EFFECT OF BARK AND STEM EXUDATES OF *Eucalyptus camaldulensis* L. ON THREE AGRICULTURAL CROPS

A THESIS

BY

ISRAT JAHAN SARMIN

Registration No. 1605112

Session: 2016

Thesis Semester: January-June, 2017

MASTER OF SCIENCE (M.S.)
IN
AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

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Hajee Mohammad Danesh Science and Technology University, Dinajpur.

June 2017

Dedicated

To

My Beloved Parents And

Honorable Teachers

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June, 2017 *The Authoress*

EFFECT OF BARK AND STEM EXUDATES OF *Eucalyptus camaldulensis* L. ON THREE AGRICULTURAL CROPS

ABSTRACT

A study was conducted in the the Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during October 2016 to March 2017. There were two experiments in the study. Experiment 1 was conducted to find out the effect of bark and stem exudates of *Eucalyptus camaldulensis* on the three agricultural crops in laboratory condition. There were three concentrations of bark and stem seperately *viz.*, 10%, 25%, 50% and a control (only water). Experiment 2 was conducted with 50% concentration of bark and stem exudates in the field condition of 1m x 1m plot size. In both experiments three agricultural crops namely Maize (*Zea mays*), Country bean (*Lablab purpureus)* and Bottle gourd (*Lagenaria siceraria)* were taken to satisfy the objectives of the study. Designs of laboratory and field experiments were CRD and RCBD with three replications, respectively. Results of laboratory experiment showed that 50% concentration of both bark and stem exudates of *E. camaldulensis* inhibited more in germination of all three tested crops compared to other concentrations. Bark exudates of *E. camaldulensis* showed germination percentage 24.74% in Maize, 31% in Country bean and 54.33% in Bottle gourd over control and stem exudates of *E. camaldulensis* showed germination percentage 35.36% in Maize, 37.33% in Country bean and 45.67% in Bottle gourd over control. The results indicated that inhibition increases with the increase of concentration. In case of field experiments, both bark and stem exudates of *E. camaldulensis* also inhibited the germination of the three tested crop. Application of 50% concentration of *E. camaldulensis* bark exudates showed germination percentage 52.0% in Maize, 34.33% in Country bean and 50.0 % in Bottle gourd over control and 50% stem exudates showed germination percentage 40% in Maize, 19.67% in Country bean and 40% in Bottle gourd over control. Morphological parameters like plant height (cm), collar diameter (mm),central root length (cm), no. of first order lateral roots showed significantly higher growth in control over bark and stem exudates in all the tested crops at both the laboratory and field experiments. Similar results were recorded for biomass allocation like shoot dry weight (g), root dry weight (g), total dry weight (g), shoot/root ratio and quality index. From the results of laboratory experiment it is also indicated that though both bark and stem exudates inhibited the germination of Maize, Country bean and Bottle gourd in different rates but inhibition by stem exudates is less compared to bark exudates of respective crops except bottle gourd. In the field experiment, inhibition by bark exudates is less compared to stem exudates of respective crops.Consequently, germination speed of tested crops was more in control than bark and stem exudates of *E. camaldulensis* due to the inhibitory effect. From the overall result it can be concluded that in addition to the allelopathic effect of leaf and root of *E. camaldulensis*, bark and stem have also allelopathic effect on the agricultural crops which inhibited more in laboratory compared to field condition. This effect may be minimized through proper management of the agroforestry field by removing the fallen bark and stem residues.

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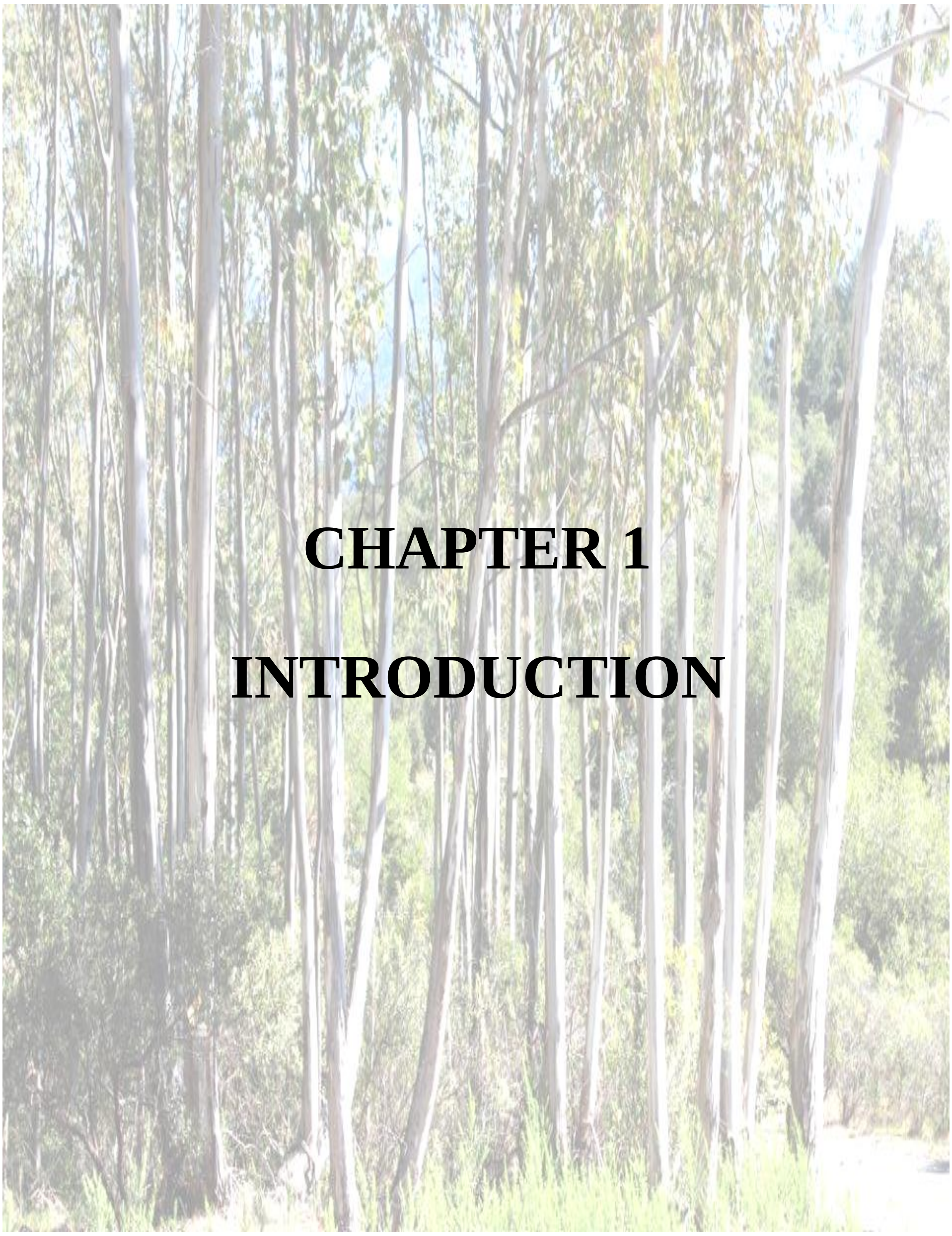
ACRONYM AND ELABORATIONS

AEZ	=	Agro-ecological zone
BADC	=	Bangladesh Agriculture Development Corporation
CRD	=	Complete Randomized Design
e.g.	=	For example
FOLR	=	First Order Lateral Root
HSTU	=	Hajee Mohammad Danesh Science and Technology University
i.e.	=	That is
MS Excel	=	Microsoft Excel
QI	=	Seedling Quality Index
RCBD	=	Randomized Complete Block Design
RCD	=	Root Collar Diameter



CHAPTER 1

INTRODUCTION

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INTRODUCTION

Agroforestry has attracted a great attention in recent years because of its potential to reduce poverty, improve food security, reduce land degradation and mitigate climate change (Luedeling *et al.,* 2016). It can also provide a more even income for landowners since all of their income is not tied to a few crops or a single season. In agroforestry system as trees grow in close proximate to crops, interaction takes place and this interaction between trees and crops are common phenomena. The spatial root distribution of plants to be important for interspecific interactions in agricultural intercropping, few experimental studies have quantified patterns of root distribution and their impacts on interspecific interactions in agroforestry systems (Zhang *et al.,* 2013), competitive interactions between trees and crop causes decrease in productivity and the economic yield of intercropping system (Cao *et al.*, 2012). Besides this positive and negative interaction or above and below ground interaction (Ong *et al.,* 1991), many researchers found the allelopathic effect of trees on crops (Zhang and Fu, 2010). Some trees are considered of having allelochemicals and volatile compounds in all parts. These chemicals (allelochemicals) have harmful effects on the crops in the ecosystem resulting in the reduction and delaying of germination, mortality of seedling and reduction in growth and yield (Ghafar *et al*., 2000) and this effect is called allelopathic effect.

The term allelopathy is a Greek word meaning to suffer from each other. The allelopathic study has become a major issue nowadays. The effect of these allelochemicals has traditionally been considered as negative on other organisms. Allelochemicals inhibit seed germination by blocking hydrolysis of nutrients reserve and cell division and cause significant reductions in the growth of plumule and radical of various crops (Kayode and Ayeni, 2009). Some studies focus that allelochemicals are present in many organs, including leaves, flowers, fruits and buds (Inderjit, 1996; Ashrafi *et al.,* 2007). The allelochemicals have diverse applications in agriculture, especially in weed management in crop systems as growth regulator, weed maganement and as pesticides etc. Most of the studies asserted the inhibitory action of allelochemicals as well explored known dimension of allelopathy on the weed and pest management with the use of allelochemicals (Rizwan *et al.,* 2017).

Allelochemicals are present in practically all plant tissues. Modern research suggests that allelopathic effects can be both positive and negative, depending upon the dose and organism affected (Rice, 1984). Allelopathic interactions might lead to either stimulation or inhibition of growth. Allelopathy has the active or passive effects which influence the releaser itself or other organisms.Besides trees weeds also have allelopathic effect. Decline in crop yields in cropping and agroforestry system in recent years has been attributed to allelopathic effects (Oyun, 2006). Willis (1991) and Luo (2005) stated that less vegetation exists under *Eucalyptus* canopy than indigenous trees. Study by Lin *et al.,* (2003) showed that water, ethanol, or acetone extracts from *Eucalyptus* also have allelopathic effect on *Pisolithus tinctorius,* a common fungus in South China.

Several studies focused on the allelopathic effects caused by forest trees (Blanco, 2007). The forest trees, *Eucalyptus* spp were tested for their allelopathic effects on different plant species (Del Moral and Muller, 1970, Sasikumar *et al.,* 2001, Zhang and Fu, 2009, Kikuchi *et al.,* 2009).

The word *Eucalyptus* comes from Greek words “Eu” and “Kalypta” with the meaning “Well” and “Cover” respectively.Therefore the name *Eucalyptus* refers to the small cap covering the closed flower and described as ever green flowering tree and shrubs concerning the specific habitats (Chappendal, 1993). *Eucalyptus* belongs to the family Myrtaceae and mostly found in tropical region (Hegab *et al.*, 2016). The total numbers of *Eucalyptus* species are estimated to be more than 700, originated in Australia and its neighbouring countries (Zhang and Fu, 2009, Bonald *et al*., 1984; Gratapaglia and Sederoff, 1994); about 30 species are widely grown as exotics around the world.

Eucalyptus is a cropland agroforestry tree species planted along with various annual crops like paddy, wheat, and cereals and other cash crops in farmers’ lands either in scattered or in bund (Raj *et al.,* 2016). *Eucalyptus camaldulensis* is one of the most important plants used to prevent soil erosion and to recover the plant cover. This plant also used in farmland as windbreak and medical plant (Saberi *et al.*, 2013).

Many studies have evaluated the allelopathic effects of *Eucalyptus camaldulensis* and confirmed the strong inhibitory effects of *Eucalyptus* extracts on some crops (Zhang and Fu, 2010). Leaf extract of *Eucalyptus* inhibited seed germination and reduced root and shoot lengths of cucumber and maximum inhibition was observed in higher concentrations of extract (Allolli and Narayanareddy, 2000). The leaf leachate of *E.*

globulus inhibited germination and growth of rice, sorghum and blackgram (Djanaguiraman *et al.*, 2005). Moreover, the extract of *E. globulus* inhibited germination and seedling growth of greengram and cowpea (Djanaguiraman *et al.*, 2002) and blackgram (Sasikumar *et al.*, 2002). El-khawas and Shehata (2005) found that leaf extract of *E. globulus* inhibited germination of maize and kidney-bean. The allelopathic effect of extract from *E. camaldulensis* was tested on tomato; the extract significantly inhibited germination and growth of this plant (Fikreyesus *et al.*, 2011). Allelopathic effects of *Eucalyptus* are widely reported and are considered the major factor limiting the cultivation of agricultural crops intercropped. However, reports of the allelopathic effects of *Eucalyptus* are mostly based on laboratory bioassay, not on field trials (Wasihun Regu, 2012).

Eucalyptus camaldulensis have been introduced into many countries, owing to their fast growth and their rising demand for paper and plywood (Cossalter and Pye-Smith, 2003). *Eucalyptus* is widely grown in the tropics and subtropics and thus is of great commercial importance. At present, *Eucalyptus* is grown on more than 20 million ha of plantations around the world (Booth, 2013). In Bangladesh, like many other developing countries, *Eucalyptus* was introduced in the 19^{th} century (Hossain and Hoque, 2013). To fill the widening gap between supply and demand of forest raw materials, many *Eucalyptus* species are grown in homestead, road side and cropland agroforestry (Malik, 2004) for fast growth, wider adaptability and high productivity. But there is continuing controversy about the ecological functions of *Eucalyptus*; it reduces the diversity and productivity of under storey species because of its negative effects on other plant species (May and Ash, 1990). Aqueous extracts of *Eucalyptus* are known to exert phytotoxicity on many weeds and crops, but there is also experimental evidence of the relative tolerance of maize (Carolina *et al*., 2013).

Eucalyptus species effect on the environment, on undergrowth vegetation and soil fertility may vary within different geographical areas, rainfall regimes and between species. So to discourage or promote the planting of *Eucalyptus* and to use them for agroforestry purposes, sufficient scientific evidences on the ecological impact, on undergrowth vegetation, soil fertility, and the quality of the product should be further investigated (Kumar *et al*., 2008).

