plantation × Depth | 2 | 0.2673 | 0.7664 |
| N:P | Plantation | 1 | 8.6822 | 0.0047 |
| | Distance | 2 | 0.5050 | 0.6063 |
| | Depth | 2 | 1.3095 | 0.2784 |
| | Plantation × Distance × Depth | 4 | 0.3573 | 0.8379 |
| | Plantation × Distance | 2 | 0.2823 | 0.7551 |
| | Distance × Depth | 4 | 0.2254 | 0.9231 |
| | Plantation × Depth | 2 | 0.2090 | 0.8121 |

Mean values of soil moisture content (%), pH, soil electrical conductivity (µS/cm), organic carbon (%), available nitrogen (%), phosphorus (%) and N:P ratio from different distance (1 ft, 3 m, 6 m) and depth (10 cm, 20 cm, 30 cm) of two plantation (*Eucalyptus* and Teak) are shown in Table 3.1.6. Highest moisture content (6.77 ± 1.60%) was found at 30 cm depth, 6 m away from the base of the tree trunk under *Eucalyptus* plantation and the lowest moisture content was at 10 cm depth (3.47 ± 0.35%) from 1 ft away of teak plantation. For *Eucalyptus* plantation at 1 ft distance, highest moisture content was recorded at 10 cm depth (6.05 ± 1.78%) and the lowest at 30 cm depth (3.97 ± 0.83%). From 3 m distance of the base of the plant, highest moisture content was found at 30 cm depth (5.63 ± 1.09%) and the lowest at depth 20 cm (3.48 ± 0.72%). From 6 m distance of plant base, highest moisture content was recorded at 30 cm depth (6.77 ± 1.60%) and lowest at 10 cm depth (4.29 ± 0.78%). For teak plantation, from 1 ft distance, highest moisture content was found at 30 cm depth (6.47 ± 1.09%) and lowest at 10 cm depth (3.47 ± 0.35%), from 3 m distance highest moisture content was recorded at 30 cm depth (5.03 ± 0.61%) and lowest at 10 cm depth (4.17 ± 0.44%). From 6 m distance of plant base, highest moisture was at 30 cm depth (5.75 ± 1.54%) and lowest at 10 cm depth (4.85 ± 0.92%).

Among soil samples from three different distance and depth highest and lowest pH was recorded in teak plantation. Highest at 1 ft distance at 20 cm depth (6.30 ± 0.32) and lowest at 3 m distance at 10 cm depth (5.52 ± 0.48). For *Eucalyptus* plantation, at 1 ft distance, highest pH was found at 30 cm depth

(5.98 ± 0.34) and the lowest at 10 cm depth (5.75 ± 0.17). From 3 m distance of plant base, the highest pH was recorded at 20 cm depth (6.08 ± 0.38) and the lowest at depth 30 cm (5.78 ± 0.24). From 6 m distance of plantation base, highest pH was found at 20 cm depth (6.03 ± 0.22) and lowest at 10 cm depth (5.9 ± 0.19). For teak plantation, at 1 ft distance, highest pH was found at 20 cm depth (6.30 ± 0.32) and lowest at 10 cm depth (6.03 ± 0.35), from 3 m distance, highest pH was recorded at 30 cm depth (5.68 ± 0.28) and lowest at 10 cm depth (5.52 ± 0.48). At 6 m distance from plant base, the highest pH was recorded at 20 cm depth (6.22 ± 0.33) and the lowest at 30 cm depth (5.92 ± 0.29).

The highest soil electrical conductivity value (363.75 ± 28.3) was found at 1ft distance at 20 cm depth in teak plantation and the lowest conductivity was at 6 m distance at 20 cm depth (147.15 ± 19.45) under *Eucalyptus* plantation. For *Eucalyptus* plantation, at 1 ft distance, highest conductivity was recorded at 10 cm depth (329.15 ± 36.95) and lowest at 20 cm depth (225.25 ± 18.5). From 3 m distance from plant base, highest conductivity was found at 10 cm depth (265 ± 53.95) and lowest at the depth 30 cm (155.9 ± 3.95). At 6 m distance from plant base, highest conductivity was recorded at 10 cm depth (216.9 ± 39.8) and the lowest at 20 cm depth (147.15 ± 19.45). For teak plantation, at 1 ft distance, highest conductivity was found at 20 cm depth (363.75 ± 28.3) and lowest at 30 cm depth (343.65 ± 63.4), at 3 m distance highest conductivity was recorded at 10 cm depth (249.4 ± 58.55) and lowest at 30 cm depth (192.4 ± 34.8). From 6 m distance of plant base, highest electrical conductivity was

recorded at 10 cm depth (308.15 ± 53.75) and lowest at 20 cm depth (179.4 ± 20.25).

Highest amount of organic C (0.63 ± 0.075%) was found at 1 ft distance at 10 cm depth and lowest was at 3 m distance at 20 cm depth (0.15 ± 0.09%) under *Eucalyptus* plantation. Under *Eucalyptus* plantation, at 1 ft distance, highest organic carbon was recorded at 10 cm depth (0.63 ± 0.075%) and the lowest at 30 cm depth (0.45 ± 0.09%). At 3 m distance, highest organic carbon was found at 30 cm depth (0.53 ± 0.175%) and the lowest at depth 20 cm (0.15 ± 0.09%). At 6 m distance, highest organic carbon was recorded at 20 cm depth (0.62 ± 0.08%) and the lowest at 10 cm depth (0.37 ± 0.09%). For teak plantation at 1 ft distance, the highest organic C was recorded at 20 cm depth (0.72 ± 0.033%) and the lowest at 10 cm depth (0.51 ± 0.08%). At 3 m distance, highest organic carbon was found at 10 cm depth (0.57 ± 0.04%) and lowest at depth 20 cm (0.48 ± 0.08%). At 6 m distance, highest organic C was recorded at 20 cm depth (0.53 ± 0.04%) and lowest at 10 cm depth (0.42 ± 0.05%).

Highest available N (0.0143 ± 0.0049%) was found at 1 ft distance at 30 cm depth and the lowest was at 1 ft distance at 10 cm depth (0.0078 ± 0.001%) under *Eucalyptus* plantation. Under *Eucalyptus* plantation, at 1 ft distance, the highest available nitrogen was recorded at 20 cm depth (0.0128 ± 0.003%) and the lowest at 10 cm depth (0.0098 ± 0.003%). At 3 m distance, highest available N was found at 30 cm depth (0.0143 ± 0.0049%) and the lowest at depth 20 cm (0.0113 ± 0.0023%). At 6 m distance, the highest available N was

recorded at 10 cm depth (0.0128 ± 0.005%) and the lowest at 30 cm depth (0.0098 ± 0.0029%). Under teak plantation, at 1 ft distance, highest available nitrogen was recorded at 30 cm depth (0.0115 ± 0.004%) and lowest at 10 cm depth (0.0078 ± 0.001%). At 3 m distance, highest available nitrogen was found at 20 cm depth (0.0113 ± 0.002%) and lowest at depth 30 cm (0.007 ± 0.001%). At 6 m distance, highest available N was recorded at 30 cm depth (0.0115 ± 0.002%) and the lowest at 20 cm depth (0.008 ± 0.003%).

Highest amount of P (0.021 ± 0.002%) was found at 1ft distance at 10 cm depth and lowest was at 3 m distance at 20 cm depth (0.008 ± 0.001%) under *Eucalyptus* plantation. Under *Eucalyptus* plantation, at 1 ft distance, highest P was recorded at 10 cm depth (0.0133 ± 0.00085%) and lowest at 30 cm depth (0.0088 ± 0.001%). At 3 m distance, highest P was found at 10 cm depth (0.0118 ± 0.003%) and lowest at depth 30 cm (0.0083 ± 0.002%). At 6 m distance, highest phosphorus per cent was recorded at 10 cm depth (0.0128 ± 0.005%) and lowest at 20 cm depth (0.008 ± 0.001%). Under teak plantation at 1ft distance, highest P was recorded at 10 cm depth (0.021 ± 0.002%) and lowest at 30 cm depth (0.0135 ± 0.002%). At 3 m distance, highest P was found at 20 cm depth (0.0163 ± 0.003%) and lowest at depth 30 cm (0.012 ± 0.002%). At 6 m distance, highest P was recorded at 30 cm depth (0.0140 ± 0.005%) and lowest at 20 cm depth (0.0083 ± 0.001%).

Highest ratio between nitrogen and phosphorus (N:P) was at 3 m distance at 20 cm depth (1.99 ± 1.12) under *Eucalyptus* plantation and lowest was at 1ft distance at 10 cm depth (0.38 ± 0.06) under teak plantation. Under *Eucalyptus*

plantation, at 1 ft distance, highest nitrogen versus phosphorus ratio (N:P) was recorded at 20 cm depth (1.77 ± 0.77) and lowest at 10 cm depth (0.73 ± 0.21). At 3 m distance, highest N:P value was found at 20 cm depth (1.99 ± 1.12) and lowest at depth 10 cm (1.12 ± 0.27). At 6 m distance, highest N:P value was recorded at 10 cm depth (1.49 ± 0.59) and lowest at 20 cm depth (1.36 ± 0.45). Under teak plantation, at 1 ft distance, highest N:P value was recorded at 30 cm depth (0.9 ± 0.30) and lowest at 10 cm depth (0.38 ± 0.06). At 3 m distance, highest N:P value was found at 20 cm depth (0.9 ± 0.28) and lowest at depth 30 cm (0.68 ± 0.24). At 6 m distance, highest N:P value was recorded at 30 cm depth (1.07 ± 0.28) and the lowest at 10 cm depth (0.76 ± 0.16).