In the traditional agroforestry system, people are growing several tree species in or around the agricultural fields as a boundary or woodlot. Among these are *E.*

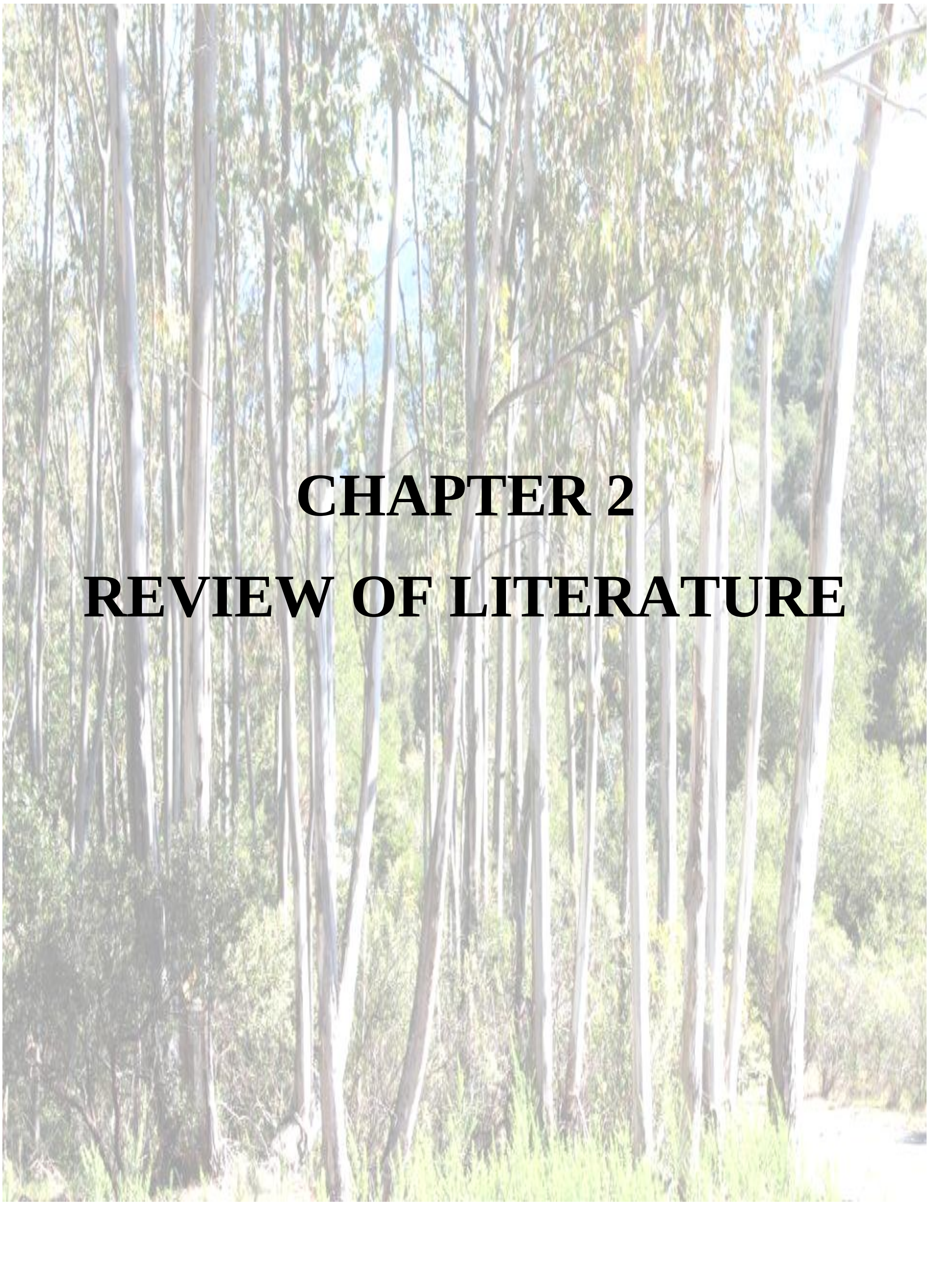
grandis and *E. camaldulensis* and due to their adverse effects some of the farmers are now reluctant to grow these tree species in their agricultural fields (CNST, 1997).

Very few researches have yet been undertaken to verify objections under Bangladesh conditions. In some cases, it is assumed that the effects in Bangladesh are the same as those in India (Hossain and Hoque, 2013). Certain phenolic acids and volatile oils released from the leaves, bark, stem and roots of certain *Eucalyptus* spp. act as allelopathic agents and are harmful to other plant species (Florentine and Fox, 2003). The allelopathic effects have been mostly studied of leaf litter and root extracts and least of live stem and bark exudates (Zhang and Fu, 2010). As *E. camaldulensis* is now an integral part of our agroforestry system. Due lack of knowledge of allelopathy, people sometimes are getting low income from the practice. Therefore this study will be an attempt to assess the effect of bark and stem exudates of *Eucalyptus camaldulensis* on germination and growth of three agricultural crops in different concentrations.

Objectives:

The study was carried out with the following objectives:

1. To assess the effects of bark and stem exudates of *Eucalyptus camaldulensis* on germination and seedling growth of maize, country bean and bottle gourd.
2. To find out above and below ground biomass allocation of the tested crops due to the exudates.
3. To measure root architecture of maize, country bean and bottle gourd due to the effect of *E. camaldulensis* bark and stem exudates.



CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Agroforestry is relatively a new area of research. A lot of studies have been conducted on allelopathic effect of agroforestry tree species on vegetable crops but very few research projects have been done to observe the effects of *Eucalyptus camuldulensis* under Bangladesh conditions (Hossain and Hoque, 2013). Therefore, the research was carried out to observe the effects of *Eucalyptus camuldulensis* on some agricultural crops like country bean, bottle gourd, maize. Literatures some way linking to the subject of interest from home and abroad are reviewed and outlined below the following headings:

2.1 Concept of Agroforestry

The word agroforestry is derived from the combination of two words that is agro, meaning "agriculture crops," and forestry, meaning "forest trees”. It is a farming method that allows trees and shrubs to grow along with agriculture crops and/or livestock that means blending agriculture and forestry in the same production system.

Agroforestry is a system which is not only ecologically rational but also economically sound. In recent years, agroforestry is developed as a science for improving the productivity, profitability and sustainability of production of available lands, and soil conservation.

Agroforestry has three components that are forestry (trees), agriculture (crops) and livestock (animals)/fodder and forage. The combination of these components is known as agroforestry. However, the definitions of agroforestry given by various scientists and institutions are as follows:

"Agroforestry is a sustainable management system for land that increases overall production, combines agriculture crops, tree crops, and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population" (Bene *et al.*, 1977).

Nair (1977) defined Agroforestry is a land use system that integrates trees, crops and animals in a way, which is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers.

"Agroforestry has been defined as a sustainable land management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population" (King and Chandler, 1978).

King (1978) to add to the definitions, to explain more fully the concepts of agroforestry, and to delineate various sub-divisions of the subject. Agroforestry should be considered to be a generic term which embraces the following specific components:

Agri-silviculture - the conscious and deliberate use of land for the concurrent production of agricultural crops (including tree crops) and forest crops.

Sylvo-pastoral systems - land management systems in which forests are managed for the production of wood as well as for the rearing of domesticated animals.

Agro-sylvo-pastoral systems - in which land is managed for the concurrent production of agricultural and forest crops and for the rearing of domesticated animals. This system is, in effect, a combination of agri-silviculture and the sylvo-pastoral system.

Multi-purpose forest tree production systems - here forest tree species are regenerated and managed for their ability to produce not only wood, but leaves and/or fruit that are suitable for food and/or fodder.

Agroforestry is a land use practice in which farmers deliberately integrate woody perennial plants—trees and shrubs—with crops or livestock on the same tract of land. Agroforestry systems, (whereby there is a deliberate planting of trees in combination with food/forage crops for the benefit of people and the environment) have been reported to be potentially productive in degraded and marginal soils. The trees and shrubs in agroforestry systems can be selectively protected and regenerated, or planted and managed. Agroforestry systems can include native species as well as introduced non-native species. As farmers include woody species that produce wood, fodder, edible leaves, and other products, agroforestry systems evolve into more complex production systems that can provide a broader range of benefits and more resilient farming systems than those relying on simplified annual crop production. There are numerous definitions of agroforestry which stress different aspects of and expectations about the integration of trees in farming landscapes. Following the predominant definition over the past two decades, agroforestry is a set of land use practices that involve the deliberate combination of woody perennials including trees, shrubs, palms and bamboos, with agricultural crops and/or animals on the same land management unit in some form of spatial arrangement or temporal sequence such that there are significant ecological and economic interactions among the woody and non woody components (Sinclair, 1999).

Agroforestry practices offer practical ways of applying various specialized knowledge and skills to the development of sustainable rural production systems. Agroforestry is recognized as a land use option in which trees provide both products and environmental services. In agroforestry systems, the trees grown on different farmlands in the same locality when aggregated can bring about improved wooded situation thereby enhancing environmental protection (Otegbeye, 2002).

World Agroforestry Center (ICRAF, 2000), agroforestry is defined here as a dynamic, ecologically based natural resource management practices that, through the integration of trees and other tall woody plants on farms and in the agricultural landscape, diversifies production for increased social, economic and environmental benefits.

Agroforestry has been defined as a dynamic, ecologically based natural resources management system that through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Leakey, 1996).

Saxena (1984) pointed out that agroforestry utilizes the inter space between tree rows for intercropping agricultural crops and that does not impair the growth and development of the trees but enables farmers to derive extra income in addition to benefits accrued from the use of fuel and timber from trees.

The International Centre for Research in Agroforestry (ICRAF, 1997) defines agroforestry as a dynamic, ecologically based, natural resources management system that through the integration of trees on farms and in the agricultural landscape diversifies and sustains production for increased social, economic and environmental benefits for all land users at all levels.

Agroforestry include the optimal use of land for both agricultural and forestry production on a sustainable basis including the improvement of the quality of soil. This is in addition to the socio-economic benefits that are accruable from agroforestry. Indeed the advantage of agroforestry is all encompassing and germane to a sustainable production system and livelihood. (Alao and Shuaibu, 2013)

Saka *et al*. (1990) stated that an agroforestry system can provide a sound ecological basis for increased crop and animal productivities, more dependable economic returns and greater diversities in social benefits on a sustained basis.

Agroforestry has been defined as a dynamic ecologically based natural resources management system that through the integration of trees on farms and in the agricultural landscape diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Verma *et al.,* 2016).

Lundgren and Raintree (1983) defines agroforestry is a collective name for land use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, in either a spatial arrangement or a temporal sequence, there being both ecological and economical interactions between the different components.

Whether on marginal or high-potential lands, diversified agroforestry systems may be the most appropriate form of land use where land tenure constraints, lack of marketing infrastructure or an unfavourable political economy make it imperative for small landholders, in trying to reduce risks, to try to satisfy most of their basic needs directly from the land resources under their control (Lundgren and Raintree, 1983).

2.2 Tree Crop Interaction

The integration of agriculture and/or farming with forestry so the land can simultaneously be used for more than one purpose. This practice is meant to have both environmental and financial benefits.

In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Raintree, 1982).

When promoting agroforestry one should then stress the potential of it to achieve certain aims, not only by making theoretical and qualitative remarks about the benefits of trees, but also, and more importantly, by providing quantitative information (Lundgren, 1982).

Whenever tree-crop combination is tried as an agroforestry intervention, there can be strong above-ground and below-ground interaction for critical and limited resources. In general, trees have been found to improve soil physical and chemical properties by various means (Nair, 1984; Lai, 1989).

Trees act as nutrient pumps i.e. exploiting the nutrients from the deeper depths and in the process of recycling make it accessible to the companion shallow rooted ground crop (Kellman, 1979; Yamoah *et al.,* 1986). This situation although is not applicable where "cut and carry" practice is a common feature which depletes the soil nutrients year after year and may result into unsustainable proposition (Nair, 1993). The intensity and severity of interaction for nutrients between the trees and crops will depend on the planting geometry and density of each component. However, direct evidence as to where, and how severely, nutrient competition occurs is limited due to the difficulties of separating nutrient competition from competition for light, water and from allelochemical interactions (Young, 1989). Imo and Timmer (2000) concluded that tree-crop interactions are not constant, and may be affected by severalfactors, including total planting densities, component combinations, climatic and soil conditions, and management regimes.

Tree-crop combination competes for available moisture in the soil, more severely under rainfed agroforestry system. So, inadequate moisture will become the limiting factor which will deleteriously affect the growth and yield of the components (Singh *et al.,* 1989; Corlett *et al.,* 1989).

Progress in promoting agroforestry is held back because decision-makers lack reliable tools to accurately predict yields from tree-crop mixtures. Amongst the key challenges faced in developing such tools are the complexity of agroforestry, including interactions between various system components, and the large spatial domains and timescales over which trees and crops interact. A model that is flexible enough to simulate any agroforestry system globally should be able to address competition and complementarity above and below ground between trees and crops for light, water and nutrients. Most agroforestry practices produce multiple products including food, fiber and fuel, as well as income, shade and other ecosystem services, all of which need to be simulated for a comprehensive understanding of the overall system to emerge. Several agroforestry models and model families have been developed, but as of 2015 their use has remained limited for reasons including insufficient flexibility, restricted ability to simulate interactions, extensive parameterization needs or lack of model maintenance. An efficient approach to improving the flexibility and durability of agroforestry models is needed. Various types of agroforestry systems are currently being promoted in many contexts, and the impacts of these innovations are often unclear. Rapid progress in reliable modeling of tree and crop performance for such systems is needed to ensure that agroforestry fulfills its potential to contribute to reducing poverty, improving food security and fostering sustainability (Luedeling *et al.*, 2016).

Modeling competition and complementarity in capture of light, water and nutrients must often be considered in attempts to predict yield of tree-crop mixtures. The impact of trees on crop microclimate can be of key importance (Ong *et al.*, 2015). In all crop models, crop growth is simulated as a response to available water and ambient temperature, often also to light capture. All of these are substantially altered by trees, and the impact will depend on tree canopy structure and, for water, on rooting patterns (Anderson and Sinclair, 1993). Accurate simulation of these interactions is one of the major challenges in agroforestry modeling, since they are central for verifying one of the primary pathways through which agroforestry is expected to contribute to climate change adaptation in hot climates. Likewise, competition and complementarity below-ground is an area for model development. How water and nutrients are partitioned between different parts of the tree, as well as between trees and crops is one of the more complex questions in agroforestry modeling. To what level of detail these processes should be simulated is amongst the central decisions that an agroforestry modeler has to take. There are certainly arguments for simulating many nutrient and water acquisition processes at the root level, including hydraulic lift, but the complexity that this might add to a model, its parameterization needs and processing time during simulation runs may often not be desirable.

Incorporation of tree hedges along contours has been proposed as a means of reducing soil erosion and increasing soil fertility of tea (*Camellia sinensis* L.) plantations on sloping terrain in high-rainfall zones of Srilanka. Tea yields in these hedgerow intercrops are determined by the balance between the positive (i.e., increased soil fertility) and negative (i.e., resource competition) effects of hedgerows.Tea yields, measured over one complete pruning cycle from October 1998 to September 2001, showed reductions relative to a sole tea crop under all hedgerow species except *Euphatorium*. The yield reductions ranged from 22 to 40%. Tea yields under *Euphatorium* showed increases up to 23% relative to the sole crop control. Addition of hedgerow prunings as mulch increased tea yields in all hedgerow intercrops. The yield increases ranged from 11 to 20%, with the highest being under *Euphatorium*. Tea yields showed a negative relationship (R^2=0.38) with the pruned biomass of hedgerows. Limitation of environmental resources (e.g., water and light) and hedgerow characters which intensified resource competition (i.e., greater canopy lateral spread and height and greater root length densities, especially in the top soil layer) were responsible for observed tea yield reductions in hedgerow intercrops (De Costa and Surenthran, 2005).

Integration of trees in agroforestry system results in positive or negative interactions between trees and crops. Micro-climate amelioration and maintenance or improvements in soil productivity are the major positive interactions while competition for light, water and nutrients, and allelopathy are the major negative interactions in agroforestry systems. The balance between negative and positive interactions determines the over all effect of interactions in a given agroforestry system. Selection of suitable tree species for agroforestry is important, however many a times it is not possible to select tree species having all the desirable characters for agroforestry because of different production or protection goals. In such situations agroforestry systems have to be managed through planting optimum density of trees, proper spatial arrangement and pruning and thinning of tree crowns and roots to reduce the negative effects of trees (Basavaraju and Rao, 2000).

In recent decades, integrating trees with crops for food and wood production has received considerable attention in both tropical (Garrity *et al.*, 2010) and temperate regions (Palma *et al.*, 2007). Agroforestry has shown potential to increase and sustain food production per unit area in systems like the parklands of the Sahel (Bayala *et al.*, 2012), through the use of ‘fertilizer trees’ intercropped or in fallow rotations with crops throughout sub-Saharan Africa (Sileshi *et al.*, 2008) and through integrating trees with crops on sloping land (Tiwari *et al.*, 2009). It is increasingly seen as a promising approach to improving food security (Glover *et al.*, 2012), largely because the trees are associated with enhancing and sustaining soil health and hence crop yield (Barrios *et al.*, 2012). Trees also produce fodder, fuel and construction materials, which are in high demand in many rural areas and if produced on farm may reduce the costs of obtaining them off-farm. Through production of high value timber, farmers can often generate substantial additional revenue in both temperate (Dupraz *et al.*, 1997) and tropical contexts (Dupraz *et al*., 1997; Bertomeu, 2006; Santos-Martin and van Noordwijk, 2009). Fruits obtained from trees can enhance both income (Mithofer and Waibel, 2003; Luedeling and Buerkert, 2008) and human nutrition (Goenster *et al*., 2009; Kehlenbeck *et al*., 2013).

Agroforestry practices are often part of strategies to improve natural resource management (Ong and Kho, 2015), and they are often more effective than other land uses in providing regulating, supporting and cultural ecosystem services (Pagella and Sinclair, 2014), such as microclimatic buffering, amelioration of soil structure and water infiltration, reduction of overland flow, regulation of the water cycle and provision of habitat for wild species (Bayala *et al.,* 2014). The potential of agroforestry practices to sequester carbon in wood and soil has been widely demonstrated (Luedeling *et al*., 2011; Kuyah *et al*., 2013). Agroforestry may also affect emissions of other greenhouse gases either positively or negatively (Rosenstock *et al.*, 2014) and is expected to help farmers adapt to climate change through the risk-mitigating effects of additional farm products derived from trees, positive microclimatic effects through shading and enhanced farm productivity through tighter nutrient and water cycles (Garrity *et al.,* 2010).

Agroforestry interventions are envisaged in many places, including locations where they have never been tested. In a number of cases, substantial positive contributions of agroforestry to food security, natural resource management, and climate change mitigation and adaptation have been demonstrated, but it is clear that not all these successes can be replicated everywhere. The magnitude of all documented or assumed benefits of agroforestry depends on site-specific responses by trees, crops or other components of the system, with strong variation between locations and farming contexts (Coe *et al.,* 2014). Benefits also vary over time, because many effects of trees on soils are slow to materialize (Barrios *et al.*, 2012). For instance, the beneficial effects of *Faidherbia albida* on crop yields have been reported to start only after the trees reach 20 to 40 years of age (Ong and Kho, 2015).

The long life span of trees, and the large number of potential tree species means that it often takes a long time to establish the viability and relative merits of alternative agroforestry practices in new environments through empirical approaches. This makes recommendation domains for particular technologies difficult to delineate. Tools are needed for faster ex-ante assessment of performance potentials. Since planted trees can remain in place for decades, such tools need to consider the impacts of climate change (Luedeling *et al.*, 2014). Process-based modeling has been identified as a viable approach to making such projections (Bayala *et al.*, 2015), but a number of obstacles must be overcome for agroforestry models to successfully meet this challenge.

Many farming systems in developing countries are complex assemblages of several species, and they often include trees or other woody elements, that exhibit competitive as well as complementary interactions with field crops (Bayala *et al.,* 2015). Trees can affect crop production in a number of ways, negatively through competition for light, nutrients and water, as well as positively through increased input of biomass from leaves and roots that often enhance nutrient cycling (Rao *et al.*, 1998). Positive effects on crops may also arise through improved water relations (Bayala *et al.*, 2008) and microclimate (Muthuri *et al.*, 2014). Modeling approaches for capture of water, nutrients and light that produce reliable predictions in monocultures may not suffice in more complex situations, because they do not consider critical competitive and facilitative interactions between trees and crops. In monocultures, accurate prediction of the timing and location of water uptake, nutrient uptake and light interception, is less critical than in mixtures, because all modeled plants are similar in their uptake and interception characteristics. Resource availability dynamics in different soil layers and over a sequence of days can be thus simulated relatively easily. In mixed cropping situations, this may be true for aggregated plant growth, but not for growth of competing components (Van Noordwijk *et al.*, 1998). The wide range of existing empirical and mechanistic tree models that operates from leaf to stand scales, while capable of modeling discrete trees and, in principle, their interaction with crops, have rarely been successfully coupled with crop models (Van Oijen *et al.,* 2010). Similarly to monoculture crop models, most tree models are designed to simulate single trees or single-species forests or plantations. More complex arrangements, such as mixed-tree stands or seedling development in forests, have been modeled (Lopez-Serrano *et al.,* 2015), but such models remain limited to situations that are much simpler than most agroforestry settings (Porte and Bartelink, 2002).

Zhang *et al.* (2013) a field experiment was conducted to investigate the relationship between root distribution and interspecific interactions between intercropped jujube tree (*Zizyphus jujuba* Mill.) and wheat (*Triticum aestivum* Linn.) in Hetian, south Xinjiang province, northwest China. They found that the interspecific competition effects in jujube tree/wheat agroforestry systems.

In agro-ecosystems, several weeds, crops, agroforestry trees and fruits trees can interact negatively with crops by exerting an allelopathic influence on crops, thus, affecting their germination and growth adversely (Kohli *et al.,* 1998).

2.3 Allelopathy of different multipurpose trees /crops

Literature reveals that higher plant (tree-crops) releases some phytotoxins into soil, which adversely affect the germination and yield of crops. This type of tree-crop interactions was named phytochemical ecology/ecological biochemistry by (Harborne, 1977).

Parvin *et al.* (2017) carried out a study to determine the allelopathic effect solid bamboo *Dendrocalamus stocksii* on growth and yield of paddy. Results revealed that in lab experiment the increasing concentration of the leaf leachates had inhibitory effect on growth parameters (germination, plumule and radicle length) of paddy *(Oriza sativa)*, except the leachates of lower concentration (25% concentration), which had stimulatory effect on plumule length, the effect was concentration dependent. In pot culture experiment the leaf leachates had both stimulatory and inhibitory effect on yield parameters. Stimulatory effect was observed for number of tillers per plant, number of seeds per panicle, test seed weight (except 100% concentration), and straw yield per hectare as compared to control. While inhibitory effect was observed for number of panicles per plant, seed yield per plant (except 50 per cent concentration) and grain yield per hectare (except 50 % concentration).

Ayeni and Kayode (2013) worked on allelopathic effects of extracts derived from the residues of sorghum stem and maize inflorescence on the germination and growth of okra (*Abelmoschus esculentus* L.). Both crop residues (powder) inhibited the growth of okra. The degree of inhibition increased with increase in the concentration of the extracts, thus suggesting that the effects of the extracts from the residues were concentration dependent. Seeds treated with extracts from maize inflorescence revealed that there were no significant differences in the number of leaves at harvest, dry root weight and relative growth rate when compared to the results obtained in the control experiments. The degree of retardation was more pronounced in seeds treated with extracts derived from the residues of maize inflorescence.

Azadiracta indica, or Neem Tree, is an evergreen tree native to Southeast Asia. All parts of the tree have been used medicinally for centuries. It is widely used in toothpastes, soaps and lotion today, as well as biological insecticide. Neem (*Azadiracta indica*) is a versatile tree native to South and Southeast Asia, Japan, tropical USA, South America, Australia and Africa (Bokhari and Aslam, 1985; Von Maydell, 1986).

Amalraj and Shankarnarayan (1986) investigated that the aqueous extracts of *Balanites roxburghii* leaf fruit have inhibitory effects on germination of *Pennisetum typhoides, Sesamum indicum, Vigna radiate* and *Vigna aconitifolia.* At 10% concentration of extract, the germination percentage was reduced in all, but the effect was statistically significant only in the case of *Pennisetum typhoides.*

The allelopathic effect of three tree species (*Azardiracta indica, Vitellaria paradoxa, and Parkia biglobosa*) on germination and growth of cowpea was investigated in the Southern Guinea Savannah agro ecological zone of Nigeria. Results showed that the tree species brought about considerable inhibition in the germination of cowpea seeds and in its growth parameters. The statistical germination value of the cowpea seeds under the tree species had decreased value thus indicating that growth inhibitions were seriously felt. It was apparent that *Parkia biglobosa* (53.33) and *Vitellaria paradoxa* (60.00) had more inhibitory effect on cowpea seeds germinability than that of *Azardiracta indica*. (63.33) while all the treatments are lower than that of control (100). The tree species had similar inhibition capability in the cowpea plant height, stem circumference, number of leaves, above grand biomass and below grand biomass. (Aleem *et al.*, 2014).

Gulzar and Siddiqui (2015) conduct research to investigate the effect of aqueous extract from *Calotropis procera* on the growth of *Brassica oleracea var botrytis.* They found that higher concentrations of extract (60% and 80%) significantly reduced germination percentage, radicle length, plumule length, dry matter accumulation, and relative water content of the brassica seedlings as compared to control. The retardatory effect increases with the increase in the concentration of three types of extract used, with more pronounced effect noticed by leaf extract followed by fruit and flower extract. There were significant interactions among the different concentrations of extracts used, type of extract with respect to gemination percentage, seedling length, dry biomass, and relative water content. The effect of pot based assay in relation to chlorophyll content was significantly reduced and antioxidant enzymes [superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) activities] show both significant and non-significant effect on antioxidant enzymes based on concentrations of extract and extract type used. The antioxidant enzymes show the significant decrease in its activity at low concentrations (20% and 40%) and non-significant increase at higher concentration (60% and 80%) of extracts in contrast to control.

Albuquerque *et al.* (2010) observed that the phenomenon of allelopathy has recently received greater attention from researchers and farmers worldwide crop failures and low yields caused by the reseeding, over seeding, crop rotation and replanting of fruit trees in orchards are believed to be caused by allelopathic activity. Moreover, the expensive and environmentally impacting herbicides for weed control have motivated studies directed at developing cheaper, environmentally-friendly alternatives. The release and dynamics of allelochemicals in the soil are discussed herein. Examples of allelopathic crops, the allelochemicals produced and their uses in cropping systems are also presented along with current research trends regarding allelopathy.

Adhikary (2017).conducted a research to evaluate the allelopathic effect of *Xanthium indicum L.* on seedling growth and total chlorophyll content in green gram (*Phaseolus radiatus* L.). The results showed that different concentrations of various types of aqueous leachate of test weed (5, 10, 15, 20 and 25%) were reduced seedling growth and total chlorophyll content. The findings reveals that there might have diversified group of allelochemicals present in test weed which leached to soil medium and there after absorbed by crop plant where they reduced or inhibited the intermediate metabolic pathways as a result seedling growth and total chlorophyll content reduced.

Mubeen *et al*. (2012) conducted a study to evaluate the allelopathic effects of water extracts of sorghum and sunflower alone and in combination on the germination and seedling growth of rice and weeds *viz., Trianthema portulacastrum, Dactyloctenium aegyptium* and *Eleusine indica*. Distilled water treatment was included as control. Sorghum and sunflower water extracts when applied in combination caused maximum inhibitory effects on time taken to 50% germination, mean germination time of *E. indica* seeds and germination index of *T. portulacastrum* seeds as compared to the sole application of these water extracts. Water extracts of sorghum and sunflower when applied alone or in combination increased the root, shoot length and the seedling biomass of rice over control. Combined application of sorghum and sunflower water extracts has overall more inhibitory effects on the germination of rice, *T. portulacastrum*, *D. aegyptium* and *E. indica* when compared to their sole application.

Manimegalai *et al.* (2012) worked out aspects of allelopathy in natural, managed and manipulated ecosystems are the role in agriculture. Extract were prepared from dried leaves using distilled water. The sterilized fifty seeds were placed in petridishes containing different concentrations of *Tectona grandis* leaf extract (5, 10, 25, 50, 75 and 100%). Seeds with distilled water were maintained as control. The emergence of radicle was taken as criteria for germination from 2nd day after sowing. Germination percentage was maximum in 5% extract treatment and the percentage of germination was gradually decreased as the concentration of extract increased. A low percentage of germination was observed in 100% concentration of leaf extract. The 5% extract alone showed a promontory effect, while the other concentrations exhibited inhibitory effect. The intensity of inhibition increased as the concentration of the leaf extract increased.

Hossain *et al*. (2012) carried out a study to examine the allelopathic effect of different concentrations of leaf, root, bark, fruit kernel and seed aqueous extracts of *Moringa oleifera* on the germination of *Vigna radiata* cv. BU Mung 4. The rate of germination of *V. radiata* decreased with the increase of aqueous extract concentration, irrespective of plant parts. The rate of germination was found to suffer more when treated with 10.0, 12.5 and 15.0% extracts. Among the plant parts root and bark aqueous extract were found to inhibit mungbean germination more than the other plant parts used. The inhibitory effect of leaf, fruit kernel and seed aqueous extracts were almost similar, while those were relatively less than bark and root extracts. The allelochemicals released from different plant parts of *M. oleifera* impeded the rate of germination in laboratory condition.

Hassan *et al.* (2012) studied the allelopathic potential of the aqueous extracts and powder of Khella (*Ammi majus*), Ghobaish (*Guiera senegalensis*) and Safsaf (*Salix spp*.) on germination and seedling growth of two *Sorghum bicolor* L. cultivars. Khella extract sustained the maximum reduction in germination percentage and mean germination time. Botanical extracts exhibited extra inhibitory effects on radical emergence than on plumule growth. Pot experiment indicted variations in seedlings germination and postgermination growth between the two cultivars in response to different botanical residues. Fatarita seedling emergence improved by Khella and decreased with Ghobaish and Safsaf. While, Hybrid seedling emergence improved with Ghobaish and Safsaf and reduced by Khella as compared to control. The higher MGT was recorded in Fatarita in some treatments as compared to control. Hybrid exposes a constant MGT in all treatments. Botanical extracts stimulated some growth parameters and reserve others in both cultivars. The results suggest that allelopathic potentials of these plants may entitle them to control specific weeds especially in non-sequential crops by preparing them as natural herbicides.

Gupta and Mittal (2012) studied the allelopathic effects of some selected weeds (*Phalaris minor* L., *Chenopodium murale* L., *Sonchus oleraceus* L., *Cyanodon dactylon* L. and *Convolvulus arvensis* L.*)* of Ajmer district on seed germination and seedling growth of wheat (*Triticum aestivum* L.). Root, stem and leaf aqueous extracts of weeds at 2, 4, 6, 8, 10% concentrations were applied on test plant under laboratory conditions. The aqueous extracts of all the weeds under study caused inhibitory effects on seed germination; seedling length and seedling dry weight of crop, which increased progressively on increasing the concentration of weed plant part extracts. The leaf extract of *Phalaris minor* have more inhibitory effect on the germination percentage of crop as compared to other weeds under study. The inhibition caused by the leaf extract of *Phalaris minor* was found to be more than stem and root extracts of all the weeds under study.

Evangeline *et al*. (2012) studied the allelopathic impact of *Tectona grandis* L. on the germination and seedling growth of *Vigna mungo* (L.). Seed germination and seedling growth of *V. mungo* were inhibited. In addition, the reduction of seed germination was found to be up to 48% at 10% concentration. At this concentration, the epicotyls showed 67.30% reduction in length when compared to the control. Consequently, the hypocotyl demonstrated 64.70% reduction in length. In pot culture experiments, a 4% aqueous extract of the leaves was found to inhibit seed germination and the growth of the seedlings. This concentration of leaf extracts reduced seed germination percentage to the tune of 70.00%. There was reduction in shoot length to about 33.30% and the root length about 54.30%. Higher concentration of aqueous extracts of the leaves prevented seed germination. As for the biomass of *V. mungo* is concerned, aqueous extracts of the leaves of *T. grandis* caused a corresponding reduction.