**Table 3.1.6. Mean values with standard error mean of the physico-chemical properties of soil measured at different distance (1 ft, 3 m, 6 m) and depths (0-10 cm, 10-20 cm and 20-30 cm ) under *Eucalyptus* and teak plantation at Dr. Muhammad Shahidullah Hall play-ground, Dhaka University, Dhaka.**

| Soil properties | Distance | depth (cm) | Eucalyptus | Teak |
|---|---|---|---|---|
| Moisture (%) | 1ft | 10 | 6.05 ± 1.78 | 3.47 ± 0.35 |
| | | 20 | 4.25 ± 0.49 | 4.7 ± 0.68 |
| | | 30 | 3.97 ± 0.83 | 6.47 ± 1.09 |
| | 3m | 10 | 4.39 ± 0.64 | 4.17 ± 0.44 |
| | | 20 | 3.48 ± 0.72 | 4.15 ± 0.20 |
| | | 30 | 5.63 ± 1.09 | 5.03 ± 0.61 |
| | 6m | 10 | 4.29 ± 0.78 | 4.85 ± 0.92 |
| | | 20 | 4.96 ± 1.39 | 5.19 ± 0.50 |
| | | 30 | 6.77 ± 1.60 | 5.75 ± 1.54 |
| pH | 1ft | 10 | 5.75 ± 0.17 | 6.03 ± 0.35 |
| | | 20 | 5.9 ± 0.20 | 6.30 ± 0.32 |
| | | 30 | 5.98 ± 0.34 | 6.23 ± 0.34 |
| | 3m | 10 | 6.03 ± 0.35 | 5.52 ± 0.48 |
| | | 20 | 6.08 ± 0.38 | 5.63 ± 0.27 |
| | | 30 | 5.78 ± 0.24 | 5.68 ± 0.28 |
| | 6m | 10 | 5.9 ± 0.19 | 5.94 ± 0.22 |
| | | 20 | 6.03 ± 0.22 | 6.22 ± 0.33 |
| | | 30 | 5.9 ± 0.25 | 5.92 ± 0.29 |
| Electrical Conductivity (µS/cm) | 1ft | 10 | 329.15 ± 36.95 | 362.65 ± 55.8 |
| | | 20 | 225.25 ± 18.5 | 363.75 ± 28.3 |
| | | 30 | 227.9 ± 55.55 | 343.65 ± 63.4 |
| | 3m | 10 | 265 ± 53.95 | 249.4 ± 58.55 |
| | | 20 | 217.9 ± 34.95 | 195.9 ± 44.05 |
| | | 30 | 155.9 ± 3.95 | 192.4 ± 34.8 |
| | 6m | 10 | 216.9 ± 39.8 | 308.15 ± 53.75 |
| | | 20 | 147.15 ± 19.45 | 179.4 ± 20.25 |
| | | 30 | 189 ± 56.55 | 210.5 ± 35.85 |
| Organic C (%) | 1ft | 10 | 0.63 ± 0.075 | 0.51 ± 0.08 |
| | | 20 | 0.5 ± 0.28 | 0.72 ± 0.033 |
| | | 30 | 0.45 ± 0.09 | 0.53 ± 0.06 |
| | 3m | 10 | 0.48 ± 0.11 | 0.57 ± 0.04 |
| | | 20 | 0.15 ± 0.09 | 0.48 ± 0.08 |
| | | 30 | 0.53 ± 0.17 | 0.49 ± 0.03 |
| | 6m | 10 | 0.37 ± 0.09 | 0.42 ± 0.05 |
| | | 20 | 0.62 ± 0.08 | 0.53 ± 0.04 |
| | | 30 | 0.39 ± 0.06 | 0.46 ± 0.04 |
| N (%) | 1ft | 10 | 0.0098 ± 0.003 | 0.0078 ± 0.001 |

| | | | | |
|---|---|---|---|---|
| | | 20 | 0.0128 ± 0.003 | 0.0083 ± 0.003 |
| | | 30 | 0.0120 ± 0.002 | 0.0115 ± 0.004 |
| | 3m | 10 | 0.0118 ± 0.004 | 0.0113 ± 0.001 |
| | | 20 | 0.0113 ± 0.0023 | 0.0113 ± 0.002 |
| | | 30 | 0.0143 ± 0.0049 | 0.0070 ± 0.001 |
| | 6m | 10 | 0.0128 ± 0.005 | 0.0088 ± 0.001 |
| | | 20 | 0.0103 ± 0.0027 | 0.0080 ± 0.003 |
| | | 30 | 0.0098 ± 0.0029 | 0.0115 ± 0.002 |
| P (%) | 1ft | 10 | 0.0133 ±0.00085 | 0.021 ± 0.002 |
| | | 20 | 0.0098 ± 0.002 | 0.0143 ± 0.002 |
| | | 30 | 0.0088 ± 0.001 | 0.0135 ± 0.002 |
| | 3m | 10 | 0.0118 ± 0.003 | 0.0163 ± 0.003 |
| | | 20 | 0.0088 ± 0.002 | 0.0140 ± 0.001 |
| | | 30 | 0.0083 ± 0.002 | 0.0120 ± 0.002 |
| | 6m | 10 | 0.0093 ± 0.000 | 0.0120 ± 0.002 |
| | | 20 | 0.0080 ± 0.001 | 0.0083 ± 0.001 |
| | | 30 | 0.0090 ± 0.001 | 0.014 ± 0.005 |
| | 1ft | 10 | 0.73 ± 0.21 | 0.38 ± 0.06 |
| N:P | | 20 | 1.77 ± 0.77 | 0.67 ± 0.25 |
| | | 30 | 1.34 ± 0.31 | 0.90 ± 0.30 |
| | 3m | 10 | 1.12 ± 0.27 | 0.75 ± 0.14 |
| | | 20 | 1.99 ± 1.12 | 0.9 ± 0.28 |
| | | 30 | 1.88 ± 0.75 | 0.68 ± 0.24 |
| | 6m | 10 | 1.49 ± 0.59 | 0.76 ± 0.16 |
| | | 20 | 1.36 ± 0.45 | 1.03 ± 0.35 |
| | | 30 | 1.44 ± 0.63 | 1.07 ± 0.28 |

## 3.2 Effects of *Eucalyptus* litter on the decomposition and nutrient release

Two-way ANOVA statistics on the effects of time, litter and their interactions on the mass loss rate and nitrogen release in soil are shown in Table 3.2.1. Mass loss rate of Mahagony was significantly affected by litter (P = 0.023) and time (P = 0.075) but not by their interactions. In case of teak, mass loss rate was significantly affected by time (P = 0.002) and time versus litter interactions (P = 0.017) but not by litter. In case of Mahagony, highly significant effects was found by time (P = 0.001) and litter (P = 0.035) but not by their interactions.

Soil N content was significantly affected by time (P = 0.000) only in teak and by only time versus litter interactions (P = 0.019) in Mahogony. Litter effect was absent for each species.

**Table 3.2.1. Two-way ANOVA statistics on the effects of time, litter and time versus litter interaction on the mass loss rate (%) and nitrogen content in soil (n=3).**

| Species | Source of variation | Mass loss rate (%) | | | N content | | |
|---|---|---|---|---|---|---|---|
| | | df | F ratio | P value | df | F ratio | P value |
| *Axonopus* | Treatment | 1 | 6.735 | 0.023 | 1 | 0.186 | 0.674 |
| | Time | 2 | 3.234 | 0.075 | 2 | 0.663 | 0.533 |
| | Treatment × Time | 2 | 1.277 | 0.314 | 2 | 0.208 | 0.815 |
| Teak | Treatment | 1 | 3.659 | 0.080 | 1 | 0.536 | 0.478 |
| | Time | 2 | 10.3871 | 0.002 | 2 | 16.481 | 0.0001 |
| | Treatment × Time | 2 | 5.797 | 0.017 | 2 | 0.733 | 0.501 |
| Mahagony | Treatment | 1 | 5.396 | 0.035 | 1 | 0.156 | 0.699 |
| | Time | 2 | 11.534 | 0.001 | 2 | 3.824 | 0.052 |
| | Treatment × Time | 2 | 0.898 | 0.428 | 2 | 5.644 | 0.019 |

The result of Two-way ANOVA statistics on the effects of litter species, incubation time and their interaction on the N content and mass loss rate (%) of leaf litter are shown in Table 3.2.2. Mass loss rate was significantly affected by litter species ($F = 20.20$, $P = 0.0001$), incubation time ($F = 23.50$, $P = 0.0001$) and their interaction ($F = 3.63$, $P = 0.0009$). N content in soil was significantly affected by only incubation time ($F = 5.58$, $P = 0.0071$) but not by litter species ($F = 0.14$, $P = 0.99$) and time versus litter species ($F = 1.26$, $P = 0.28$).

**Table 3.2.2. Two-way ANOVA statistics on the effects of litter species, incubation time and their interaction on the N soil content and mass loss rate of litter (n=3).**

| Sources of variations | Mass loss rate | | Soil N content | |
|---|---|---|---|---|
| | F ratio | P value | F ratio | P value |
| Litter spp. | 20.20 | 0.0001 | 0.14 | 0.99 |
| Time | 23.50 | 0.0001 | 5.58 | 0.0071 |
| Litter spp.× Time | 3.63 | 0.0009 | 1.26 | 0.28 |

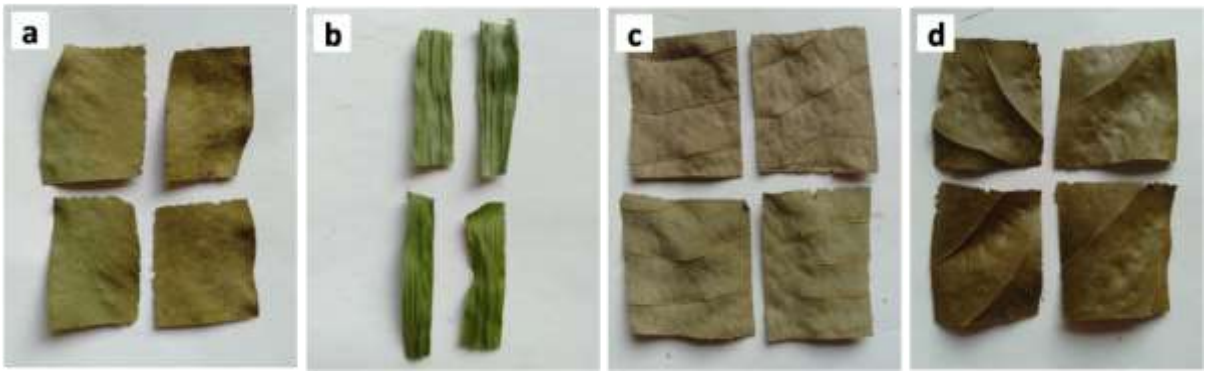


**Fig. 3.1(a).** Leaf litter of *Eucalyptus camaldulensis* (a), *Axonopus compressus* (b), *Tectona grandis* (c) and *Swietenia mahagoni* (d) before incubation.

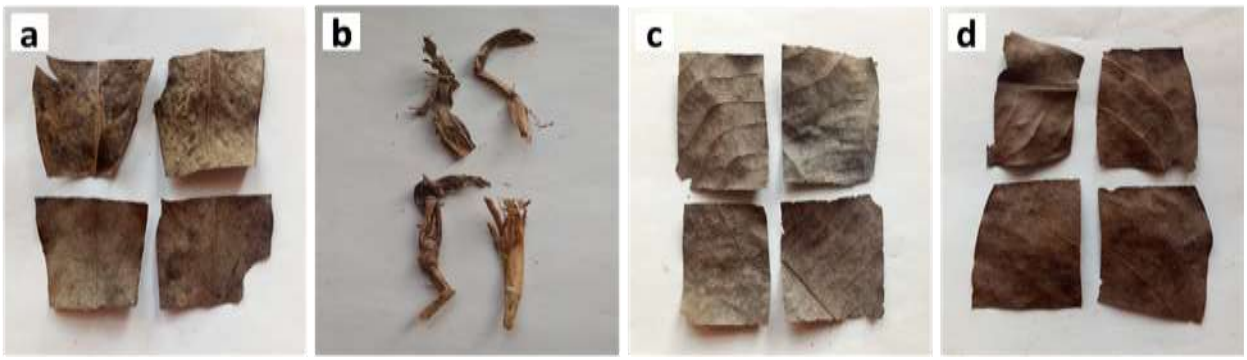


**Fig. 3.1(b).** Leaf litter of *Eucalyptus camaldulensis* (a), *Axonopus compressus* (b), *Tectona grandis* (c) and *Swietenia mahagoni* (d) after 4 months of incubation.


**Fig. 3.1(c).** Leaf litter of *Eucalyptus camaldulensis* (a), *Axonopus compressus* (b), *Tectona grandis* (c) and *Swietenia mahagoni* (d) after 8 months of incubation.


**Fig. 3.1(d).** Leaf litter of *Eucalyptus camaldulensis* (a), *Axonopus compressus* (b), *Tectona grandis* (c) and *Swietenia mahagoni* (d) after 12 months of incubation.

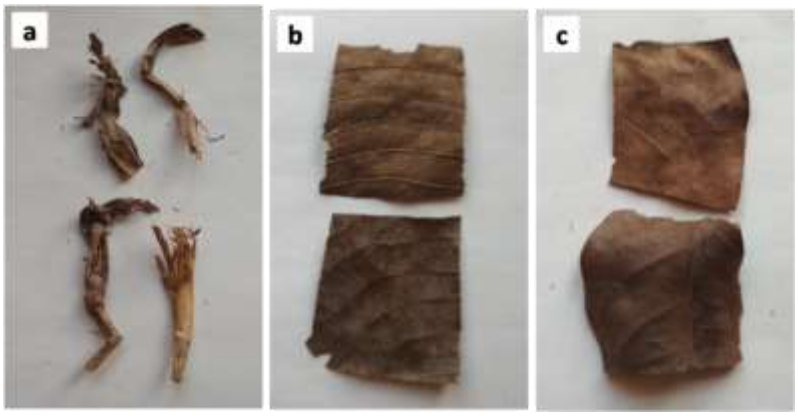


**Fig. 3.2(a).** Leaf litter of *Axonopus compressus* (a), *Tectona grandis* (b) and *Swietenia mahagoni* (c) after 4 months of incubation with *Eucalyptus camaldulensis*.

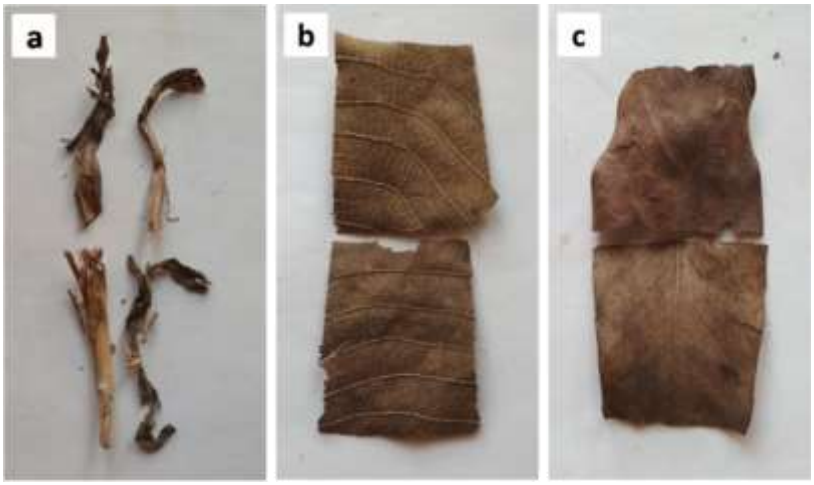


**Fig. 3.2(b).** Leaf litter of *Axonopus compressus* (a), *Tectona grandis* (b) and *Swietenia mahagoni* (c) after 8 months of incubation with *Eucalyptus camaldulensis*.

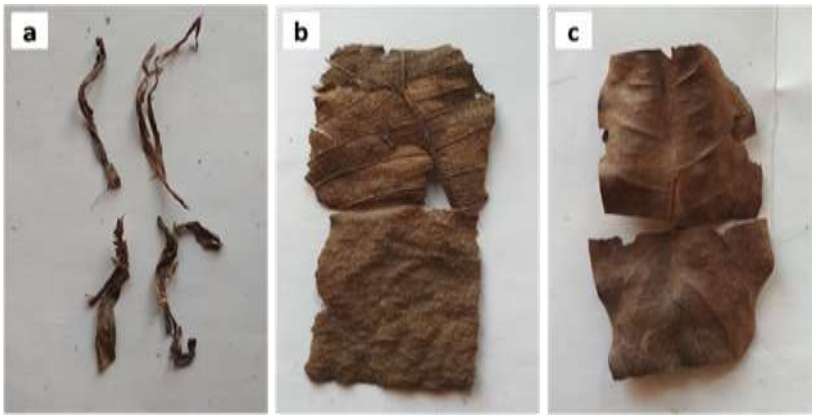


**Fig. 3.2(c).** Leaf litter of *Axonopus compressus* (a), *Tectona grandis* (b) and *Swietenia mahagoni* (c) after 12 months of incubation with *Eucalyptus camaldulensis*.

Table 3.2.3 shows the mean values of mass loss rate of four different species and the soil N content at four month interval and it was found that mass loss rate was highest in *Axonopus* and lowest in Mahagony across all measurement times. Mass of the *Axonopus* leaf litter, teak leaf litter, Mahogany leaf litter and *Eucalyptus* leaf litter were gradually lost from the initial time through 4 months, 8 months to 12 months. Mass loss rate of litter mixed with *Eucalyptus* were lower than the control across all species but varied with time.

After 4 months of incubation, *Axonopus* shows the highest mass loss rate (27.33 ± 2.31%) and Mahogany shows the lowest mass loss rate (17 ± 1.52%) compared to control. Though *Axonopus* showed highest mass loss rate (19.33 ± 0.67%) it decreased when mixed with *Eucalyptus* litter. Teak mixed with *Eucalyptus* litter showed lowest mass loss rate (8 ± 1.15%). After eight months of incubation, highest mass loss rate was found in *Axonopus* (48.26 ± 2.94%), lowest in Mahagony (15.83 ± 0.94%) when not mixed with *Eucalyptus* litter. Lowest mass loss rate was recorded in Mahagony (13.8 ± 1.14%) and highest in *Axonopus* (36.53 ± 1.75%) when mixed with *Eucalyptus* litter. Mass loss rate after 12 months of incubation was similar to as that at 8 months of incubation. Highest mass loss rate was in *Axonopus* both with (53.7 ± 2.3%) and without (39.73 ± 7.16%) *Eucalyptus* litter mixing and lowest in Mahagony (23.83 ± 3.18%, 15.6 ± 1.2%) respectively.

In case of soil N content, after 4 months of incubation period, highest N content was found in *Axonopus* (0.0793 ± 0.00123) and the lowest in *Eucalyptus* (0.0103 ± 0.00332) without mixing *Eucalyptus* litter. Highest N release was

recoded in *Axonopus* (0.016 ± 0.00127), the lowest in both Teak (0.0131 ± 0.00126) and Mahagony (0.0131 ± 0.00171) when mixed with *Eucalyptus* litter.

After 8 months of incubation, highest N content was found in *Axonopus* (0.0189 ± 0.00420) and lowest in teak (0.0117 ± 0.00097) when mixed with *Eucalyptus* litter. Without *Eucalyptus* litter, highest N content in soil was highest in *Axonopus* (0.0189 ± 0.0042) and lowest in Teak (0.0117 ± 0.00097)

Without mixing *Eucalyptus* litter, N content in soil was highest in *Eucalyptus* (0.0105 ± 0.00558) and lowest in Teak (0.0076 ± 0.00033) after 12 months of incubation. With *Eucalyptus* litter mixing, highest soil N content was found in *Axonopus* (0.0189 ± 0.00010) and lowest in Teak (0.0073 ± 0.00003).

**Table 3.2.3. Mean values with standard error mean of the mass loss rate(%) and soil available N content affected by *Eucalyptus* litter (n=3).**

| Litter species | Mass loss rate (%) | | | Soil available N content | | |
|---|---|---|---|---|---|---|
| | 4 months | 8 months | 12 months | 4 months | 8 months | 12 months |
| *Axonopus* | 27.33 ± 2.31 | 48.26 ± 2.94 | 53.7 ± 2.3 | 0.0793 ± 0.00123 | 0.0189 ± 0.0042 | 0.0104 ± 0.00325 |
| Teak | 25.66 ± 2.33 | 29.4 ± 1.37 | 30.76 ± 2.8 | 0.0155 ± 0.00165 | 0.0117 ± 0.0010 | 0.0076 ± 0.00033 |
| Mahagony | 17 ± 1.52 | 15.83 ± 0.94 | 23.83 ± 3.18 | 0.0103 ± 0.00330 | 0.0127 ± 0.0017 | 0.0103 ± 0.00452 |
| *Eucalyptus* | 26.66 ± 5.81 | 40.06 ± 5.51 | 31.8 ± 1.6 | 0.0103 ± 0.00332 | 0.0127 ± 0.003 | 0.0105 ± 0.00558 |
| *Eucalyptus* × *Axonopus* | 19.33 ± 0.67 | 36.53 ± 1.75 | 39.73 ± 7.16 | 0.016 ± 0.00127 | 0.0117 ± 0.0013 | 0.0189 ± 0.00010 |
| *Eucalyptus* × Teak | 8 ± 1.15 | 18.6 ± 9.12 | 38 ± 2.3 | 0.0131 ± 0.00126 | 0.0122 ± 0.0019 | 0.0073 ± 0.00003 |
| *Eucalyptus* × Mahagony | 16.33 ± 0.88 | 13.80 ± 1.14 | 15.6 ± 1.2 | 0.0131 ± 0.00171 | 0.0136 ± 0.0024 | 0.0095 ± 0.00230 |

As shown in Figure 3.3(a), there was a significant effect of *Eucalyptus* leaf litter on the litter decomposition rate of *Axonopus*. For each time of incubation, mass loss rate was higher when *Eucalyptus* was not mixed compared to when *Eucalyptus* litter was mixed.