Ashafa *et al.* (2012) carried out an investigation on the allelopathic effects of dry and fresh aqueous leaf extracts of *Mangifera indica* at 5, 10, 15 and 20% on the seed germination percentage and seedling growth rate of C*assia occidentalis* seeds in a greenhouse. Both dry and fresh leaf extracts exhibited different degrees of inhibition in *C. occidentalis* germination percentage and growth rate of seedlings at varying concentration. Dry leaf extract at 15 and 20% completely inhibited the emergence of *C. occidentalis* while the aqueous fresh leaf extract at these concentrations yielded some degree of seed germination and growth rate. The seedling radicle and plumule length were adversely affected as the treatment level increases in both extracts. The concentration dependent responses of *C. occidentalis* to both dry and fresh leaf extracts confirmed that both extracts contain allelochemicals which are likely to be phenolic compounds. On the basis of overall toxicity potency of *M. indica* leaves, result showed that 15 and 20% dry leaf extract exerted the highest germination percentage and growth inhibition on *C. occidentalis* seeds. The compounds from *M. indica* leaves especially the dry ones possess a strong phytotoxic potential and can serve as lead molecules for the synthesis of bioherbicides**.**

Shapla *et al.* (2011) revealed that inhibition of germination and growth parameters of mungbean and soybean were varied according to different parts of plants and soil from different place. *Melia azedarach*: T2 (root zone soil) >T3 (soil mulched dry leaf) >T4 (soil watered with aqueous leaf extract T1 (top soil T5 control / fresh garden soil).

Alagesaboopathi (2011) reported that leaves stem and root extracts of *Andrographis paniculata* significantly decreased germination and seedling growth in *Sesamum indicum*.

Alagesaboopathi and Deivannai (2011) stated that the plumule and radicle length of *Cajanuscajan* var. Vamban 2 and var. Vamban 3 seedlings with increase of *S. grandiflora* extracts concentration. The result revealed that the inhibitory and stimulatory effect may be due to the presence of these allelochemicals like sterols, saponins, phenols and tannins.

Mehar (2011) reported that mesquite (*Prosopis juliflora* (Sw.) DC.), which is widespread in Saudi Arabia, United States of America and India, inhibits the germination or growth of many plant species growing in its vicinity, through by releasing allelopathic substances into the environment. Due to this, it has not been put to good use despite of enormous biomass production. The present study was attempted to observe the effect of aqueous extract of mesquite tree on the growth of rice seedlings. For this two different concentrations of an aqueous extract (0.1 and 1%) were used as treatments. The results indicated that except for some treatments, both at low concentrations; most of the treatments had led to comparable or better growth of seedlings than the control treatment. Even when there was less reserve mobilization from seeds during germination; seedlings were able to make up the loss in due course of time and showed better growth than control.

Rebecca and Sahoo (2011) studied the effects of aqueous leaf extracts of *Tectona grandis* L. and *Mikania micrantha* L. on germination and growth of *Zea mays* L. (maize) and *Oryza sativa* L. (paddy) during 2009-2010. The extracts suppressed the germination of paddy to an extent of 10-30% under high extract concentration and 40-50% suppression in maize under similar concentration. The growth of root and shoot of both the test crops also got suppressed under high extract concentration. Similar was also the case with *M. micrantha* where germination of paddy was suppressed to an extent of 10-35% and 45-65% suppression in maize under high extract concentrations. As the concentration increased from 30-100% the aqueous leaf extract of *M. micrantha* has detrimental effect on the root and shoot growth of both the test crops.

Dhole *et al.* (2011) investigated the allelopathic effect of five weed species *viz.*, *Ameranthus tricolor* L., *Euphorbia heterophylla* L., *Physalis angulata* L., *Alternanthera sessilis* L. and *Portulaca oleracea* L. collected from Jawar fields from Nanded District. The aqueous extract of *Portulaca oleracea* L. was found to be stimulatory effect towards seed germination root length, shoot length and seedling growth of Jawar. The *Physalis angulata* L. had shown inhibitory effect while *Ameranthus tricolor* L., *Alternanthera sessilis* L. and *Euphorbia heterophylla* L. having moderate inhibitory effect. Further the allelopathic potential of five different weeds in same Jawar field and suggested that those weeds may affect Jawar seed germination and seedling growth due to inhibitory or stimulatory effect of allelochemicals which are present in the aqueous extract of weeds.

Salam and Kato (2010) studied allelopathic potential of aqueous methanol extract of Neem leaves on seed germination and seedling growth of different plants *viz.,* Cress (*Lepidum sativum* L.), Lettuce (*Lactuca sativa* L.), Alfalfa (*Medicago sativa* L.), Wild Buckwheat (*Eriogonum compositum*), Sand Fescue (*Festuca myuros* L.), Timothy

(*Phleum pratense* L.), Barnyard grass (*Echinochloa crusgalli*) and *Echinochloa colonum* .Neem leaves may contain growth inhibitory substances and may possess allelopathic potential. Therefore, Neem leaves may be a possible candidate for the isolation and identification of allelopathic substances and for the development of natural herbicides for sustainable agricultural production.

Hossain and Alam (2010) revealed that different concentrations of *Lantana camara* leaf extracts caused significant inhibitory effect on germination, root and shoot elongation and development of lateral roots of the *Oryza sativa* L., *Triticum aestivum* L., *Vigna sinensis* (L.) Hassk., *Cucurbita pepo* L., *Abelmoschus esculentus* (L.) Moench, *Amaranthus tricolor* L.) and forest crops (*Acacia auriculiformis* A. Cunn. ex Benth. And Hook., *Paraserianthes falcataria* (L.) Nielson, *Albizia procera* (Roxb.) Benth.

Sahoo *et al.* (2010) used aqueous leaf extract of different concentrations of *Mangifera indica* L. to investigate their effects on germination, shoot and root lengths and dry matter yield of 5 food crops *viz.*, *Capsicum annum* L. (Chilli), *Glycine max* (L.) Merr. (Soybean), *Zea mays* L. (Maize), *Oryza sativa* L. (Rice) and *Abelmoschus esculentus* (L.) Moench (Lady's finger). Both bioassays and pot culture indicated that the inhibitory effect was much more pronounced at higher concentrations, while the lowest concentration showed stimulatory effect in some cases. The most affected crop was lady's finger among the test crops. The inhibitory effect was much pronounced ($P<0.001$) in shoot and root lengths as compared with the germination of the receptor crops.

Romman *et al.* (2010) carriedout an investigation on effect of *Euphorbia hierosolymitana* in Wheat (*Triticum durum* local var. Hourani), in both laboratory and glasshouse. Higher concentration of aqueous leachate of *E. hierosolymitana* reduced the germination rate. On the other hand, the radicle and coleoptile length of the germinated seeds of Wheat were significantly inhibited by the leachate. Also, the aqueous leaf leachate of *E. hierosolymitana* was found to inhibit significantly the growth of Wheat seedlings. Allelochemicals caused significant reduction in root and shoot length, fresh, dry weights and decreased the amount of total chlorophyll and protein contents.

Rokiek *et al*. (2010) studied the effect of mango leaves on growth and propagative capacity of purple nutsedge. Two experiments were carried out include soil treatments with mango leaf extract(weekly for one month) at concentrations, 0, 5, 10, 15 and 25%.

The second experiment included soil treatments with mango leaf powder at the rate of, 0, 20, 40, 60, 80 and 100g/kg soil. Maximum inhibition was recorded by 25% leaf extract. Moreover, soil treatment with mango leaf powder showed significant reduction in dry weight of foliage and underground organs. The highest inhibitions were observed by using 80 and 100 g/kg soil of mango leaf powder. In general, non significant differences were found between inhibitions caused by 80 and 100g/kg soil. The total phenols in foliage and underground organs of purple nutsedge revealed that the inhibitory effects were concomitant with the accumulation of total phenols compared to controls.

Mahmood *et al.* (2010) conducted an experiment to test the potentiality of sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*), brassica (*Brassica napus*), maize (*Zea mays*), rice (*Oryza sativa*) and mulberry (*Morus Alba*) water extract on growth of horse purslane. In the laboratory bioassay, sorghum + sunflower water extract combination at higher concentration (100%) completely inhibited germination of horse purslane. In pot experiment, the foliar application of sorghum + sunflower water extract combination at higher concentration (100%) greatly suppressed growth traits (shoot and root length) of horse purslane seedling and this combination reduced shoot dry weight by 66% over control. Inhibitory effect was proportional to the concentrations of the extracts and higher concentration had the stronger inhibitory effect. In crux, combination of sorghum + sunflower water extracts may be used as natural herbicide to control horse purslane.

Soyeymani and Shahrajabian (2012) studied allelopathic effects of sesame (*Sesamum indicum*) on canola (*Brassica napus*) growth and germination. Treatments include leaf, root, stem and flower extract. Each extract includes 4 levels 0, 25, 50 and 100%. The *Brassica napus* sensitized to exuding allelochemical materials form sesame and the rate of germination, percentage of germination, seedling weight, coleoptile length, radicle length decreased by increasing density of extracts.

Sahoo *et al.* (2007) reported that teak has a potentials harmful allelopathic chemicals and the toxic effect of teak followed the order: leaf litter > crushed seeds > soil root zone in maize.

Maharjan *et al.* (2007) studied allelopathic effects of aqueous extract of leaves of *Parthenium hysterophorus* on seed germination and seedling growth of three cereal crops (*Oryza sativa* L., *Zea mays* L. and *Triticum aestivum* L.), three cultivated crucifers

(*Raphanus sativus* L., *Brassica campestris* L. and *Brassica oleracea* L.) and two wild species of family Asteraceae (*Artemisia dubia* Wall ex. Besser and *Ageratina adenophora* (Spreng) King and HE Robins). Seed germination of all crucifer species was completely inhibited at >2% leaf extract of *Parthenium hysterophorus* but in other species, except maize, complete failure of seed germination was recorded only at >6% in *Triticum aestivum* and *Ageratina adenophora;* at 10% in *Oryza sativa* and *Artemisia dubia*. Seed germination of *Zea mays* was not completely inhibited but it was low at high concentration of the extract. The extract had strong inhibitory effect to root elongation of seedling in cereals and to shoot elongation in crucifers and wild Asteraceae. Leaves of *Parthenium* hysterophorus may be a source of natural weedicide against *Ageratina adenophora* which will help to control invasive plants.

Hiwale *et al*. (2007) carried out a study on allelopathic effect of leaf leachate of four species *viz.,* Custard apple (*Annona squamosa*), Aonla (*Emblica officials*), Neem (*Azadirachta indica*) and Subabool *(Leucaena leucocephala)* on Soybean (*Glycin max*), Maize (*Zea mays*), Okra (*Abelmoschus esculentus*), Sunhemp (*Crotolaria juntia*), Green gram (*Phaseolus aurus),* Pigeon pea (*Cajanus cajan),* Fodder jowar (*Sorgham vulgar*), Sesamum *(Seasamum indicum)* and Moth bean *(Phaseolus aconitifolius*). Seed germination was suppressed by leaf leachate of all tree species as compared to control (seed treatment with distilled water). The shoot and root length was significantly influenced by the leaf leachates of the tree species. Root length was highly influenced as compared to shoot length. Custard apple, Aonla and Subabool were found to have beneficial effect on Soya bean, Green gram, Pigeon pea and Sesamum and suppressing effect on Okra, fodder Jowar, Sunhemp, Maize and Moth bean.

Sharma *et al.* (2005) conducted an experiment on effect of leaf leachate of *Terminalia chebula* and *Sapindus mukorossi* on germination and growth of commonly cereals, pulses and vegetable crop under laboratory condition. The tested crops *viz.,* Wheat, Maize, Gram, Peas, Lentil and Brinjal responded differently to aqueous leaf extracts of *T. chebula* and *S. mukorossi* indicating the presence of different phyto active compound which are either phyototoxic or promoters. Some strains had synergistic or no adverse effect on germination and growth of tested field crops where other had antagonistic effect.

The allelopathic extracts from *Tectona grandis* leaves significantly inhibited germination and growth of tomato *(Lycopersium esculentum*), eggplant (*Solanum melongena*) and *Capsicum annum*. The allelopathic extract from *Tectona grandis* has also shown high allelopathic activity on *Triticum aestivum* (Krishna *et al.*, 2003).

Macias *et al.* (2000) reported the phytotoxicity activity of extracts from bark and leaves of *Tectona grandis* between 1000-1250 ppm, on the germination, root and shoot length of *Lepidium sativum* L., *Lactuca sativa*, *Lycopersicum*, *Allium cepa* and *Triticum astivum* L. Bioassary results showed that bark extract of *T. grandis* had higher phytotoxicity. The most affected parameters were root length of tomato, onion and wheat.

Mathela (1994) reported that the secondary metabolites (glycosides, steroids, flavonoids and diterpenoids) of some medicinal and aromatic plants accounted for allelopathic activity.

Gaynar and Jadhav (1992) observed the decrease in germination of rice and cowpea under the influence of leaf leachates of *Terminalia tomentosa,* after 3 days of sowing but it was non-significant after 5 days of sowing. They also reported the decrease in germination percentage of rice and cowpea under the influence of leaf leachates of *Acacia auriculiformis.*

Horticultural tree crops for cash purposes are extensively planted by small landholders as an outgrowth of shifting cultivation in many parts of the world, notably the oil palm, cacao, coffee and cola nut plantations of West Africa, covering as much as 67 percent of the land in southern Nigeria (Getahun *et al*., 1982) and the coconut, rubber, oil-palm, cacao and coffee plantations of smallholders in Southeast Asia (Pelzer, 1978; Liyanage *et al*., 1984 and Dove, 1983).

The transition to tree-crop-based systems is not equally feasible from all stages in the main sequence of intensification in tropical land use. There are few ecological constraints in stages 1 and 2 to the planting of extensive areas to tree crops, although the economic incentives will generally have to be rather attractive since leisure time is likely to be highly valued in integral swidden societies at this stage of development. Nevertheless, as Dove (1983) has pointed out, extensive cash cropping of trees is a common feature of many relatively long-fallow swidden systems. At stages 3 to 5, however, the transition to tree crops is less easily achieved, because of the commitment of land to other uses and the relatively long lag between planting and first harvest. Here *taungya* practices can ease the burden of the establishment phase by providing early returns of interplanted field crops.

Thakur (2014) tested the allelopathic effects of three agroforestry tree species viz mulberry, plum and pomegranate by growing soybean crop for 30 days in pots containing field soil either mulched with leaves or irrigated with aqueous leaf extracts of the woody species. The maximum adverse effect on seed germination, germination relative index, vigor index, root length, shoot length and dry matter production of soybean was caused by leaf leachate after Hollis *et al.* (1982) followed by leaf leachate obtained after Tukey and Mecklenberg (1964) and minimum by foliage mulched at the soil surface.

The allelopathic effects of aqueous extracts from sorghum stem and rice husks were examined on the germination and growth of maize. The extracts brought about considerable inhibitions in the germination of maize seeds and in the growth of radical and plumule. In both extracts, the degree of inhibition increased with the increase in the concentrations of the extracts thus suggesting that the effects of the extracts were concentration dependent. However, the results obtained also tend to suggest that the degree of retardation might be more pronounced in the extracts derived from the sorghum stem than those from the rice husks. In the sorghum extract-treated seeds, no growth of the plumule was obtained until the 72-hour period of the experiments whereas plumule growths were recorded at the lower extract concentrations of the rice-husk derived extracts (Kayode and Ayeni, 2009).