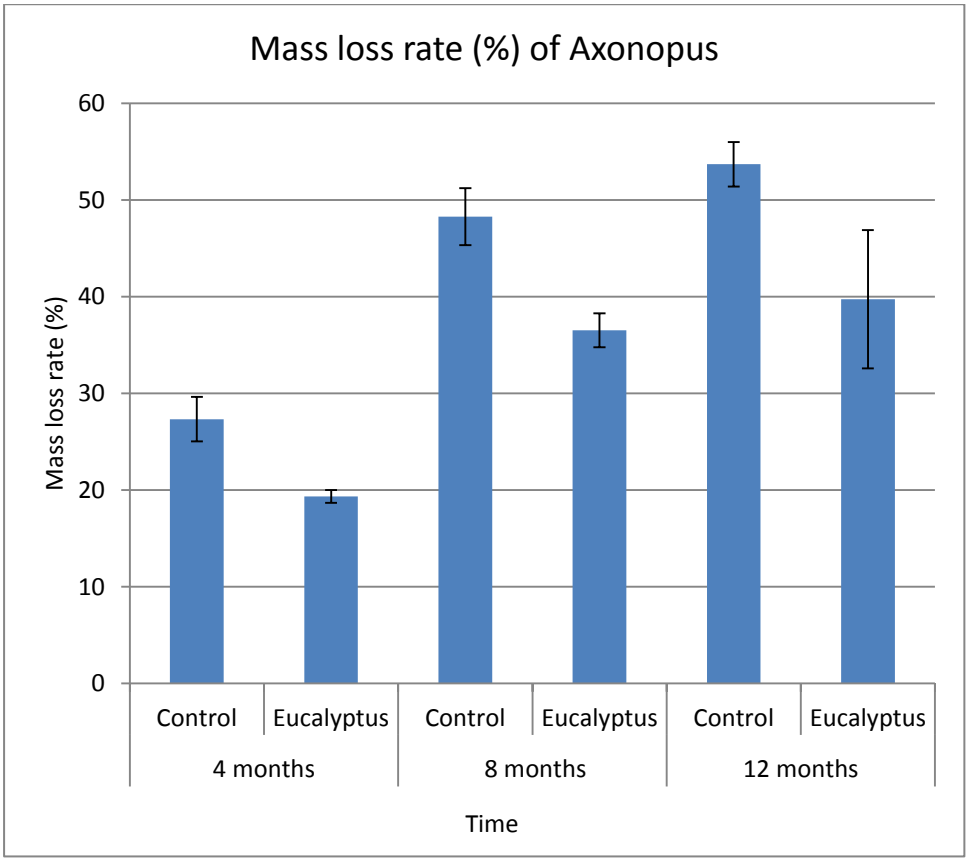


**Fig. 3.3(a)** Mass loss rate of litter of *Axonopus compressus* at three different time of incubation with and without *Eucalyptus camaldulensis* leaf litter.

Figure 3.3(b) showed that there was significant effect of *Eucalyptus* litter on the decomposition rate of teak leaf litter at 4 months and 8 months of incubations. Mass loss rate of teak is lower when mixed with *Eucalyptus* litter. After 12 months of incubation, without *Eucalyptus* litter mixing mass loss rate was higher than when mixed with *Eucalyptus* litter. In case of teak, there was significant effect of time but not of *Eucalyptus* litter mixing.

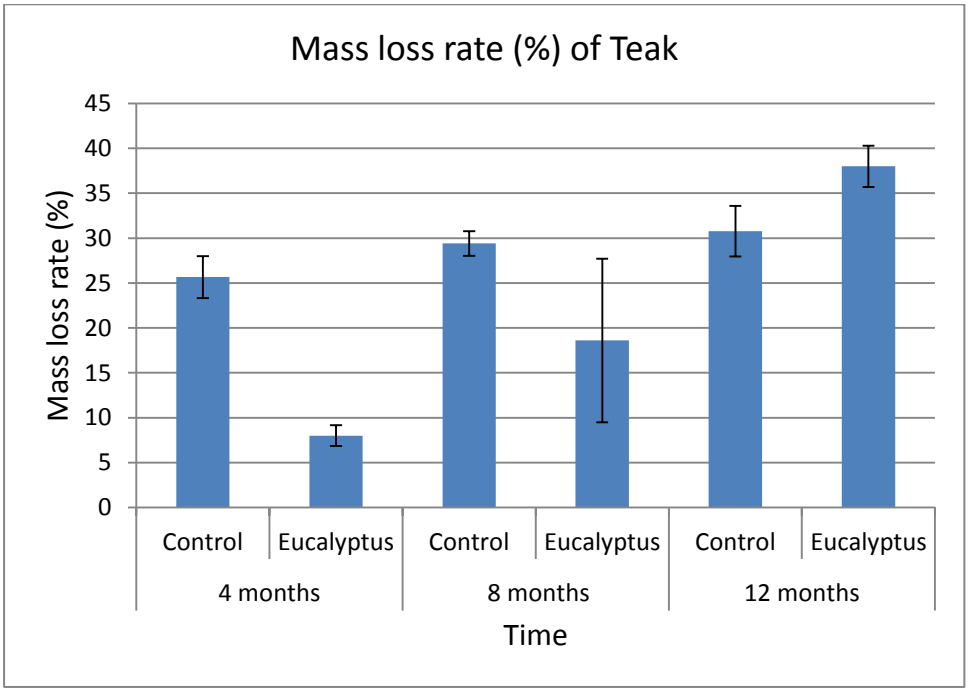


**Fig. 3.3(b).** Mass loss rate of litter of teak at three different times of incubation with and without litter of *Eucalyptus.*

The mass loss rate of Mahogany was lower at all measurements time when *Eucalyptus* litter was mixed (Figure 3.3(c)). There was a significant effect of *Eucalyptus* leaf litter on the decomposition rate of litter of Mahogany.

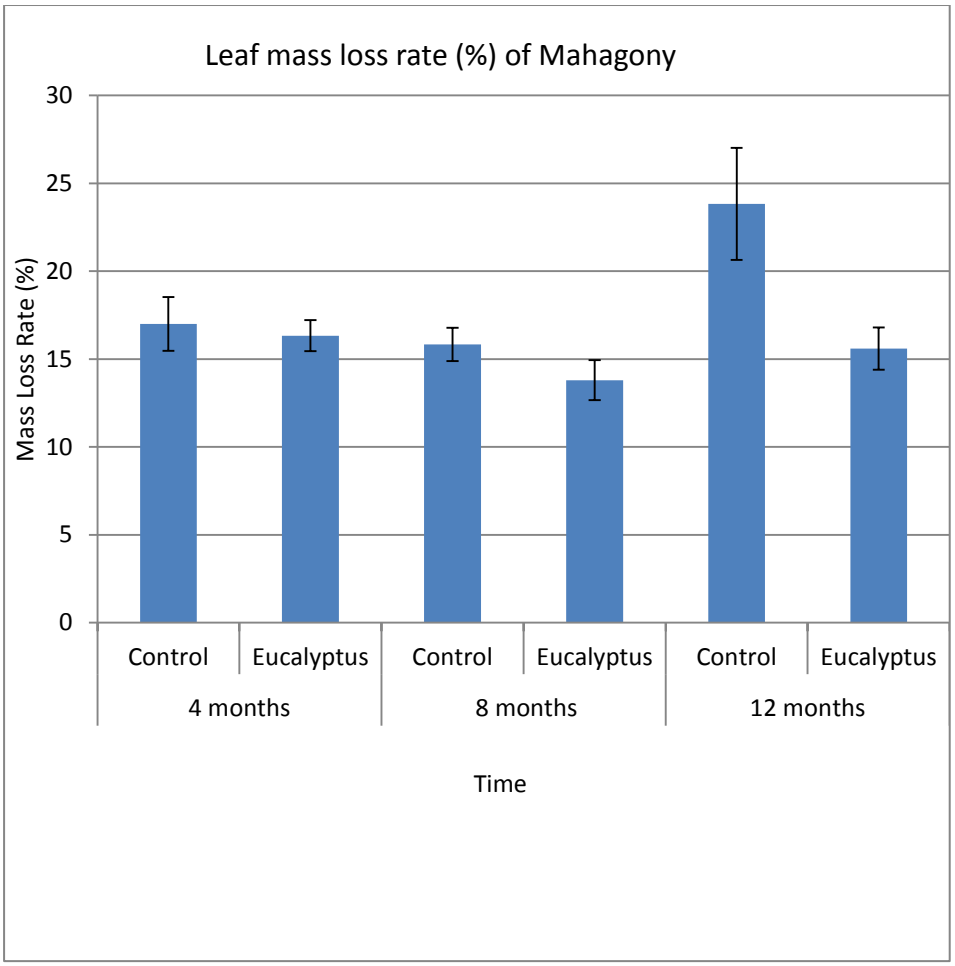


**Fig.3.3(c).** Mass loss rate of Mahogany litter at three different time of incubation with and without leaf litter of *Eucalyptus.*

Mixing of *Eucalyptus* litter caused reduction of N mineralization rate till 8 months of incubation but increased at 12 months as compared to *Axonopus* litter without litter of *Eucalyptus* (Figure 3.4(a)).

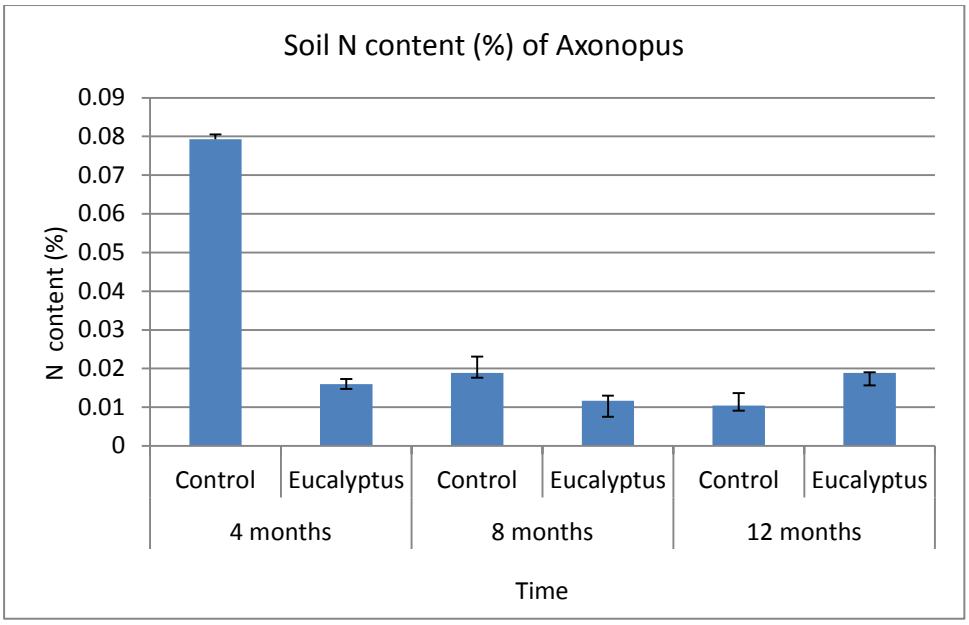


**Fig.3.4(a).** Nitrogen content in soil of *Axonopus* at three different time of incubations with and without *Eucalyptus* leaf litter.

Teak litter showed significant time effect on N content in soil. With time of incubation, N release generally decreased, when mixed with *Eucalyptus* leaf litter except at 4 months (Figure 3.4(b)).

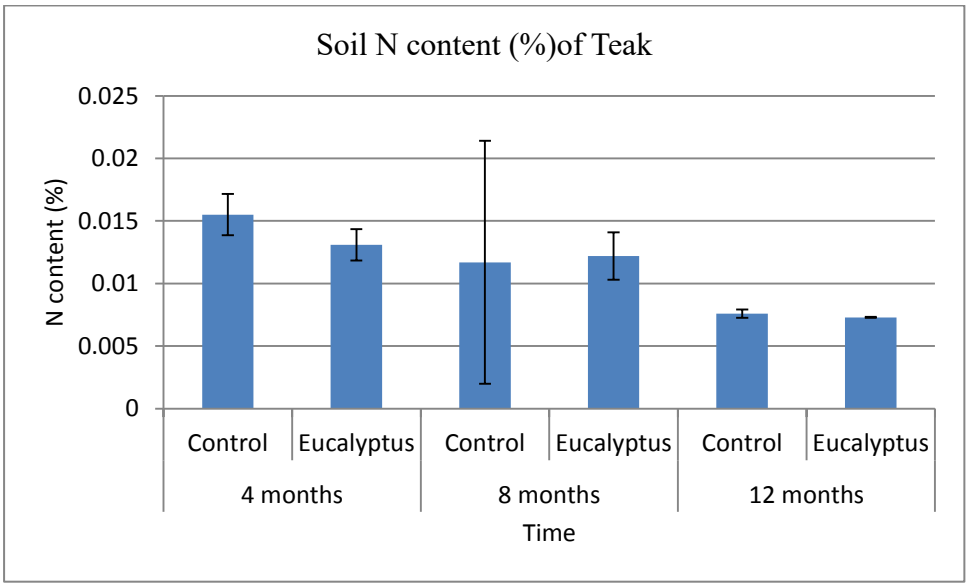


**Fig. 3.4(b).** Nitrogen content in soil of teak at three different time of incubation with and without *Eucalyptus* leaf litter.

Mahagony showed significant effects on N mineralization when mixed with *Eucalyptus* litter. N release was higher in *Eucalyptus* litter mixing after 4 months and 8 months of incubations than without *Eucalyptus* litter but it decreased at 12 months of incubations although not significant (Figure 3.4(c)).

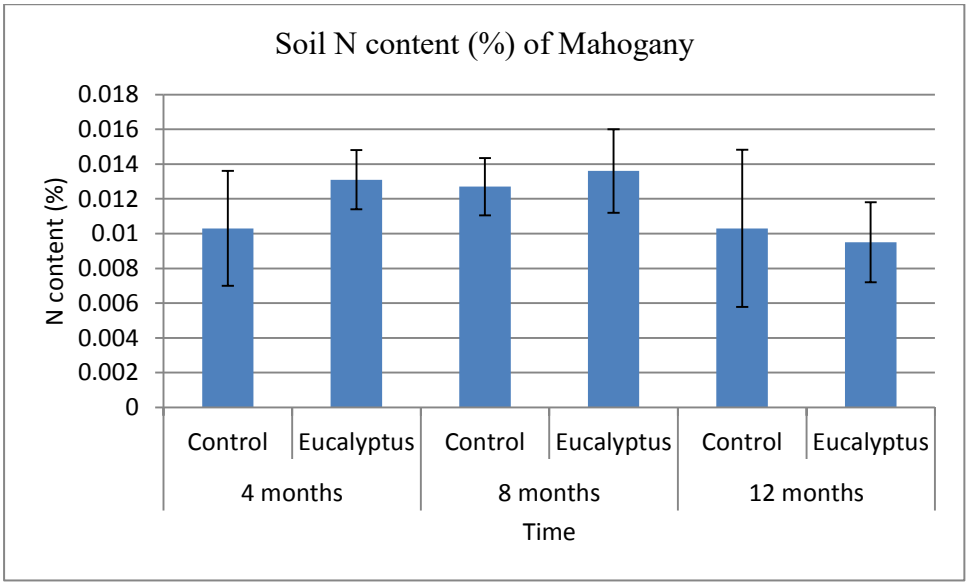


**Fig. 3.4(c).** Soil N content of Mahagony litter at three different time of incubations with and without *Eucalyptus* leaf litter.

## 3.3 Chemical composition of leaf litter

Mean values of the leaf nitrogen, phosphorous, phenolic compound and tannin contents were presented in Table 3.3. Leaf N showed significant difference (P = 0.0392) among the four plant species. The highest mean value of leaf N (0.92 ± 0.04) was found in *Axonopus* and the lowest mean value of leaf N (0.72 ± 0.01) was found in *Eucalyptus*. However, leaf P did not show any statistically significant differences among them. The highest mean value of P % was found in Mahagony (0.3 ± 0.29) and the lowest value was found in *Eucalyptus* (0.01 ± 0.01). The four plant species showed significant differences in phenol content (P = 0.0001). The highest mean value of phenol was found in Mahagony (4 ± 0.0) and the lowest mean value (0.29 ± 0.02) was found in *Axonopus*. Like phenol, the four plant species showed significant differences in tannin content (P = 0.0001). The highest mean value of tannin (0.36 ± 0.01) was found in Mahagony and the lowest mean value was found in both teak (0.02 ± 0.0) and *Axonopus* (0.02 ± 0.01).

**Table 3.3. Chemical composition of the leaf litter of the four plant species *Axonopus*, Teak, Mahagony, and *Eucalyptus* and their effect tests.**

| Plant spp. | Total N (%) | Total P (%) | Phenol (%) | Tannin (%) |
|---|---|---|---|---|
| *Axonopus* | 0.92 ± 0.04 | 0.06 ± 0.05 | 0.29 ± 0.02 | 0.02 ± 0.01 |
| Teak | 0.88 ± 0.01 | 0.04 ± 0.02 | 1.54 ± 0.18 | 0.02 ± 0.00 |
| Mahagony | 0.89 ± 0.07 | 0.3 ± 0.29 | 4.0 ± 0.00 | 0.36 ± 0.01 |
| *Eucalyptus* | 0.72 ± 0.01 | 0.01 ± 0.01 | 3.56 ± 0.27 | 0.07 ± 0.02 |
| F ratio | 4.5140 | 0.8302 | 114.8292 | 244.7659 |
| P value | 0.0392 | 0.5136 | 0.0001 | 0.0001 |

# DISCUSSION

Plantation of *Eucalyptus* has created enormous concerns about its socio-economic and environmental impacts (Calder *et al.* 1997, Poore and Fries 1987). Because of its rapid growth and wide range of conditions in which the various species can grow, the genus has been a popular choice for introduction especially in the warmer parts of the world. Plantation of this species has been strongly criticized in some quarters because they are accused to cause adverse effects on soil and on hydrology. Criticisms on *Eucalyptus* plantation are varied. It is said that *Eucalyptus* is a poor habitat of birds because of their canopies and fruit type. *Eucalyptus* has high demand of water, strong absorption of nutrients, allelopathy effects, desertification of the land, soil erosion and so on. According to the IUCN, the biggest threats to biodiversity are those related to human activity. Of those threats, introduced species like *Eucalyptus* are a significant cause of biodiversity loss.

Conductivity of soil collected from Tangail region was significantly affected by plantation and vertical depth although not by interactions. Mean conductivity values were more than double in Acacia plantation than those in the *Eucalyptus* plantation. Soil pH generally increased with the increase of vertical depth from 10 cm to 30 cm in both *Eucalyptus* and Acacia plantation. Soil moisture and available N were not significantly affected by plantation, depth and their interactions. Total P was significantly affected by plantation and vertical depth although not by interactions. Total P increased with the increase of vertical

depth in both *Eucalyptus* and Acacia plantation. N:P was not significantly affected by plantation, depth and their interactions but increases with the vertical depth in Acacia plantation. Thus result obtained from Tangail site, suggest a potential reduction of electrical conductivity by the plantation of *Eucalyptus* compared with Acacia plantation. Electrical conductivity is related to nutrient availability. Thus, plantation with *Eucalyptus* may influence nutrient availability.

Soil moisture (%) in Dinajpur site was significantly affected by plantation. Mean moisture (%) values were almost three times higher in Jarul plantation than those in the *Eucalyptus* plantation. Perhaps it may be because of leaf size and position. *Eucalyptus* leaf is vertically arranged but Jarul leaf is horizonetally arranged. Jarul's leaf size is also bigger than the *Eucalyptus* leaf. Large horizonetally arranged leaf of Jarul, interrupt the sun light which decreases soil evaporation. Soil pH was significantly affected by both plantation and depth. Soil pH was increased with vertical depth in *Eucalyptus* plantation but decreases in Jarul plantation. Total P % was significantly affected by both plantation and depth but not by interactions. Electrical conductivity and available N were not affected by plantation, depth and their interactions. Soil organic carbon was significantly affected by plantation but not by depth and their interactions. Higher organic carbon was found in Jarul plantation and decreased with the increase of vertical depth from 10 cm to 30 cm in both plantations. N:P was significantly affected by plantation but not depth and their interactions. These results indicate that plantation with

*Eucalyptus* has the potential to reduce soil moisture and organic C compared with Jarul plantation.

For Dhaka site, plantation, distance, depth and their interactions effects were measured. In case of total P (%) only significant plantation effect was found. P decreased with the increase of vertical depth and horizontal distance in both plantations. This result is reasonable since organic matter decreases with depth. N:P ratio also significantly affected by plantation. Organic carbon was significantly affected by depth versus distance interactions. Soil moisture %, conductivity, organic carbon, available N were not significantly affected by plantation, distance, depth and their interactions in this site. Lower amount of soil phosphorous under the *Eucalyptus* plantation indicates that *Eucalyptus* might have influenced the soil P availability.