The pace of evaluating allelochemicals released from higher plants in nature has greatly accelerated, with promising results in field screening (Khan *et al*., 2005). In Agriculture, the inhibitory effect of weed species on germination and growth of crops has been attributed to phytotoxic chemicals released from the leaf litter and roots. Further, Rice (1974) observed that many species of weeds produce toxins that are inhibitory to other weeds and often to themselves. *Lantana camara*, one of the world's 10 worst weeds was introduced in the Indian subcontinent during the early part of the nineteenth century (Bansal, 1998). Frequently allelopathy caused decrease in plant growth more than what caused by competition in plants on sunlight, water and nutrition (Rice, 1984).

Allelopathic compounds restrict plant growth through negative interactions with important physiological processes such as changes in cell wall structure, prevention of cell division and activity of some enzymes. These compounds can also affect the equilibrium of plant hormones, pollen tube germination, absorption of nutrient elements, displacement of stomata, photosynthesis, respiration, protein synthesis, pigment, and changes in DNA and RNA structures (Glass ADM, 1974). Alellopthic effect of Umbelliferae family on lotus was verified by (Lydon *et al.,* 1997; Ghorbanli *et al.,* 2008) investigated the allelopathic effect of *Artemisia annua* on redroot pigweed (*Amarantus retroflexus*), common lambsquarters (*chenopodium album*), soybean (*Glycine max*) and corn (*Zea mays*).

Melkania (1984) recorded allelopathic potential in non-forest tree species of Himalayan region in the order: *Celtis australis* > *Juglans regia* > *Grewia optiva* > *Bauhinia retusa* > *Melia azedarach.* Among the agro-crops studied as phytomer species, the inhibitory effects varied. Germination of *Glycine soja* seed was inhibited by 51.57 and 53.13 per cent when treated with *Celtis australis* and *Melia azedarach,* respectively.

Bhardwaj (1993) conducted laboratory studies to notice the effect of leaf leachates of *Robinia pseudoacacia* on maize, wheat, mustard, soybean and urd and observed reduced germination per cent, root shoot length and vigour index as compared to control.

Srinivasan *et al.* (1990) conducted a pot experiment where in *Vigna mungo, Vigna radiata,* cowpeas, pigeon peas and soybeans were grown for 30 days in top soil taken from under *Eucalytpus tereticornis, Casuarina equisetifolia, Leucaena leucocephala* and *Acacia holosericea.* Top soil from under all 4 tree species reduced crop germination and growth. *E. tereticornis* had the greatest inhibitory effect. Soybeans were the most sensitive crop. Soybean germination in top soil under *E. tereticornis* was 69 per cent of germination in control plants and dry matter production was reduced by 10 per cent.

Bhatt and Todaria (1990) studied the allelopathic effect of *Adina cordifolia, Alnus nepalensis, Celtis australis* and *Prunus cerasoides* by growing crops of *Eleusine coracana, Glycine max* and *Hordeum Vulgare* on top soil, rhizosphere soil from the plantation of these trees and on field soil either mulched with dry leaves or irrigated with aqueous leaf extracts of the tree species. Maximum reduction in germination percentage, root-shoot length and dry matter production was obtained with experimental garden soil mulched with dry leaves of trees and by the effect of *A. cordifolia* followed by *P.*

cerasoides. H. vulgare proved most susceptible and *E. coracana* highly resistant to these tree-crop interactions.

Aleem *et al.* (2014) investigated the allelopathic effect of three tree species (Azardiracta indica, Vitellaria paradoxa, and Parkia biglobosa) on germination and growth of cowpea in the Southern Guinea Savannahagro ecological zone of Nigeria. They found that the tree species brought about considerable inhibition in the germination of cowpea seeds and in its growth parameters. The statistical germination value of the cowpea seeds under the tree species had decreased value thus indicating that growth inhibitions were seriously felt. Parkia biglobosa (53.33) and Vitellaria paradoxa (60.00) had more inhibitory effect on cowpea seeds germinability than that of *Azardiracta indica*. (63.33) while all the treatments are lower than that of control (100). The tree species had similar inhibition capability in the cowpea plant height, stem circumference, number of leaves, above grand biomass and below grand biomass.

Tree species selection to inter-cultivate with food crops has often been made on the basis of traditional knowledge by farmers in Ghana. Lately, Taungya system has been introduced to enable farmers produce food and at the same time retain the forest cover in communities bordering forest reserves. Fresh matured leaves and roots extracts of ten tree species were examined for their allelopathic effects on four agricultural crops to explore the allelopathic potential of the tree species and to recommend the appropriate tree species to be used under the Modified Taungya System in Ghana. Germination of *Hibiscus esculentus* seeds was significantly reduced in all the root and leaf extracts while germination of *Zea mays* seeds increased in all the root extracts except in that of *Terminalia superba*. Roots extract of *Senna siamea* promoted germination of both *Zea mays* and *Lycopersicon esculentum* seeds. Plumule and radicle extension of seedlings of the four crops were significantly reduced by all the root and leaf extracts with the exception of *Zea mays* whose plumule and radicle development was increased by *Eucalyptus grandis* leaf extracts. On the basis of the results obtained in this study the following tree species (*Senna siamea, Albizzia lebbeck, and Jatropha curcas*) could be recommended for planting (Abugre *et al.*, 2011).

Einhelling (2002) reported that individual compounds can have multiple phytotoxic effects on a plant. There was a reduction in radicle growth of the germinating seeds because the extracts might have contained allelochemicals that affected the enzymes responsible for plant hormone synthesis, in addition to nutrient and ion absorption by affecting the plasma membrane permeability of the roots (Fujii *et al*., 1991). There is an inhibitory effect on root elongation when the roots come into contact with the extract and for that matter with inhibitory chemicals as described in early works with various crops and weeds (Bhowmik and Doll, 1984; Qasem, 1995).

An experiment was carried out by Hiwale *et al.* (2007) to study allelopathic effect of leaf leachate of four tree species viz., Custard apple (*Annona squamosa*), Anola (*Emblica officials*), Neem (*Azadirachta indica*) and Subabool (*Leucaena leucocephala*) on Soyabean (*Glycine max*), Maize (*Zea mays*), Okra (*Abelmoschus esculentus*), Sunhemp (*Crotolaria juntia*), Green gram (*Phaseolus aurus*), Pigeon pea (*Cajanus cajan*), Fodder jowar (*Sorghum vulgar*), Seasum (*Seasamum indicum*) and moth bean (*Phaseolus aconitifolius*). Leaf leachates of all trees suppressed seed germination compared to control (only water). Root length was highly influenced compared to shoot length. Custard apple, Anola and Subabool were found to have beneficial effect on Soyabean, Green gram, Pigeon pea and Sesamum and suppressing effect on Okra, Fodder jowar, Sunhemp, Maize and Moth bean. Neem was found to suppress most of the growth parameters, whereas Custard apple, Anola and Subabool promoted them.

Devaranavadgi *et al.* (2003) noted that in existing agrosilvicultural systems involving different tree species (*Acacia nilotica, Albizia lebbeck, Azadiracta indica, Cassia siamea, Dalbergia sissoo, Hardwickia binata* and *Leucaena leucocephala*) to assess the allelopathic effects of different tree crops on rabi Sorghum. They observed that the control treatment produced the maximum grain and Stover yield. Plant height was maximum with *Leucaena leucocephala* while *Hardwickia binata* produced plants with the least height. Highest diameter at breast height (dbh) and crown diameter was recorded in *Acacia nilotica* while the lowest values for dbh crown diameter were recorded in *Dalbergia sissoo* and *Hardwickia binata*, respectively. Total biomass was maximum in *Acacia nilotica* and was minimum in *Hardwickia binata.* The performance of rabi Sorghum in terms of Stover and grain yield was inversely proportional to the silvicultural parameters of tree species and as well as the total dry matter produced by them. Germination of Sorghum with *Hardwickia binata* was 85% and a similar superiority was observed for root length, shoot length and dry weight of seedlings. Lower values were located in *Acacia nilotica.* The results indicate that among the tree species studied, *Hardwickia binata* had the minimum allelopathic effect on rabi Sorghum.

An experiment was carried out by Ashutosh *et al.* (2009) and studied that *Grewia optiva, Bauhinia variegata and Albizia lebbeck* are the suited tree species for plantations in the sub-tropical region of Garhwal Himalayas due to their high biomass production.

Silva *et al.* (2007) found that *Azadirachta indica* has inhibitory effects of its extract on *Phaseolus vulgaris* germination percentage and growth was evaluated, although Neem (*Azadirachta indica)* is well known for its biological activities in many countries. Both seed germination and radical growth were affected in a concentration dependent manner.

An experiment was established by Devaranavadgi *et al.* (2004) to assess the allelopathic effects of different tree species (*Acacia nilotica, Albizia lebbeck, Azadiracta indica, Cassia siamea, Dalbergia sissoo, Hardwickia binata* and *Leucaena leucocephala*) on Chickpea. Among the tree species, *Hardwickia binata* had significantly less allelopathic effect on Chickpea compared to other tree species. The germination percentage (80%), root length (18.65cm), shoot length (31.32 cm) and seedling dry weight at 10 days were least affected by *Hardwickia binata* as compared to other tree species. The maximum harmful effect was observed with *Acacia nilotica* which had higher total biomass production (3688kg/ha) and crown spread (8.2m).

Ahmed El-Shabasy (2017) found that allelopathy of *Prosopis juliflora* on *Acacia ehrenbergiana* through mineral analysis of both leaf extract and rhizoshere soil for both species. All mineral content decreased in combined soil and certain elements increased only in leaf extract of *Prosopis juliflora* as Fe^{+2} and Na^{+} whereas other elements decreased in leaf extract for two species as Mg^{+2} and Mn^{+2}. The study reported that macro and microelements might be responsible for dominance of *Prosopis juliflora.*

An experiment was conducted by Nguyen *et al.* (2003) to assess the allelopathic effects of *Galactia pendula, Leucaena glauca, Melia azedarach* and other four species including *Desmodium rezone, Euphobia hirta, Manihot esculenta* and *Morus alba*. *Galactia pendula, Leucaena glauca, Melia azedarach* were assessed the greatest allelopathic potential and the other four were second most suppressive to Radish germination and growth. Findings also indicated inhibitory exhibition of allelopathic plants were species dependent. Moreover, inhibitory effects varied among plant parts such as the leaves, stem and root.

Choudhary *et al.* (2016) evaluated the performance of two rhizomatous crops *i.e.*, turmeric (*Curcuma longa*) and ginger (*Zingibar officinale*) under rainfed conditions as Nautiyal, sole crops and with 15-year old well established stands of forest tree species located at the research farm of ICAR Research Complex for NEH Region, Research Centre, Basar, Arunachal Pradesh. The average illumination below the canopies varied from 72.0 to 79.2% of incident radiation on turmeric and 71.7 to 78.8% of incident radiation on ginger. Turmeric and ginger were cultivated in the inter row spaces of 24 and 12 Multipurpose trees (MPTs), respectively. Turmeric and ginger did not perform well under as many as 18 and 5 MPTs, respectively. Turmeric, in association with nitrogen fixing tree species *Alnus nepalensis* and *Parkia roxburghii* did not significantly reduce its productivity. Leaf area and leaf area index (LAI) significantly higher under *A. nepalensis* than the sole turmeric crop. MPTs had significantly negative effect on the growth and yield attributes of ginger crop. The reduction in yield of ginger ranged from 11.3 to 31.3%. They found that turmeric cultivation more profitable than the ginger under *A. nepalensis* based agroforestry systems in comparison to the other MPT based agroforestry systems.

Most of the earlier studies had revealed that the inhibition obtained in the laboratory experiments might differ from the situations in the fields as allelopathic effects are often due to synergistic activity of allelochemicals rather than to single compound. (Hauser, 1993; Lisanework and Michelsen, 1993; Tian and Kang, 1994; Mehar *et al.*, 1995).

Qian *et al.* (2014) studied that Walnut agroforestry systems have many ecological and economic benefits when intercropped with cool-season species. Leaf litter decomposion is one of the main sources of allelochemicals in such systems. Lettuce (*Lactuca sativa* var. *angustata*) growing with walnut leaf litter shows its allelopathic activity. Lettuce growth and physiological processes were inhibited by walnut leaf litter, especially during early growth stage or with large amount of litter addition. The plants treated by small amount of leaf litter recovered their growth afterwards, while the inhibition for 180g leaf litter persisted until harvest. Twenty-eight compounds were identified in the leaf litter, and several of them were reported to be phytotoxic.

2.4 *Eucalyptus* in Agroforestry of Bangladesh

In Bangladesh, like many other developing countries, *Eucalyptus* was introduced in the 19th century as ornamental plants to decorate parks, road side or botanical gardens.

Probably in 1930, *Eucalyptus citriodora* was introduced in eastern part of Bangladesh (Davidson and Das, 1985) and later on it spread throughout the country (Hassan, 1994). In Bangladesh *Eucalyptus camaldulensis* was planted by Forest Department. A total of 218 provenances of 37 species were introduced and planted experimentally; but only 4 species (*Eucalyptus citriodora, Eucalyptus brassiana*, *Eucalyptus camaldulensis* were found successful for future plantation programs (Davidson and Das, 1985).

2.5 Factors that make *Eucalyptus* preferable by farmers

Eucalyptus gives superior and versatile benefits compared to many other tree species due to this fact often farmers choose to plant Eucalyptus, particularly smallholders in tropical and subtropical regions.

2.5.1 Establishment

Accessibility of seeds from the mother tree (seed collection) is simple, locally available and do not require special treatment to keep (store) for long time (Getahun, 2002). *Eucalyptus* as a genus is also well known for its good coppicing ability, it usually forms a dense and productive stand if allowed to re-grow. Moreover, the germplasm of *Eucalyptus* species has proved to be easily adaptable to different environmental and climatic conditions compared to various species, like, *Cupressus lustinica,* and *Juniperus procera* that have been found to be susceptible to some naturally occurring pathogens besides having a slow growth rate *(*Kebebew and Ayele, 2010*)*. Most *Eucalyptus* species are easily established as bare root seedlings which are (Pohjonen and Pukkala, 1990) cheap and easily affordable to smallholders compared to a container or plastic bag that is labour demanding.

2.5.2 Ecological range

Eucalyptus can grow in degraded land, swampy area, unfertile and exhausted soil, and in dry areas (Pohjonen and Pukkala, 1990). *Eucalyptus* can substitute many indigenous species that have diverse environmental and biodiversity functions for the surrounding area to specific and regional benefits to a large extent (Kelemu and Tadesse, 2010). This ecological advantage of *Eucalyptus* helps the farmers not to be affected as a consequence of different ecological problems like drought, excessive runoff or water-logging.

2.5.3 Survival

Another important reason contributing to the popularity of *Eucalyptus* is its good survival rate. Leaves and barks of *Eucalyptus* are not/less palatable to most browsers such as cattle or livestock and wild animals it can be established and grows without any physical damage (Getahun, 2002; Atkinson *et al*., 1992; Jagger and Pender, 2003; Pohjonen and Pukkala, 1990) weighed against other woody species, such as *Olea African, Cuprusus lustinica, Juniperus procera, Cordia African, Acacia albida, Gravilia robusta* that are browsed by different grazers starting from their seedling stage but *Eucalyptus* not compared to most other commonly used exotic tree species *Eucalyptus* species are not sensitive for the attack of different tree diseases/ pathogens, pests, and environmental stress (water, and nutrient deficiency). High coppicing ability and its efficiency to convert the available soil resource to biomass production also contribute to its good survival (Getahun, 2002; Jagger and Pender, 2003). The root collars of *Eucalyptus* are resistant to fire even if the aerial part or above ground parts are burnt; the bark at early age not resistance against fire but when it gets older it is not burnt easily.

2.5.4 Management requirements

Eucalyptus does not require intensive management hence reducing the labor cost. Farmers prioritize to plant *Eucalyptus* on their pieces of land in different ways, e.g. on miscellaneous land, farm boundaries, around homesteads than other plant species because of its simple management (Kebebew and Ayele, 2010; Getahun, 2002).

2.5.5 Growth rate

If the planting sites have a good condition of nutrient and water *Eucalyptus* can starts to give output from third or fourth year depending on the intention of the farmers (Pohjonen and Pukkala, 1990).

2.5.6 Multiple uses

Small scale farmers consider *Eucalyptus* as a Nature's gift; as a contribution to retirement owing to the different benefits it provides assisting in their daily livelihoods expenses. *Eucalyptus* is used for fuel woods, construction material, making farm utilities (equipments), generating income, production of charcoal, also used as, shelter belt; drainage and wind break for their fragmented land (Lemenih *et al.,* 2004).

2.6 The Environmental Controversies over *Eucalyptus*

Eucalyptus species are generally assumed to cause different environmental problems.

2.6.1 Effects on ground water

Eucalyptus has taken the vast area of the world and raising fears over water resources and Eco hydrological effects (Shi *et al.*, 2012). *Eucalyptus tereticornis* (Mysure gum) is fast growing, straight and thus has low shading effect and has luxurious water consumption where excess soil moisture conditions exist. High water table caused deficiency of oxygen and excess of carbon dioxide in the root zone of wheat, which finally reduced the yield. *E. tereticornis* worked as bio-pumps and lowered the water table. This agroforestry model of bio-drainage has proved a low-cost, socially-acceptable and environment-friendly technique for the reclamation of waterlogged areas. Lowering of water table and associated soil improvement by *Eucalyptus* plantations increased the wheat grain yield by 3.4 times and resulted in reclamation of waterlogged areas (Raj *et al.*, 2016).

Jagger and Pender (2003) assert that *Eucalyptus* is one of the exotic plant that convert water and other available resources to biomass and it is suitable for the benefit of rural small scale farmers in support of their daily livelihoods.

Akhter *et al.* (2005) wrote that the water use efficiency (WUE) of *Eucalyptus* in dry areas is less than that of *Acacia* species. They did a test for WUE of both *Acacia ampliceps* and *Eucalyptus camnaldulensis* grown for one year in a lysimeter and the result approved that *A. ampliceps* could use the water 5 times more efficient than *E. camaldulensis* in low moisture soil (less watered) (50%), 9 times more efficient in medium moisture soil (75%) and 12 times more efficient in high moisture soil (well watered) (100%)*;* WUE of *Eucalyptus* compared to *Acacia* decreases as moisture content of the soil decreases.

Teshome (2009) also concludes that *Eucalyptus* does not consume more water than any tree species and crops in Ethiopia; rather it is efficient in using moisture around roots and converts to biomass.

When the water consumption of *Eucalyptus* is compared with different agricultural crops and tree species the result found from different literature approve that *Eucalyptus* consumes less water (Calder, 1992). However others (notably Zahid and Nawa, 2007) conclude that *Eucalyptus* consumes more water than other crops such as maize and woody species. Also, *D. sissoo* show a better water use efficiency compared to *Eucalyptus*.

2.6.2 Effects on Nutrient Uptake

Another controversy of *Eucalyptus* is its efficient nutrient uptake that gradually exhausts the soil nutrient. *Eucalyptus* is a non-nitrogen fixing tree and does not have capacity to replace the nitrogen it consumes like leguminous tree species.

Jagger and Pender (2003) found that for degraded land and waste land *Eucalyptus* helps to conserve the top soil of hill sides and improves the fertility (nutrient content) of the soil through litter fall. Hence, planting of *Eucalyptus* in degraded and non fertile area (barren land) getting trees to survive add both value and improve sustainability of the land. The negative impact of *Eucalyptus* might be clearly visible if planted near the annual crops (competition for nutrients); but the details of how much nutrients is depleted and how much organic matter contributed is not clearly identified.

Debell *et al*. (1985) demonstrated that inter-planting of leguminous tree in *Eucalyptus* stands in Hawaii was the best solution to reduce the depletion of nutrients. In a field trial (about 6 years) *Eucalyptus* mixed with *Acacia* and *Albizzia* was compared with the pure stand of *Eucalyptus*. The result showed the mixed stand of *Eucalyptus* (both with *Acacia* and *Albizzia*) have better performance both in diameter and height (63 percent taller and 55 percent larger in diameter with mixed stand of *Albizia*, and 25 percent taller and 28 percent larger in diameter with mix of *Acacia*) than the pure stand. The mixed stand of *Eucalyptus* also gave higher yield per hectare than the pure stand.

2.6.3 Effects on biodiversity

The exotic invasive species are considered to be the second largest cause of biodiversity loss after habitat destruction (Schwartz *et al.*, 1996; Shinwari *et al.*, 2012). Exotic invasive plants have been found to change the composition of native communities and been associated with reduced native plant diversity (Shinwari and Qaisar, 2011). Most of the exotic plant effects reported have been identified as caused by allelopathic interaction which resulted in interference with physiological and biochemical processes in plants, due to chemicals released by exotic plants (Alhammadi, 2008). Even if *Eucalyptus* has an allelopathic effect there is no concrete evidence and agreement that prove its detrimental effect on the undergrowth species.The *Eucalyptus* is now considered a threat to both plant and animal biodiversity because it reduces the growth of under-story and adjacent plant communities by secreting allele-chemicals in the soil and declining the avifaunal and other animal populations by habitat loss (Raj *et al.*, 2016).

For *Eucalyptus* plantation land must be cleared and have nutrients added into the soil. This takes away from the habitat of animals and leaves them dead or in search of a new place to live. However, when grown in areas not native to the *Eucalyptus*, it can also become very grassy around the trees, possibly providing the animals with an area of shelter and habitat to live. On the other hand, farmers would not want this in their plantation and might use pesticides and other chemicals that could adversely affect the animals indirectly. Also, when fire enters Eucalypt plantations, the eucalypt can provide shelter and food for most flightless invertebrates. *Eucalyptus* has thicker bark to protect it from the fire, and this can protect those animals as well. But globally, fire makes a bad impact on the surrounding environment causes pollution, ecological imbalance and loss of biodiversity in the natural forest. Therefore, use of controlled fire, fire lines, fuel breaks, fuel load removal and mapping of fire sensitive areas are key principles to minimize fire risk (Jhariya and Raj, 2014).

Alem and Weldemariyam (2010) study the undergrowth of different species of *Eucalyptus* plantation and natural forest and found that the condition for under growth is more conducive in natural forest for shade tolerant plant species (52 species) compared to *Eucalyptus* (46 species); the density of understory growth in *Eucalyptus* was 3282 stem per ha and that of natural forest 4122 stem/ha.

2.6.4 Effects on soil

The extent of enrichment in soil properties depends on the tree species, management practices and the quantity and quality of litter and their decay rate. Moreover, the leaf litter deposition from *Eucalyptus* vegetation and resultant soil acidity might also affected intercrop yield. Owing to these negative effects, the positive effects like increased organic matter content from leaf litter decomposition might have resulted in improvement in soil water holding capacity, porosity, texture, essential nutrient and yield improvement of kharif and Rabi crop. Further, Litter fall and decomposition are the two major processes responsible for soil enrichment in agroforestry systems. Decomposition process plays an important role in soil fertility in terms of nutrient cycling and the formation of soil organic matter. Litter fall and their decomposition play a crucial role in pattern of weight loss (more rapid weight loss due to leaf litter decomposition in 1 year old plantation of *Eucalyptus* species and decrease with plantation age) and nutrient release (potassium was released most rapidly) of any plantation.Various soil physical and chemical properties (notably organic carbon, total N, P and K) decreased with increasing age of plantation. Increase in soil carbon through plantations may also act as an important carbon sink (Raj *et al.*, 2016). The better drainage by the bio drainage plantation might have resulted in reduced sulphide toxicity, improved soil aeration, nutrient use efficiency as was reflected in better tillering in rabi paddy and was not evident in nearby field without plantation(Chowdhury *et al.,* 2011).

Agroforestry practices increase the soil organic matter through litter production which is responsible to enhance the population of beneficial microorganisms. The soil biological attributes are also responsible for determination and maintenance of physical properties of soil (Raj *et al.*, 2014). All the microbiological activities in soil enhance cycling of nutrients and other ecosystem functions. Recycling in natural system is one of the many ecosystem services that sustain and contribute to the human well being (Jhariya and Raj, 2014). The added soil organic matter acts as a source of energy and enhances nutrient cycling and moderates soil microclimate and improves soil aggregate system (Manikandan and Prabhu, 2011).

It has been argued that *Eucalyptus* plantation (monoculture) as well as natural forests including *Eucalyptus* can decrease runoff through improved infiltration. The dense canopies of any forest (tree) helps to protect the ground from splash erosion (Oballa *et al.*, 2010).

Jiayu and Siming (1996) reported a 99% decrease in runoff and in the movement of sand and mud in *Eucalyptus* plantation compared to the previous conditions (without plantation). Planting of *Eucalyptus* in areas where erosion is the main problem helps to control overland flow through increased infiltration.

Jagger and Pender (2003) indicated that *Eucalyptus* has potential to reduce the top soil runoff and slows soil erosion in different climatic zones where there is maximum rain fall.

Furthermore, *Eucalyptus* contributes in decreasing the formation of degraded or waste lands in different regions (Grewal *et al.,* 1992).

2.6.5 Effects of plantation age on biomass and productivity

In traditional agroforestry, crop density, above ground biomass, below ground biomass and their productivity are affected by tree canopy size, age and distance from tree trunk. The biomass of 25 years old *Eucalyptus* plantation (262.9 t ha^{-1}) was two times higher than 8 years old plantation (126.7 t ha-1) but the primary productivity values are almost similar. Similarly, nutrient returns to the soil through litter fall (87.4 Kg h^{-1} yr^{-1} of N and 4.8 Kg h^{-1} yr^{-1} of P) and decomposition rate of leaves (0.242% day-1) were higher than that of 8 years old plantation (75.6 Kg h^{-1} yr^{-1} of N, 4.3 Kg h^{-1} yr^{-1} of P and 0.223% day^{-1}) (Bargali and Singh, 1995). This is very significant information which compares of biomass, productivity and nutrient parameters as per age groups of *Eucalypts tereticornis* species. The biomass of vegetation, forest floor litter mass, tree litter fall and net primary productivity (NPP) of trees and shrubs increased with the increase in plantation age, whereas herb biomass and NPP significantly (P < 0.01) decreased with the increase in plantation age (Bargali *et al.,* 1992). Under seasonal dynamics of forest floor biomass, rainy season has maximum total forest floor biomass (including herbaceous vegetation) followed by summer and winter. Forest floor biomass increase significantly (P < 0.01) but herbaceous live biomass significantly decrease (P < 0.01) with increase in plantation age (Bargali, 1994).

2.6.6 Effect of distance on biomass

Distance from tree base also played significant role on the yield of crops. The yield of wheat as well as paddy increased with the increase in distance from the boundary tree lines. Further, as a distance increase the grain yield also increase (Ram *et al*., 2011). In Ethiopia, tef (*Eragrostis tef*) yield was significantly reduced up to a distance of 12 m from *Eucalyptus* tree line (Kidanu *et al.,* 2005), whereas in India wheat (*Triticum sp.*), chickpea (*Cicer arietinum*), lentil (*Lens esculentum*) yields were depressed between 2 and 12 m from the tree row (Saxena, 1991; Singh and Kohli, 1992) when trees were grown on field boundaries. Similar reduction in yield of intercrop under *Eucalyptus* vegetation has been reported in literature (Sasikumar *et al.,* 2001) particularly with age of the tree (Singh *et al.,* 1998). Wood biomass production rates of *Eucalyptus* on bund also increased with corresponding age (Kidanu *et al.,* 2005).

2.6.7 Effect of shade on yield performance of crop

Due to shading effect and strong root system of *Eucalyptus,* which compete for moisture and nutrient with crops resulting grain yield near the tree lines was comparatively low. Tree density or spacing between rows of *Eucalyptus* tree is also influence the yield of wheat grain and straw (Ahmed *et al.,* 2004). Even the best trees in soil improvement may be detrimental to biodiversity, especially when planted at a narrow spacing where the reduction in the amount of light reaching the ground may suppress shade intolerant plants (FAO, 2005). But reverse is favourable for shade loving plant. The better performance of intercrops in widely spaced *Eucalyptus* was likely because of limited competition from trees for light and water (Prasad *et al.,* 2010).

2.6.8 Effects of tending operation on tree-crop parameter

Tending operation including pruning of tree crop also influence the productivity of associated crops and wood biomass of tree. Branch pruning effectively reduces light interception by the tree canopy, and thus prolongs the number of years that annual crop production can be practiced. For reducing tree crop competition, tending operation including pruning is an effective tools which enhance the crop productivity otherwise there is reduction in yield (41 to 61% reduction in wheat yield in unpruned *Eucalyptus* tree (Khymbri *et al.,* 1992). Farmers often practice severe branch pruning every season before the planting of crops, to reduce tree-crop competition as well as to improve tree form (Bertomeu, 2004).However, to minimize crop yield suppression, farmers often practice intensive pruning annually before planting annual crops. Intensive pruning may enhance crop yield, but it is incompatible with commercial timber production because the growth rate and quality of the over-storey timber trees are severely reduced.

2.7 Allelopathy of *Eucalyptus* species

Sidhu and Hans (1988) observed that as the concentration of extracts of *Eucalyptus* increased, the growth of the plant decreased.

Khan and Khan (2006) studied the germination percenatge, age and plant height of both species were significantly affected by different concentrations. Prosopis showed stimulatory effect on germination of both the species. In wheat, maximum germination and plant height of 52.50% and 32.22 cm, respectively was recorded in Prosopis treated pots as against 15 and 31.50 cm in control however in *Eucalyptus* @150 g L-1 also 15%

germination of wheat was recorded. Similarly, for wild oats, maximum germination percentage and plant height of 47.5% and 51.9 cm was recorded in Prosopis treated pots. Low concentration of Prosopis proved stimulatory as compared to higher concentrations. *Eucalyptus* showed slighly negative effect on the species tested. The effect of other concentrations of tree extracts was comparable to each other in the species tested. Hence, it can be concluded from the results that allelopathy of trees can be used as viable weed management technique in the future as allelopathins stimulate the germination of wild oats which give the chance of making soil seed bank weaker.

Djanaguiraman *el al*. (2005) conducted an experiment on effect leaf leachate of *Eucalyptus globulus* on rice, sorghum and blackgram. Leaf leachate was tried at 5, 10 and 20% concentrations. Seed germination, shoot length, seedling dry matter and vigour index were significantly reduced by leaf leachate and highest inhibition was observed in 20% concentration. The magnitude of inhibition followed the order of Blackgram > Rice > Sorghum. The leaf leachate application also influenced the metabolism of seedlings *viz*., chlorophyll *a*, *b* and total chlorophyll, soluble protein, proline and phenol content. In general, leaf leachate increased the proline and phenol content and decreased the chlorophyll and soluble protein contents, in all the test crops over control. Among the parameters studied, proline was found to be associated with higher seedling growth of Rice (200% increased over control), Blackgram (94% increased over control) and Sorghum (183% increased over control).