Litter decomposition is a dominant fundamental process that affects nutrient and carbon (C) cycle in ecosystems. Plant litter decomposition is affected by the quality of the litter, microbial community composition and soil properties (Wardle 2002). Two decomposition parameters, namely the mass loss rate and the rate of N mineralization were determined in this study. The litter nitrogen (N) concentration and soil N availability also have important influences on litter decomposition. Litters containing a high amount of N are easily decomposable by soil microbes (Hobbie 1992; Hossain *et al*. 2010b). Nitrogen concentration could be responsible for the difference in the decomposition parameters among the litter species (Hossain and Sugiyama 2010a). Mineral N is important resource for microbial growth (Hossain *et al.* 2010b). According to

some studies, it is also important in controlling the rate of decomposition (Findlay 1934, Miller 1936). Abundant C storage inhibits decomposition process (Wardle 2002).

Nitrogen rich litter, considered as high quality litter, enhances decomposition rate at the early stage of decomposition (Koukoura *et al*. 2003, Teklay *et al.* 2007, Hossain and Sugiyama 2008). Because, N-rich litter provides readily available C for microbes; nutrients released from soil consequently promote microbial growth and activity. Several studies have reported that slow growers favor fungal dominated food web and slow cycling of nutrients (Coleman *et al.* 1983, Moore and Hunt 1988). It is thought that fast growing plant's nutrient cycling also fast and bacterial decomposers are involved here. Higher C:N indicates poor litter quality and lower C:N indicates high quality of litter. High quality litter (low C:N) of fast growing plants stimulates the growth and activity of bacterial community (Bardgett 2005).

The process by which organic N is converted to plant-available inorganic forms is nitrogen mineralization. Ammonium ($NH_4^+$) and nitrate ($NO_3^-$) are the mostly available inorganic nitrogen to plants. Organic nitrogen needs to convert in inorganic forms before absorption. An understanding of temperature effects on mineralization can help to predict mineralization during the year. Cool weather will slow mineralization during the winter (Crohn 2004).

Phenol and tannin are considered as secondary metabolic compounds. These secondary metabolites are known as 'defense chemicals. The secondary

metabolites not only defend the plants from different stresses, but also increase the fitness of the plants (War *et al.* 2012).These chemicals qualify the litter quality. It is reported that phenolic compound has positive response in nitrogen depletion (Bongue-Bartelsman and Phillips 1995; Stewart *et al*. 2001, Stout *et al*., 1998). Insect, pest and herbivores attack the plant body for their shelter and nutrients. This may happen at any stage of plant's life cycle (Levin 1976). Tannins have a strong effect on insect growth (War *et al.* 2012), indirectly protect the plants. Phenol and tannin strongly prohibit activities of soil microbes (Hättenschwiler and Vitousek 2000). Phenols act as a defensive chemical not only against herbivores, but also against microorganisms and competing plants. Although leaf N content did not differ among the studied four plant species *Axonopus*, *Eucalyptus*, Mahagony and Teak, total leaf P content differed significantly among the four species. The highest total P (0.121%) was found in *Axonopus* and the lowest was found in *Eucalyptus* leaf litter. The four plant species showed significant differences in both phenolic and tannin.

Addition of *Eucalyptus* leaf litter with that of *Axonopus*, Mahagony and teak species caused decreased mass loss rate. The reason behind such differences in the effects of *Eucalyptus* leaf litter on the mass loss rate of other litter species could be attributed to the alteration in chemical composition after addition of *Eucalyptus* litter with those species. Litter decomposition is done by the activities of the microbial communities (Hossain *et al.* 2010b). Rate of microbial function depends on substrate quantity and quality like N/P ration

(Hossain and Sugiyama 2008). Since both N and P content in *Eucalyptus* leaf litter were significantly lower than other species, this litter was inferior in quality. Besides, defense chemicals such as phenolics and tannins also negatively influence the litter decomposition by the soil microbial communities.

Overall, the results of the present study indicate that plantation with *Eucalyptus* may potentially influence soil properties like moisture, organic carbon and phosphorous contents although the effects are site specific. Results also suggest that plantation with *Eucalyptus* influence decomposition rate (e.g. mass loss rate) of an ecosystem through mixing with litter of other plant species. Therefore, ecological consequences should be considered with while plantation is to be done with *Eucalyptus*.

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## Appendix 1: Values of different soil properties in Eucalyptus plantation and Acacia plantation from Tangail site.

| Soil ID | plantation | depth | Replicate | Moisture (%) | pH | Electrical conductivity (µS/cm) | N (%) | P (%) | OC (%) | N:P |
|---|---|---|---|---|---|---|---|---|---|---|
| 1EQ-10 | Eucalyptus | 10cm | 1 | 14.12 | 6.1 | 78.9 | 0.013 | 0.006 | 0.33 | 2.0679 |
| 1EQ-20 | Eucalyptus | 20cm | 2 | 12.37 | 5.6 | 128.1 | 0.007 | 0.005 | 0.19 | 1.4758 |
| 1EQ-30 | Eucalyptus | 30cm | 3 | 13.30 | 6.5 | 146.1 | 0.014 | 0.008 | 0.34 | 1.8062 |
| 2EQ-10 | Eucalyptus | 10cm | 1 | 14.14 | 6.1 | 62.7 | 0.014 | 0.006 | 0.31 | 2.3191 |
| 2EQ-20 | Eucalyptus | 20cm | 2 | 13.24 | 5.9 | 59.7 | 0.017 | 0.007 | 0.29 | 2.3278 |
| 2EQ-30 | Eucalyptus | 30cm | 3 | 12.46 | 6.5 | 80.4 | 0.020 | 0.007 | 0.46 | 3.0200 |
| 3EQ-10 | Eucalyptus | 10cm | 1 | 18.64 | 5.8 | 85.2 | 0.018 | 0.005 | 0.33 | 3.6173 |
| 3EQ-20 | Eucalyptus | 20cm | 2 | 14.52 | 5.8 | 85.5 | 0.018 | 0.005 | 0.31 | 3.5820 |
| 3EQ-30 | Eucalyptus | 30cm | 3 | 12.78 | 6.2 | 57.3 | 0.014 | 0.007 | 0.01 | 2.1028 |
| 1AQ-10 | Acacia | 10cm | 1 | 9.69 | 5.7 | 146.7 | 0.007 | 0.005 | 0.87 | 1.3219 |
| 1AQ-20 | Acacia | 20cm | 2 | 7.81 | 5.5 | 201 | 0.021 | 0.008 | 0.33 | 2.7809 |
| 1AQ-30 | Acacia | 30cm | 3 | 7.10 | 6.8 | 203.1 | 0.020 | 0.007 | 0.10 | 2.6641 |
| 2AQ-10 | Acacia | 10cm | 1 | 15.02 | 6.4 | 154.2 | 0.021 | 0.003 | 0.06 | 8.3977 |
| 2AQ-20 | Acacia | 20cm | 2 | 10.68 | 6.2 | 259.5 | 0.018 | 0.009 | 0.14 | 2.0569 |
| 2AQ-30 | Acacia | 30cm | 3 | 12.55 | 5.9 | 240.9 | 0.018 | 0.014 | 0.04 | 1.3327 |
| 3AQ-10 | Acacia | 10cm | 1 | 9.27 | 5.7 | 138.9 | 0.023 | 0.008 | 0.06 | 2.9009 |
| 3AQ-20 | Acacia | 20cm | 2 | 15.65 | 5.7 | 196.5 | 0.018 | 0.010 | 0.21 | 1.9123 |
| 3AQ-30 | Acacia | 30cm | 3 | 15.78 | 6 | 186 | 0.021 | 0.012 | 0.29 | 1.7031 |

## Appendix 2: Values of different soil properties in Eucalyptus plantation and Acacia plantation from Dinajpur site.

| Soil ID | Plantation | Depth | Repli. | Moisture (%) | pH | Electrical conductivity (µS/cm) | N (%) | P (%) | OC (%) | N:P |
|---|---|---|---|---|---|---|---|---|---|---|
| 1EQ-10 | Eucalyptus | 10cm | 1 | 4.90 | 5.12 | 110.7 | 0.011 | 0.003 | 0.50 | 3.5976 |
| 1EQ-20 | Eucalyptus | 20cm | 2 | 5.37 | 5.11 | 99.9 | 0.010 | 0.004 | 0.36 | 3.5976 |
| 1EQ-30 | Eucalyptus | 30cm | 3 | 4.40 | 5.32 | 77.7 | 0.017 | 0.003 | 0.37 | 5.4629 |
| 2EQ-10 | Eucalyptus | 10cm | 1 | 5.12 | 5.16 | 145.8 | 0.023 | 0.004 | 0.37 | 5.7284 |
| 2EQ-20 | Eucalyptus | 20cm | 2 | 3.05 | 5.32 | 77.4 | 0.014 | 0.003 | 0.30 | 4.3019 |
| 2EQ-30 | Eucalyptus | 30cm | 3 | 4.16 | 5.31 | 81 | 0.011 | 0.003 | 0.34 | 3.2825 |
| 3EQ-10 | Eucalyptus | 10cm | 1 | 3.93 | 4.89 | 1263 | 0.010 | 0.004 | 0.34 | 2.2444 |
| 3EQ-20 | Eucalyptus | 20cm | 2 | 3.34 | 5.48 | 127.8 | 0.016 | 0.003 | 0.30 | 6.2047 |
| 3EQ-30 | Eucalyptus | 30cm | 3 | 1.35 | 5.71 | 53.7 | 0.011 | 0.002 | 0.27 | 5.2906 |
| 1JQ-10 | Jarul | 10cm | 1 | 18.41 | 4.71 | 219.9 | 0.011 | 0.005 | 0.62 | 2.0819 |
| 1JQ-20 | Jarul | 20cm | 2 | 14.97 | 4.44 | 528.3 | 0.016 | 0.005 | 0.60 | 3.3906 |
| 1JQ-30 | Jarul | 30cm | 3 | 18.30 | 4.91 | 147.3 | 0.013 | 0.003 | 0.37 | 3.8381 |
| 2JQ-10 | Jarul | 10cm | 1 | 12.74 | 4.69 | 321.3 | 0.018 | 0.004 | 0.37 | 4.6184 |
| 2JQ-20 | Jarul | 20cm | 2 | 16.41 | 4.81 | 225 | 0.014 | 0.004 | 0.37 | 3.5443 |
| 2JQ-30 | Jarul | 30cm | 3 | 22.26 | 5.21 | 128.1 | 0.010 | 0.004 | 0.32 | 2.5672 |
| 3JQ-10 | Jarul | 10cm | 1 | 18.76 | 4.54 | 477 | 0.016 | 0.005 | 0.56 | 3.4280 |
| 3JQ-20 | Jarul | 20cm | 2 | 17.05 | 4.6 | 279.9 | 0.004 | 0.005 | 0.45 | 0.8734 |
| 3JQ-30 | Jarul | 30cm | 3 | 21.91 | 5.25 | 85.5 | 0.011 | 0.004 | 0.40 | 2.9980 |