Rao and Reddy (1984) reported increase in germination percentage of green gram and cowpea under the influence of leaf extract of *Eucalyptus* hybrid but inhibitory effect was observed in case of wheat, Bajra and Tur.

Das *et al.* (2012) worked on Gram seeds (*Cicer arietinum* L.) under treatment of different leaf leachate in laboratory conditions. The aqueous leaf leachate of seven variety of selected tree species *viz., Acacia auriculiformis*, *A. cunn* ex. Benth, *Anacardium occidentale* L., *Albizia lebbeck* (L) Benth, *Eucalyptus citriodora* Hook, *Emblica officinalis* Gaertn, *Shorea robusta* Gaertn. F. and *Tectona grandis* Linn was studied on physiological changes during gram seed germination. Aqueous extracts of tree species significantly reduced the frequency of seed germination, vigour index; shoot length, root length, fresh and dry weight. Plant pigment *viz.,* chlorophyll and carotenoids reduced significantly. The soluble sugar content reduced with 100% (v/v) of leachate treatment but proline and phenol content increased on the test plant. The result revealed that *Eucalyptus citriodora* and *Shorea robusta* extract had greater inhibitory effect on germination and vigour index over the control due to the presence of allelochemicals in the leachate. Leachate biochemical analysis also supports the inhibitory effect of seed germination and biochemical effects of seedlings.

Rassaeifar *et al*. (2013) reported the allelopathic effect of essential oil extracted from leaves of *Eucalyptus globulus* against two weeds, the experiments were laid out as a randomized complete design with factorial layout in two stages (laboratory and greenhouse) in khoy-Iran, during growing season of 2010. Studied factors were *Eucalyptus* essential oil concentrations (0.5, 2, 3.5 and 5 nl/ml–in laboratory and 0.25, 0.5, 0.75 and 1 v/v–in greenhouse) and weeds which included '*Amaranthus blitoides'* and *'Cynodon dactylon'*. Results indicated that, with increasing of Eucalypt oil concentration under laboratory and greenhouse conditions, germination percentage, Germination rate, Radicle length, Plumule length, Seedling height, Primary root length and Primary pedicle length, significantly decreased. Among the weed species tested, the highest inhibitory effect of essential oil was observed in *'A. Blitoides'*. Under laboratory condition, Eucalypt oil concentration decreased seedling height in *'A. Blitoides*' from 61.65 to 37.92 mm, whereas in pot study, eucalypt oil greatly suppressed the seedling height of '*A. Blitoides'* from 34.67 to 22.17 mm. Findings suggest that Eucalypt volatile essential oil possess strong inhibitory potential against weeds that could be exploited for weed management and can be recommended as a biological herbicide with the aim of weeds control.

Sanginga and Swift (1992) compared maize growth on indigenous miombo woodland soils with *E. grandis* soils in Zimbabwe. Greenhouse experiments indicated for the first crop of maize planted in *E. grandis* soils with *Eucalyptus* leaf litter at the equivalent of 5 t per ha, that shoot dry weight was reduced by 68%. However, in the second crop rotation, shoot dry weight was positively correlated with increases in *E. grandis* leaf litter (a 97% increase in shoot dry weight was observed when the equivalent of 5 tons per ha was applied to the experimental plot). Field results comparing *Eucalyptus* and miombo woodland soils indicated that K and Mg were lower on *Eucalyptus* sites, and that the best crop yields would be achieved if potassium and magnesium are supplemented through fertilization of *Eucalyptus* soils, likely at a minimum rate of approximately 50 kg/ha. These findings suggest that *Eucalyptus* should not be completely dismissed for use in agroforestry, particularly when fertilizer application is considered as a major input to the production process.

Michelsen *et al.* (1993) provide empirical evidence for soil nutrient depletion by exotic tree species in Ethiopia. Plots of dimension 10 × 10 m of cupressus and *E. globulus* are compared with indigenous juniper and natural forest soils. Soils of cupressus and *E. globulus* were generally found to have the lowest nutrient content (mainly low in phosphorus and nitrogen), although herbaceous plants were important providers of nutrients in all sites. Indigenous woodland (i.e., juniper and natural forest soils) provided much higher nitrogen and phosphorus content in above ground herbaceous plants, indicating that nutrient cycling in sites dominated by exotic tree species is more constrained. Bioassay results indicated that low soil uptake of phosphorus, calcium and potassium was likely the factor limiting growth in agricultural crops such as *Eragtrostis tef* in *Eucalyptus* soils.

Carolina *et al*. (2013) uses *Eucalyptus* leaves for weed control in maize-based cropping systems. Results shows that the incorporation of *E. globulus* residues to soil could be a feasible practice to reduce the reliance on synthetic herbicides in maize-based cropping systems.

It was noted by Solomon (2016) that aqueous extracts at a concentration of 10%, 15% and 20% had inhibitory effect on wheat germination and the effect was found significantly higher than control treatment. Fresh and dry weight of seedling was also reduced significantly over control. The inhibitory effects were increased as the extract concentration increased. These finding indicates that wheat seeds sown in fields which had leaf litter of *Eucalyptus* will be adversely affected regarding germination, growth and ultimately resulting in lower yields of wheat.Several volatile and water-soluble toxins were found in *Eucalyptus* tissues. Cineole and a-pinene, both highly toxic terpenes, were found adsorbed to colloidal soil particles of the litter and bare zones. Adsorbed terpenes were toxic to germinating seeds and seedlings.

Guo (2006) studied the allelopathic effects of *Eucalyptus* spp. on seed germination and seedling growth of some crops, revealing that maximum inhibition of seed germination rate and seedling growth were recorded when using the highest concentration of the aqueous extract of *Eucalyptus* leaves. Reduction in yield of agri-crops and or poorer growth of tree seedlings is often blamed on mismatching of crop combinations.

Allelopathic chemicals secreted by some plants are natural compounds that have shown far-reaching effects on the growth and development of plants even at low concentration (Moradshahi *et al*., 2003 and Lisanework and Michelsen (1993) provide an example of allelopathic evidence from Ethiopia by testing the effect of *Cupressus lusitanica, E. globulus, E. camaldulensis* and *E. salinga* on seed germination, radicle and seedling growth of four crops: chickpea, maize, pea and teff. Bioassay results indicate that all of the tested tree species significantly reduced germination in chickpea and teff, and growth in teff, and that the observed allelopathic effects were most significant under *E. camaldulensis* and *E. salinga.* The results of this particular study indicate the importance of considering interactions between tree species and agricultural crops if two species are to be planted in the same cropping system and suggests that *E. globulus* may be preferable, at least in terms of minimizing allelopathic effects.

Ghnaya *et al.* (2016) conducted a research to evaluate the allelopathic impact of *Eucalyptus erythrocorys* L. on seed germination and seedling growth of two weeds: *Sinapis arvensis* L. and *Phalaris canariensis* L.; on one cultivated crop: *Triticum durum* L. Aqueous; and on ethanolic leaf extracts of *E. erythrocorys* L. The results showed that the *E. erythrocorys* L. crude extracts had an inhibitory effect on seed germination and seedling growth of both studied weeds and wheat. The inhibition rate was increased by the increase in extract concentration. Only ethanolic extracts of *E. erythrocorys* L. induced a significant inhibition of seed germination of durum wheat. The effect of *E. erythrocorys* L. crude extracts was more severe on weeds than on durum wheat. These results indicate that the seedling growth, especially radicle elongation, was the more sensitive indicator to evaluate the effects of extracts than was the seed germination.

Dejam *et al.* (2014) studied a research to determine allelopathic effects of various solvent extracts (aqueous, methanolic, ethyl acetate, acetonic and benzene) of *Eucalyptus globulus* leaves on seed germination and early seedling growth of eggplant cv. Black Beauty. The results suggest that leaf extracts of *E. globulus* had potent allelopathic activity although the activity differed depending on extract and concentration.

Allelopathy is a major factor that influences the establishment of native species in *Eucalyptus* forests. Morsi and Abdelmigid (2016) studied different concentrations of aqueous leaf extract of *Eucalyptus globulus* (5%, 10%, 5% and 25%) for allelopathic impacts on growth and cytogenetic behaviour of barley (*Hordeum vulgare*) plant. Results revealed a pronounced inhibitory effect of the aqueous extract on seed germination and seedling growth of barley plant. Cytogenetic analysis showed retardation of mitotic activity as well as occurrence of high percentage of chromosomal aberrations in *Hordeum* plants. The observed abnormalities were disturbance, stickiness, laggards, vagrants, bridges and micronuclei. The results confirmed the presence of water-soluble allelochemicals in *Eucalyptus* extract which caused potential phytotoxic, cytotoxic and genotoxic effects in barley.

The allelopathic influence of *Eucalyptus tereticornis, Casuarina equisetifolia* and *Leuceana leucocephala* was tested by growing crops of sorghum, cowpea and sunflower on topsoil and rhizosphere soil from plantations of those trees or on field soil either mulched with dry leaves or irrigated with aqueous leaf extracts. Crop germination, root length and dry matter production were depressed. Maximum reductions were obtained with top soil and by the effect of *Eucalyptus*. Sorghum proved most susceptible to these influences (Suresh and Rai, 2012).

A greenhouse pot experiment was conducted by Hegab *et al.,* (2016) to investigate the possible allelopathic effect of *Eucalyptus rostrata* leaf residue on some metabolic activities associated with growth of 10, 20 and 30 day old corn plants. The lower level of *Eucalyptus* treatment (0.5%, w/w) induced a stimulatory effect on the growth of shoot and root of corn plants. The positive effect was more obvious in shoot than in root growth. Inversely, high levels of incorporated *Eucalyptus leaf* residue (1% and 2%, w/w) reduced all growth parameters of both shoot and root relative to the respective control, and this reduction was concentration dependent. The total phenolic aglycone content of mature *Eucalyptus* leaf was 16.89 mg g-1 dry weight present as water-soluble secondary metabolites. Qualitative and quantitative HPLC analysis of *Eucalyptus rostrata* leaves revealed the presence of nine phenolic compounds. The *p*-coumaric acid was the most dominant compound, while catechol and chlorogenic acid were detected in lesser amounts. A trace amount of salicylic acid, vanillin, coumarin, as well as caffeic, cinnamic and ferulic acids were also detected. The total phenolic content of corn shoot increased with the lower concentration of *Eucalyptus* residue and decreased with higher treatments. The lowest level of *Eucalyptus* residue (0.5%, w/w) increased the contents of photosynthetic pigments, particularly chlorophyll "*a*" content, which was correlated with increase in the total carbohydrate production. Similarly, the total nitrogen and total phosphorus, as well as nucleic acids were markedly higher than the control treatment. Negative pattern of changes in the contents of photosynthetic pigments, carbohydrate, nitrogen, phosphorus, phenolic compounds and nucleic acids, was observed in corn plant treated with high rates of *Eucalyptus* leaf residue (1% and 2%, w/w) as compared with their respective controls. These negative effects were concentration dependent.

Fresh matured leaves and roots extracts of ten tree species were examined by Abugre *et al.* (2011) for their allelopathic effects on four agricultural crops to explore the allelopathic potential of the tree species and to recommend the appropriate tree species to be used under the Modified Taungya System in Ghana. Germination of *Hibiscus esculentus* seeds was significantly reduced in all the root and leaf extracts while germination of *Zea mays* seeds increased in all the root extracts except in that of *Terminalia superba*. Roots extract of *Senna siamea* promoted germination of both *Zea mays* and *Lycopersicon esculentum* seeds. Plumule and radicle extension of seedlings of the four crops were significantly reduced by all the root and leaf extracts with the exception of *Zea mays* whose plumule and radicle development was increased by *Eucalyptus grandis* leaf extracts.

Ghnaya *et al.* (2016) carried out a study to evaluate the allelopathic impact of *Eucalyptus erythrocorys* L. on seed germination and seedling growth of two weeds: *Sinapis arvensis* L. and *Phalaris canariensis* L.; on one cultivated crop: *Triticum durum* L. Aqueous; and on ethanolic leaf extracts of *E. erythrocorys* L. The results showed that the *E. erythrocorys* L. crude extracts had an inhibitory effect on seed germination and seedling growth of both weeds and wheat. The inhibition rate was increased by the increase in extract concentration. Only ethanolic extracts of *E. erythrocorys* L. induced a significant inhibition of seed germination of durum wheat. The effect of *E. erythrocorys* L. crude extracts was more severe on weeds than on durum wheat. These results indicate that the seedling growth, especially radicle elongation, was the more sensitive indicator to evaluate the effects of extracts than was the seed germination.

Hanan (2015) investigate the physiological allelopathic effect of the aqueous extract of *Eucalyptus* leaves on *Malva parviflora* weed and its establishment as a tool of herbicidal potential. Seed germination and length of *Malva parviflora* seedlings exhibited different degrees of inhibition by application of different concentrations of aqueous extract of *Eucalyptus* leaves as compared with controls. The reduction of growth of *Malva* *parviflora* weed (60 days old) was accompanied by reduction in photosynthetic pigments, total carbohydrates, nucleic acids and nitrogenous compounds content. The activities of hydrolytic enzymes amylase, invertase and protease decreased as concentration gradient increased from 15 to 40%. The inhibitory effects were correlated with accumulation of the internal contents of total phenols, compared to their corresponding controls with all treatments.

Chu *et al.* (2014) reported that the allelopathy is widely considered to be one of the causes of biodiversity reduction in *Eucalyptus* plantations. However, most research conducted on the allelopathic effects of *Eucalyptus* is performed in the laboratory with weeds and crops as receptors, which fail to fully reflect natural ecosystems. In this study, we conducted two field trials and a greenhouse trial to assess the influence of soil allelopathy, allelochemical volatilization, and foliage litter decomposition on seed germination and seedling growth of three native (*Acmena acuminatissima, Cryptocarya concinna and Pterospermum lanceaefolium*) and one introduced (*Albizia lebbeck*) tree species in a *Eucalyptus urophylla* and *Pinus elliottii* plantation. In order to avoid confounding factors relating to management strategies and environmental influences, only one plantation of each species was used for experimentation. In the allelopathy experiment, the root length of the three native species was significantly inhibited in the *E. urophylla* plantation compared with that in the *P. elliottii* plantation. In the volatilization experiments, the seedling survival rate of the three native species was greater in the *E. urophylla* plantation, but significant differences were found for *A. acuminatissima* and *C. concinna.* Root length and dry weight of *P. lanceaefolium* increased significantly in the *E. urophylla* plantation, in the foliage litter decomposition experiments. There was no significant difference between the two planta-tions for *A. lebbeck*, except that the seedling survival rate was greater in the *E. urophylla* plantation in the foliage litter decomposition experiment. We concluded that allelopathy in the *E. urophylla* plantation was selective, which inhibited the growth of the native tree species but had no significant influence on the introduced *A. lebbeck* species. Allelopathy from volatilization and foliage litter decomposition contrib-uted little to the inhibitory effects. They suggest that the introduced nitrogen-fixing species, *A. lebbeck* could be a potential choice for the establishment of mixed stands with Eucalyptus.