**Appendix 3(a): Values of different soil properties in Eucalyptus plantation from Dr. Shahidulla Hall play-ground, Dhaka University Campus.**

| Soil ID | Plantation | Distance | Depth | Replicate | Moisture (%) | pH | Electrical conductivity (µS/cm) | N (%) | P (%) | OC (%) | N:P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1E1-10 | Eucalyptus | 1ft | 10cm | 1 | 4.82 | 5.9 | 161.7 | 0.0127 | 0.0131 | 0.583 | 0.9650 |
| 1E1-20 | Eucalyptus | 1ft | 20cm | 1 | 5.71 | 6.2 | 111.6 | 0.0127 | 0.0119 | 0.173 | 1.0666 |
| 1E1-30 | Eucalyptus | 1ft | 30cm | 1 | 6.04 | 6.6 | 94.5 | 0.0127 | 0.0113 | 0.583 | 1.1258 |
| 3E1-10 | Eucalyptus | 3m | 10cm | 1 | 2.77 | 6.8 | 181.2 | 0.0169 | 0.0118 | 0.583 | 1.4413 |
| 3E1-20 | Eucalyptus | 3m | 20cm | 1 | 2.56 | 7.1 | 159.6 | 0.0169 | 0.0032 | 0.130 | 5.3338 |
| 3E1-30 | Eucalyptus | 3m | 30cm | 1 | 7.41 | 6.3 | 100.2 | 0.0169 | 0.0045 | 0.205 | 3.7843 |
| 6E1-10 | Eucalyptus | 6m | 10cm | 1 | 5.15 | 6.3 | 184.2 | 0.0212 | 0.0085 | 0.130 | 2.4873 |
| 6E1-20 | Eucalyptus | 6m | 20cm | 1 | 6.95 | 6.6 | 90.6 | 0.0098 | 0.0083 | 0.853 | 1.1866 |
| 6E1-30 | Eucalyptus | 6m | 30cm | 1 | 11.36 | 6.6 | 96.3 | 0.0269 | 0.0084 | 0.378 | 3.2020 |
| 1E2-10 | Eucalyptus | 1ft | 10cm | 2 | 11.36 | 5.7 | 256.2 | 0.0155 | 0.0135 | 0.583 | 1.1490 |
| 1E2-20 | Eucalyptus | 1ft | 20cm | 2 | 3.63 | 5.6 | 155.7 | 0.0184 | 0.0046 | 1.328 | 3.9693 |
| 1E2-30 | Eucalyptus | 1ft | 30cm | 2 | 2.25 | 5.5 | 126 | 0.0184 | 0.0082 | 0.259 | 2.2320 |
| 3E2-10 | Eucalyptus | 3m | 10cm | 2 | 5.71 | 5.3 | 212.4 | 0.0198 | 0.0137 | 0.724 | 1.4492 |
| 3E2-20 | Eucalyptus | 3m | 20cm | 2 | 4.71 | 5.3 | 128.1 | 0.0127 | 0.0108 | 0.032 | 1.1755 |
| 3E2-30 | Eucalyptus | 3m | 30cm | 2 | 6.38 | 5.2 | 93 | 0.0269 | 0.0112 | 0.788 | 2.4015 |
| 6E2-10 | Eucalyptus | 6m | 10cm | 2 | 5.71 | 5.4 | 152.4 | 0.0212 | 0.0086 | 0.551 | 2.4728 |
| 6E2-20 | Eucalyptus | 6m | 20cm | 2 | 7.76 | 5.6 | 81.6 | 0.0169 | 0.0065 | 0.562 | 2.6054 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6E2-30 | Eucalyptus | 6m | 30cm | 2 | 5.04 | 5.6 | 81.9 | 0.0127 | 0.0087 | 0.508 | 1.4600 |
| 1E3-10 | Eucalyptus | 1ft | 10cm | 3 | 4.06 | 6.1 | 207.3 | 0.0027 | 0.0155 | 0.853 | 0.1750 |
| 1E3-20 | Eucalyptus | 1ft | 20cm | 3 | 3.84 | 6.3 | 152.4 | 0.0056 | 0.0126 | 0.248 | 0.4422 |
| 1E3-30 | Eucalyptus | 1ft | 30cm | 3 | 4.49 | 6.5 | 234 | 0.0056 | 0.0071 | 0.356 | 0.7790 |
| 3E3-10 | Eucalyptus | 3m | 10cm | 3 | 4.06 | 6.4 | 64.8 | 0.0041 | 0.0033 | 0.248 | 1.2601 |
| 3E3-20 | Eucalyptus | 3m | 20cm | 3 | 1.94 | 6.1 | 72.3 | 0.0070 | 0.0100 | 0.421 | 0.6991 |
| 3E3-30 | Eucalyptus | 3m | 30cm | 3 | 6.27 | 6 | 91.8 | 0.0070 | 0.0103 | 0.281 | 0.6787 |
| 6E3-10 | Eucalyptus | 6m | 10cm | 3 | 2.15 | 6 | 75.9 | 0.0084 | 0.0099 | 0.356 | 0.8503 |
| 6E3-20 | Eucalyptus | 6m | 20cm | 3 | 2.46 | 6.1 | 62.4 | 0.0041 | 0.0088 | 0.626 | 0.4676 |
| 6E3-30 | Eucalyptus | 6m | 30cm | 3 | 4.17 | 5.5 | 62.4 | 0.0084 | 0.0111 | 0.227 | 0.7581 |
| 1E4-10 | Eucalyptus | 1ft | 10cm | 4 | 3.95 | 5.3 | 164.7 | 0.0070 | 0.0113 | 0.518 | 0.6185 |
| 1E4-20 | Eucalyptus | 1ft | 20cm | 4 | 3.84 | 5.5 | 120.9 | 0.0141 | 0.0089 | 0.248 | 1.5875 |
| 1E4-30 | Eucalyptus | 1ft | 30cm | 4 | 3.09 | 5.3 | 92.4 | 0.0112 | 0.0092 | 0.605 | 1.2187 |
| 3E4-10 | Eucalyptus | 3m | 10cm | 4 | 5.04 | 5.6 | 177.6 | 0.0056 | 0.0177 | 0.378 | 0.3145 |
| 3E4-20 | Eucalyptus | 3m | 20cm | 4 | 4.71 | 5.8 | 162.9 | 0.0084 | 0.0115 | 0.011 | 0.7333 |
| 3E4-30 | Eucalyptus | 3m | 30cm | 4 | 2.46 | 5.6 | 89.1 | 0.0056 | 0.0083 | 0.842 | 0.6707 |
| 6E4-10 | Eucalyptus | 6m | 10cm | 4 | 4.17 | 5.9 | 108 | 0.0013 | 0.0092 | 0.443 | 0.1392 |
| 6E4-20 | Eucalyptus | 6m | 20cm | 4 | 2.67 | 5.8 | 118.5 | 0.0098 | 0.0084 | 0.454 | 1.1760 |
| 6E4-30 | Eucalyptus | 6m | 30cm | 4 | 6.50 | 5.9 | 213 | 0.0027 | 0.0082 | 0.443 | 0.3318 |

**Appendix 3(b): Values of different soil properties in teak plantation from Dr. Shahidulla Hall play-ground, Dhaka University Campus.**

| Soil ID | Plantation | Distance | Depth | Replicate | Moisture (%) | pH | Electrical conductivity(µS/cm) | N (%) | P (%) | OC (%) | N:P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1T1-10 | Teak | 1ft | 10cm | 1 | 2.99 | 5.8 | 129.9 | 0.0056 | 0.0254 | 0.724 | 0.2185 |
| 1T1-20 | Teak | 1ft | 20cm | 1 | 3.63 | 5.9 | 216 | 0.0013 | 0.0166 | 0.756 | 0.0770 |
| 1T1-30 | Teak | 1ft | 30cm | 1 | 5.15 | 5.6 | 168 | 0.0056 | 0.0091 | 0.551 | 0.6099 |
| 3T1-10 | Teak | 3m | 10cm | 1 | 4.06 | 5.4 | 123.6 | 0.0112 | 0.0234 | 0.572 | 0.4799 |
| 3T1-20 | Teak | 3m | 20cm | 1 | 4.06 | 5.2 | 79.2 | 0.0070 | 0.0159 | 0.497 | 0.4399 |
| 3T1-30 | Teak | 3m | 30cm | 1 | 5.60 | 5.1 | 69.3 | 0.0041 | 0.0110 | 0.421 | 0.3760 |
| 6T1-10 | Teak | 6m | 10cm | 1 | 7.41 | 5.3 | 265.8 | 0.0112 | 0.0166 | 0.400 | 0.6793 |
| 6T1-20 | Teak | 6m | 20cm | 1 | 6.61 | 5.4 | 108.3 | 0.0013 | 0.0086 | 0.529 | 0.1498 |
| 6T1-30 | Teak | 6m | 30cm | 1 | 9.65 | 5.1 | 185.4 | 0.0070 | 0.0039 | 0.400 | 1.7766 |
| 1T2-10 | Teak | 1ft | 10cm | 2 | 2.77 | 6.9 | 226.8 | 0.0070 | 0.0203 | 0.335 | 0.3439 |
| 1T2-20 | Teak | 1ft | 20cm | 2 | 4.71 | 6.8 | 261.3 | 0.0070 | 0.0148 | 0.648 | 0.4712 |
| 1T2-30 | Teak | 1ft | 30cm | 2 | 7.76 | 6.6 | 319.5 | 0.0056 | 0.0197 | 0.389 | 0.2821 |
| 3T2-10 | Teak | 3m | 10cm | 2 | 2.99 | 6.6 | 80.4 | 0.0098 | 0.0153 | 0.680 | 0.6428 |
| 3T2-20 | Teak | 3m | 20cm | 2 | 4.28 | 6.4 | 67.8 | 0.0112 | 0.0147 | 0.335 | 0.7674 |
| 3T2-30 | Teak | 3m | 30cm | 2 | 4.49 | 6.1 | 103.8 | 0.0084 | 0.0157 | 0.540 | 0.5365 |
| 6T2-10 | Teak | 6m | 10cm | 2 | 3.73 | 6.2 | 108 | 0.0056 | 0.0124 | 0.421 | 0.4494 |
| 6T2-20 | Teak | 6m | 20cm | 2 | 4.82 | 7.01 | 140.4 | 0.0084 | 0.0084 | 0.637 | 0.9996 |
| 6T2-30 | Teak | 6m | 30cm | 2 | 4.06 | 6.3 | 120.3 | 0.0127 | 0.0274 | 0.454 | 0.4627 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1T3-10 | Teak | 1ft | 10cm | 3 | 4.17 | 6.2 | 220.8 | 0.0084 | 0.0161 | 0.464 | 0.5207 |
| 1T3-20 | Teak | 1ft | 20cm | 3 | 6.61 | 6.9 | 178.2 | 0.0141 | 0.0155 | 0.680 | 0.9075 |
| 1T3-30 | Teak | 1ft | 30cm | 3 | 8.81 | 7 | 179.4 | 0.0226 | 0.0135 | 0.508 | 1.6761 |
| 3T3-10 | Teak | 3m | 10cm | 3 | 4.93 | 4.27 | 148.2 | 0.0112 | 0.0100 | 0.518 | 1.1271 |
| 3T3-20 | Teak | 3m | 20cm | 3 | 4.93 | 5.35 | 144.9 | 0.0169 | 0.0099 | 0.400 | 1.7149 |
| 3T3-30 | Teak | 3m | 30cm | 3 | 6.38 | 6.2 | 169.8 | 0.0098 | 0.0071 | 0.475 | 1.3782 |
| 6T3-10 | Teak | 6m | 10cm | 3 | 4.93 | 6.1 | 185.1 | 0.0070 | 0.0100 | 0.551 | 0.6973 |
| 6T3-20 | Teak | 6m | 20cm | 3 | 4.28 | 6.1 | 82.5 | 0.0127 | 0.0069 | 0.432 | 1.8356 |
| 6T3-30 | Teak | 6m | 30cm | 3 | 6.61 | 5.95 | 82.2 | 0.0127 | 0.0112 | 0.572 | 1.1334 |
| 1T4-10 | Teak | 1ft | 10cm | 4 | 3.95 | 5.21 | 292.8 | 0.0098 | 0.0229 | 0.529 | 0.4293 |
| 1T4-20 | Teak | 1ft | 20cm | 4 | 3.84 | 5.6 | 217.5 | 0.0112 | 0.0091 | 0.788 | 1.2321 |
| 1T4-30 | Teak | 1ft | 30cm | 4 | 4.17 | 5.7 | 157.8 | 0.0112 | 0.0108 | 0.670 | 1.0386 |
| 3T4-10 | Teak | 3m | 10cm | 4 | 4.71 | 5.79 | 246.3 | 0.0127 | 0.0169 | 0.518 | 0.7483 |
| 3T4-20 | Teak | 3m | 20cm | 4 | 4.71 | 5.57 | 178.2 | 0.0098 | 0.0149 | 0.702 | 0.6590 |
| 3T4-30 | Teak | 3m | 30cm | 4 | 3.63 | 5.3 | 118.8 | 0.0056 | 0.0139 | 0.529 | 0.4007 |
| 6T4-10 | Teak | 6m | 10cm | 4 | 3.31 | 6.17 | 180.6 | 0.0112 | 0.0094 | 0.324 | 1.1992 |
| 6T4-20 | Teak | 6m | 20cm | 4 | 5.04 | 6.36 | 99.3 | 0.0098 | 0.0086 | 0.518 | 1.1418 |
| 6T4-30 | Teak | 6m | 30cm | 4 | 2.67 | 6.33 | 117.3 | 0.0127 | 0.0142 | 0.410 | 0.8935 |

**Appendix 4(a). Values of Litter mass loss rate and soil N content after 4 months of incubation.**

| leaf sample | Time | Replicates | Mass loss rate (%) | N content |
|---|---|---|---|---|
| Auxonopus | 4 months | 1 | 30 | 0.0056 |
| Auxonopus | 4 months | 2 | 17 | 0.0098 |
| Auxonopus | 4 months | 3 | 35 | 0.0084 |
| Teak | 4 months | 1 | 30 | 0.0127 |
| Teak | 4 months | 2 | 25 | 0.0184 |
| Teak | 4 months | 3 | 22 | 0.0155 |
| Mahogoni | 4 months | 1 | 15 | 0.0169 |
| Mahogoni | 4 months | 2 | 16 | 0.0070 |
| Mahogoni | 4 months | 3 | 20 | 0.0070 |
| Eucalyptus | 4 months | 1 | 16 | 0.0155 |
| Eucalyptus | 4 months | 2 | 28 | 0.0041 |
| Eucalyptus | 4 months | 3 | 36 | 0.0112 |
| Eucalyptus x Auxonopus | 4 months | 1 | 20 | 0.0184 |
| Eucalyptus x Auxonopus | 4 months | 2 | 20 | 0.0155 |
| Eucalyptus x Auxonopus | 4 months | 3 | 18 | 0.0141 |
| Eucalyptus x Teak | 4 months | 1 | 10 | 0.0155 |
| Eucalyptus x Teak | 4 months | 2 | 8 | 0.0127 |
| Eucalyptus x Teak | 4 months | 3 | 6 | 0.0112 |
| Eucalyptus x Mahogoni | 4 months | 1 | 18 | 0.0155 |
| Eucalyptus x Mahogoni | 4 months | 2 | 15 | 0.0141 |
| Eucalyptus x Mahogoni | 4 months | 3 | 16 | 0.0098 |

**Appendix 4(b). Values of Litter mass loss rate and soil N content after 8 months of incubation.**

| leaf sample | Time | Replicates | Mass loss rate (%) | N content |
|---|---|---|---|---|
| Auxonopus | 8 months | 1 | 54.1 | 0.0171 |
| Auxonopus | 8 months | 2 | 46.1 | 0.0127 |
| Auxonopus | 8 months | 3 | 44.6 | 0.0269 |
| Teak | 8 months | 1 | 27.3 | 0.0098 |
| Teak | 8 months | 2 | 28.9 | 0.0127 |
| Teak | 8 months | 3 | 32 | 0.0127 |
| Mahogoni | 8 months | 1 | 15.2 | 0.0098 |
| Mahogoni | 8 months | 2 | 17.7 | 0.0155 |
| Mahogoni | 8 months | 3 | 14.6 | 0.0127 |
| Eucalyptus | 8 months | 1 | 47.8 | 0.0084 |
| Eucalyptus | 8 months | 2 | 43 | 0.0127 |
| Eucalyptus | 8 months | 3 | 29.4 | 0.0171 |
| Eucalyptus x Auxonopus | 8 months | 1 | 39.8 | 0.0098 |
| Eucalyptus x Auxonopus | 8 months | 2 | 36 | 0.0141 |
| Eucalyptus x Auxonopus | 8 months | 3 | 33.8 | 0.0112 |
| Eucalyptus x Teak | 8 months | 1 | 10.6 | 0.0141 |
| Eucalyptus x Teak | 8 months | 2 | 36.8 | 0.0084 |
| Eucalyptus x Teak | 8 months | 3 | 8.4 | 0.0141 |
| Eucalyptus x Mahogoni | 8 months | 1 | 12.2 | 0.0112 |
| Eucalyptus x Mahogoni | 8 months | 2 | 16.6 | 0.0184 |
| Eucalyptus x Mahogoni | 8 months | 3 | 12.6 | 0.0112 |

**Appendix 4(c). Values of Litter mass loss rate and soil N content after 12 months of incubation.**

| leaf sample | Time | Replicates | Mass loss rate (%) | N content (%) |
|---|---|---|---|---|
| Auxonopus | 12 months | 1 | 50.1 | 0.0169 |
| Auxonopus | 12 months | 2 | 58 | 0.0070 |
| Auxonopus | 12 months | 3 | 53 | 0.0073 |
| Teak | 12 months | 1 | 36 | 0.0073 |
| Teak | 12 months | 2 | 26.4 | 0.0083 |
| Teak | 12 months | 3 | 29.9 | 0.0073 |
| Mahogoni | 12 months | 1 | 19.7 | 0.0141 |
| Mahogoni | 12 months | 2 | 21.7 | 0.0155 |
| Mahogoni | 12 months | 3 | 30.1 | 0.0013 |
| Eucalyptus | 12 months | 1 | 30.4 | 0.0074 |
| Eucalyptus | 12 months | 2 | 30 | 0.0213 |
| Eucalyptus | 12 months | 3 | 35 | 0.0027 |
| Eucalyptus x Auxonopus | 12 months | 1 | 40 | 0.0071 |
| Eucalyptus x Auxonopus | 12 months | 2 | 52 | 0.0074 |
| Eucalyptus x Auxonopus | 12 months | 3 | 27.2 | 0.0071 |
| Eucalyptus x Teak | 12 months | 1 | 42 | 0.0073 |
| Eucalyptus x Teak | 12 months | 2 | 38 | 0.0074 |
| Eucalyptus x Teak | 12 months | 3 | 34 | 0.0073 |
| Eucalyptus x Mahogoni | 12 months | 1 | 14.4 | 0.0141 |
| Eucalyptus x Mahogoni | 12 months | 2 | 18 | 0.0071 |
| Eucalyptus x Mahogoni | 12 months | 3 | 14.4 | 0.0073 |

**Appendix 05: Values of chemicals and nutrients in leaf of four different plant species.**

| Leaf ID | Plantation | Replicates | Total P (%) | Total N (%) | Phenol (%) | Tannin (%) |
|---|---|---|---|---|---|---|
| E1 | Eucalyptus | 1 | 0.025 | 0.712 | 4 | 0.095 |
| E2 | Eucalyptus | 2 | 0.0025 | 0.712 | 3.08 | 0.07 |
| E3 | Eucalyptus | 3 | 0.0125 | 0.747 | 3.603 | 0.039 |
| M1 | Mahagony | 1 | 0.00228 | 0.783 | 4 | 0.364 |
| M2 | Mahagony | 2 | 0.025 | 1.032 | 4 | 0.347 |
| M3 | Mahagony | 3 | 0.875 | 0.854 | 4 | 0.373 |
| T1 | Teak | 1 | 0.0125 | 0.889 | 1.452 | 0.013 |
| T2 | Teak | 2 | 0.025 | 0.889 | 1.277 | 0.01 |
| T3 | Teak | 3 | 0.075 | 0.854 | 1.898 | 0.022 |
| A1 | Auxonopus | 1 | 0.01083 | 0.996 | 0.263 | 0.001 |
| A2 | Auxonopus | 2 | 0.1625 | 0.889 | 0.259 | 0.01 |
| A3 | Auxonopus | 3 | 0.00912 | 0.889 | 0.333 | 0.037 |