A Petridish assay was carried out by El-Rokiek and Eid (2009) for screening different concentrations of aqueous extracts of fresh and dry leaves of *Eucalyptus citriodora* on germination and seedling growth of wild oat weed (*Avena fatua*). Seed germination, root and shoot length of wild oat exhibited different degrees of inhibition according to the concentration of the aqueous extract. Maximum inhibitions of germination percentage, root and shoot length were recorded when using 25% fresh leaf extract. Based on this preliminary work (Petridish assay), studies were conducted under greenhouse conditions at the National Research Center, Egypt, in the two winter seasons of 2006/2007 and 2007/2008 to evaluate the effects of foliar and soil treatments of aqueous extracts of *Eucalyptus citriodora* fresh and dry leaves on wild oat weed as well as on the growth and flowering of amaryllis (*Hippeastrum hybridum*), compared with the recommended dose of the herbicide tralkoxydim. Amaryllis fresh and dry weights as well as flowering increased significantly when treated with the previous extracts, especially the fresh leaf extract. However, the fresh and dry weights of wild oat were significantly reduced by the aqueous extracts, either fresh or dry, indicating phytotoxic effects. Tralkoxydim caused complete inhibition of wild oat as compared with the control. The studies involved estimation of the endogenous contents of total phenols in weed. With all the treatments, the inhibitory effects on weeds were correlated with accumulation of the internal contents of total phenols, compared to their respective controls. The amount of phenols correlated well with the weed's growth performance. This study establishes the effect of the aqueous extracts on the weed wild oat, associated with amaryllis, which may serve as a tool in establishing their herbicidal potential.

Several studies revealed that large areas of the ground surface beneath the eucalypts remains completely bare and ground vegetation is very limited in extent (El-Darier, 2002).

Eucalypts can render the soil unfavorable in some way to growth of other plants; for example, by directly inhibiting under storey species or crop plants being grown in the vicinity of a *Eucalyptus* stand. It is also said that where a Eucalypt stand is harvested and replaced by an agricultural crop, that crop will not do well, at least for a number of years (Lisanework Nigatu, 2000).

Allelopathic effect of aqueous leaf extract of three different species (eucalyptus, guava, and litchi) were used to investigate their effect on germination, shoot and root lengths of two food crops *viz. Zea mays* L. (Maize) and *Triticum aestivum* (Wheat). The aqueous leaf leachate of three species was found to have inhibitory effect on germination, shoot, and root elongation on the tested crops. The study indicates that inhibitory effect was much more pronounced at higher concentrations, and the effect increased with the increase in concentration. Among trees, *Eucalyptus* has much more effect on the tested crops than other species (Khan *et al.,* 2014).

Espinosa-Garcia *et al.* (2008) investigated the allelopathic potential of soil from *Eucalyptus* species (*E. grandis, E. urophylla* and *E. grandis* × *urophylla*) plantations on the germination and early growth of 4 crops [maize (*Zea mays*), bean (*Phaseolus vulgaris*), watermelon (*Cucurbita pepo*) and squash (*Citrullus vulgaris*)]. These soils had variable effects (inhibitory to slightly stimulatory) on test crops. Inhibitory effect was minimum on maize and maximum on black bean. Among the three *Eucalyptus* species, *E. grandis, E. urophylla* was most inhibitory against maize, bean and watermelon growth, whereas, *E. grandis* adversely affected the squash. The soils from *Eucalyptus* species contained water soluble phenolics and their amount varied with soil horizons. The soil from A_0 horizon was most inhibitory, suggesting the accumulation of bioactive allelochemicals in this horizon. The study concluded that soil from *Eucalyptus* spp. contains inhibitory principles that affected the germination and early growth of crop plants.

2.8 Allelopathy of *Eucalyptus camaldulensis*

Ghanuni *et al.* (2015) conducted research for testing the allelopathic effect of *Eucalyptus camaldulensis* leaves on peanuts (*Arachis hypogaea*) crop and purple nutsedge (*Cyperus rotundus*) weed. The Extraction of *Eucalyptus* leaf components was carried out in aqueous medium using Soxhlet method, and the aqueous extract was subjected to partitioning into organic and aqueous fractions. The effect of the concentrations 0, 25, 50, 75 and 100% (0, 12, 24, 36 and 48 mg ground leaf /ml) of the aqueous extract on peanut seeds and purple nutsedge tubers was examined. The results of the treated soil in the pots exhibited a significant reduction in the germination and seedling growth of purple nutsedge and peanut plants. Percent reduction in the growth parameters ranged between 50% and 60% in the pots treated with 35 or 40 g/pot compared to the treatments 0 and 30g/pot. The reduction in peanut seed germination was greater than 50% in the pots treated with 35 or 40 g. However, the difference between these two treatments was significant. Peanut seeds or purple nutsedge tubers were planted in rows in field plots experiment revealed significant differences in their germination. The results revealed significant reduction in the germination and seedling growth of both species treated with the higher rates 178.3 and 203.8 g/row) of the powdered *Eucalyptus* leaves added to the soil. Peanut seed and nutsedge tuber germination was significantly reduced in Petridishes containing the concentrations 50% or more of the aqueous extract. The highest concentration (100%) completely inhibited germination of the tubers, and reduced peanut seed germination to about 6%. Aqueous and organic fractions recovered from crude aqueous extract inhibited the germination of lettuce seeds. In general, the results obtained suggest that the *Eucalyptus* leaf powder can be tested further on row crops grown in fields infested with purple nutsedge, and provide opportunity to try this procedure in the area of organic agriculture and chemical weed control.

Gurmu (2015) studied to determine the effects of different leaves powder proportions of *Eucalyptus* species (*Eucalyptus camaldulensis* and *Eucalyptus grandis*) on agricultural crops as well as change in soil reaction. Results suggested that leaves powder of each tree species induced significant inhibitory effect on germination and seedling growth of each crops compared to the control treatments. Application of low-dose leaves powder of either tree species had low effect on both crops. *Eucalyptus grandis* has more inhibitory effect on both crops, and the negative effect of allelochemicals is more pronounced on haricot bean. This indicates that maize and haricot bean should not be planted very close to *Eucalyptus* trees and crops seed rate should be increased to get the maximum germination.

Awan *et al.* (2015) conducted a research on Interactive Effect of Integrated Nitrogen Management on Wheat Production in *Acacia nilotica* and *Eucalyptus camaldulensis* based Alley Cropping Systems. They found that different nitrogen levels had significant effect on number of productive tillers, grains per spike, 1000-grain weight and grain yield in each alley cropping system. Performance of yield contributing attributes was found the best in open field system whereas reduction was observed in *Acacia and Eucalyptus* wheat based systems to varying extent. Based on two years average, maximum grain yield was obtained in open field followed by Acacia- and Eucalyptus-wheat based systems with application of N 60 kg[sup +] FYM 20 Mg ha[sup -1]. The results suggest that farmers may adopt Acacia-based agroforestry systems for wheat production as compared to Eucalyptus-based systems for wheat productions in salt-affected areas.

Prajapati and Tandel (2013) conducted an investigation on the effect of different tree species leaf leachate on germination and seedling growth of some vegetable crops in laboratory and nursery conditions. The tree species *are Eucalyptus hybrid*, *Tectona grandis, Casuarina equisetifolia, Mitragyna parvifolia, Terminalia Arjuna, Manilkara achras* and *Mangifera indica* and vegetable crops *are Okra,* Tomato, Brinjal, Cabbage, Chilli, Indian bean, Cowpea and Cluster bean. In laboratory and nursery condition, significantly maximum germination percentage, germination velocity, germination energy, seed vigour index, shoot length, fresh weight of shoot, dry weight of shoot, fresh weight of plant and dry weight of plant were recorded in Teak (*Tectona grandis*) whereas root length, fresh weight of root and dry weight of root were noted significantly maximum in Mango (*Mangifera indica*). However, minimum germination percentage, germination energy, germination velocity, seed vigour index, shoot length, root length, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root, fresh weight of plant and dry weight of plant were reported in Eucalyptus. In case of various vegetable crops, significantly maximum germination percentage, germination energy, seed vigour index, shoot length, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root, fresh weight of plant and dry weight of plant in laboratory condition were recorded in Indian bean; germination velocity in Cabbage and root length in Okra. While, minimum germination percentage, germination energy, seed vigour index, shoot length, root length, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root, fresh weight of plant and dry weight of plant and recorded in Chilli and germination velocity in Indian bean. Whereas, in case of nursery condition, significantly maximum germination percentage and germination energy was registered in Cabbage; germination velocity in Cluster bean; seed vigour index and fresh weight of shoot in Okra and shoot length, root length, dry weight of shoot, fresh weight of root, fresh weight of plant and dry weight of plant in Indian bean. While minimum germination percentage, germination energy, seed vigour index, shoot length, root length, dry weight of shoot, fresh weight of root, dry weight of root and dry weight of plant were reported in Chilli; fresh weight of shoot and plant in Brinjal and germination velocity in Indian bean. However in laboratory as well as nursery condition, significantly maximum germination percentage, germination energy, seed vigour index, shoot length, root length, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root, fresh weight of plant and dry weight of plant were noticed in Control thereafter decreasing trends was observed from 5% to 20% concentration of leaf leachate. The germination and seedling growth of vegetable crops decreased as the concentration of leaf leachates increased.

Saberi *et al*. (2013) carried out a research to study allelopathic effect of aerial and underground part of *Eucalyptus camaldulensis* on germination and early growth seedling of *Vicia villosa, Onobrychis sativa, Festuca arundinacea* and *Trifolium rigidom.* Different concentrations of *Eucalyptus camaldulensis* (0%, 25%, 50%, 75% and 100%) was provided by adding distilled water. Results indicated that there were significant differences among all traits (germination percentage, germination speed, root length, shoot length, plant length and seed vigor index) except for germination percentage in *Vicia villosa*. Germination percentage and speed and primary growth indices decreased by increasing of extract concentration. The highest germination percentage and speed, length of radical and plumule and seed vigority were belonged to control treatment and the lowest length belonged to 100% extraction.Germination and early seedling growth of 4 species were reduced significantly by increase of extract concentration and *Onobrychis sativa*, *Trifolium rigidom* indicated more sensitive to allelopathic effect of *Eucalyptus camaldulensis*.

An experiment was conducted by Wasihun (2012) to assess the allelopathic effects of *Eucalyptus (Eucalyptus camaldulensis* and *Eucalyptus grandis*) on two agricultural crops (haricot bean and maize) intercropped with *Eucalyptus* stands. The reports of the allelopathic effects of *Eucalyptus* are mostly based on laboratory bioassay, not on field trials. Results suggested that leaf powder of each tree species induced significant inhibitory effect on emergence and growth of each crops compared to the control treatments. *Eucalyptus grandis* has more inhibitory effect on both crops than *Eucalyptus camaldulensis*, and the negative effect of allelochemicals is more pronounced on haricot bean than maize in both tree species.

Fikreyesus *et al.* (2011) conducted an experiment to determine the allelopathic effect of *Eucalyptus camaldulensis* on tomato crop. Leaf, root, bark and fruit extracts and soil sample of *Eucalyptus camaldulensis* were used to run the experiment under laboratory and field conditions, respectively. The aqueous extracts showed significant inhibitory effect on germination, root and shoot elongation of tomato plants. The inhibitory effect was proportional to the concentrations of the extracts and the higher concentration (5-10%) had the strongest inhibitory effect. Results also revealed that inhibitory effect was more pronounced in radicle length and germination efficiency rather than plumule length. Soil sample also showed significant inhibitory effect on shoot length, root length, leaf area index and dry weight. However, there was no significant difference in the survival of the seedlings planted on the different soil samples. The *Eucalyptus* seems to be a potential threat to the vegetable industry under small-scale farming condition. The tomatoes are incompatible with *Eucalyptus* in agroforestry systems. Therefore, it could be recommend that different remedial practices (like removal of excess leaf litters, planting after the rains) should be done before planting vegetables, in land previously planted with *Eucalyptus* in order to reduce the potential risks.

Some studies using pots have indicated that several rates of dry ground leaves of *Eucalyptus* exhibited allelopathic effect on the rhizomes of bermuda grass (*Cynodon dactylon*) (Nasef *et al.,* 2010) and the tubers of purple nutsedge (*Cyperus rotundus*) (Shammam and Ghanuni, 2011).

Zhang and Fu (2010) conducted a research to assess the allelopathic effects of extracts of leaf litter and live roots of three *Eucalyptus* species [*Eucalyptus urophylla* Blake (Myrtaceae), *Eucalyptus citriodora* Hook. and *Eucalyptus camaldulensis* Dehnh] were determined on the following crops: radish [*Raphanus raphanistrum* var. *sativus* L. G. Beck, Brassicaceae), cucumber (*Cucumis sativus* L., Cucurbitaceae), and Chinese cabbage (*Brassica rapa* var. *glabra* Regel, Brassicaceae)]. The extracts of leaf litter and live roots were inhibitory or stimulatory to test species. However, the effects of leaf litter extracts at lower concentrations were similar to natural concentration in fields and were more pronounced than live roots. When litterfall were removed, Chinese cabbage should be a good candidate crop grown under *Eucalyptus urophylla* and cucumber should be a good candidate crop grown under all tested *Eucalyptus* species in the tree-crop agroforestry systems.

The presence of allelochemicals negatively affects the neighbouring or successional plants (Khan *et al.,* 2008). In case of Eucalyptus, interfere negatively with associated crops and leading to decline in plant diversity. This tendency is attributed to the allelopathy effect. *Eucalyptus* is toxic, due to allelopathic properties which serve to reduce germination of other plants (Khan *et al.,* 2005; Shiming, 2005). Release of toxic chemicals from leaf, stem and roots extracts of *Eucalyptus* may inhibit the germination and seedling growth of crops (Sasikumar *et al.,* 2002). Higher levels of allele-chemicals from root exudates and leaf leachate from older trees might be reason for more inhibitory effect on intercrop with age of the *Eucalyptus* plantation. However, the inhibitory role of allele-chemicals is also expected to be more in rabi (less water regime) than that in kharif (high water regime) when the impact of inhibitory chemicals might be diluted due to high water regime and rainfall(Chowdhury *et al.*, 2011). The aqueous extract of *E. camaldulensis* at various concentration (10, 15 and 20%) levels inhibited the germination, reduced fresh weights and dry weights of wheat seedlings (Djanaguiraman *et al.,* 2002). Thus, *Eucalyptus* extract had decreased the fresh and dry weight. It was observed that the aqueous extract of *E. globulus* caused inhibition of seed germination in green gram, black gram and cowpea. Similarly, leaf extract of *E. camaldulensis* have allelopathic effect on seed germination and seedling growth of wheat (*Triticum aestivum*) (Muhammad *et al.,* 2008).

Khan *et al.* (2008) worked on influence of aqueous extracts of *Eucalyptus camaldulensis* L. on the germination percentage and seedling growth (fresh and dry weight) of wheat. It was noted that aqueous extracts at a concentration of 10, 15 and 20% had inhibitory effect on wheat germination and effect was found significantly higher than control treatment. Fresh and dry weight of seedling was also reduced significantly over control. The inhibitory effects were increased as the extract concentration increased. These findings indicated that wheat sown in fields which had leaf litter of *E. camaldulensis* L. will be adversely affected regarding germination, growth and ultimately resulting in lower yields of wheat.

Khan *et al.* (2007) investigated the effect of aqueous extract of *Eucalyptus camaldulensis* on germination and growth of maize (*Zea mays*) and found that the extract application reduce germination percentage (%) of maize. The dry weight (g) of both shoot and root, an increase over water applied seedlings was noted. Soil pH was decreased while p_2O_5 content of soil was increased in Ramak soil series.

Two studies were conducted using Petridishes and pots to test the effect of different concentrations of sugar beet (*Beta vulgaris*) and *Eucalyptus* aqueous extracts on the growth of *Portulaca oleracea.* The results indicated that the growth of seedlings was inhibited, and was more pronounced in the concentration 20 g/L (Khan *et al.,* 2008). *Eucalyptus camaldulensis* contains volatile allelochemicals (Elaissi *et al.,* 2011, Padhy *et* *al.*, 2000), as well as other stable phenolic compounds, which exhibit allelopathic effects (Padhy *et al.*, 2000).

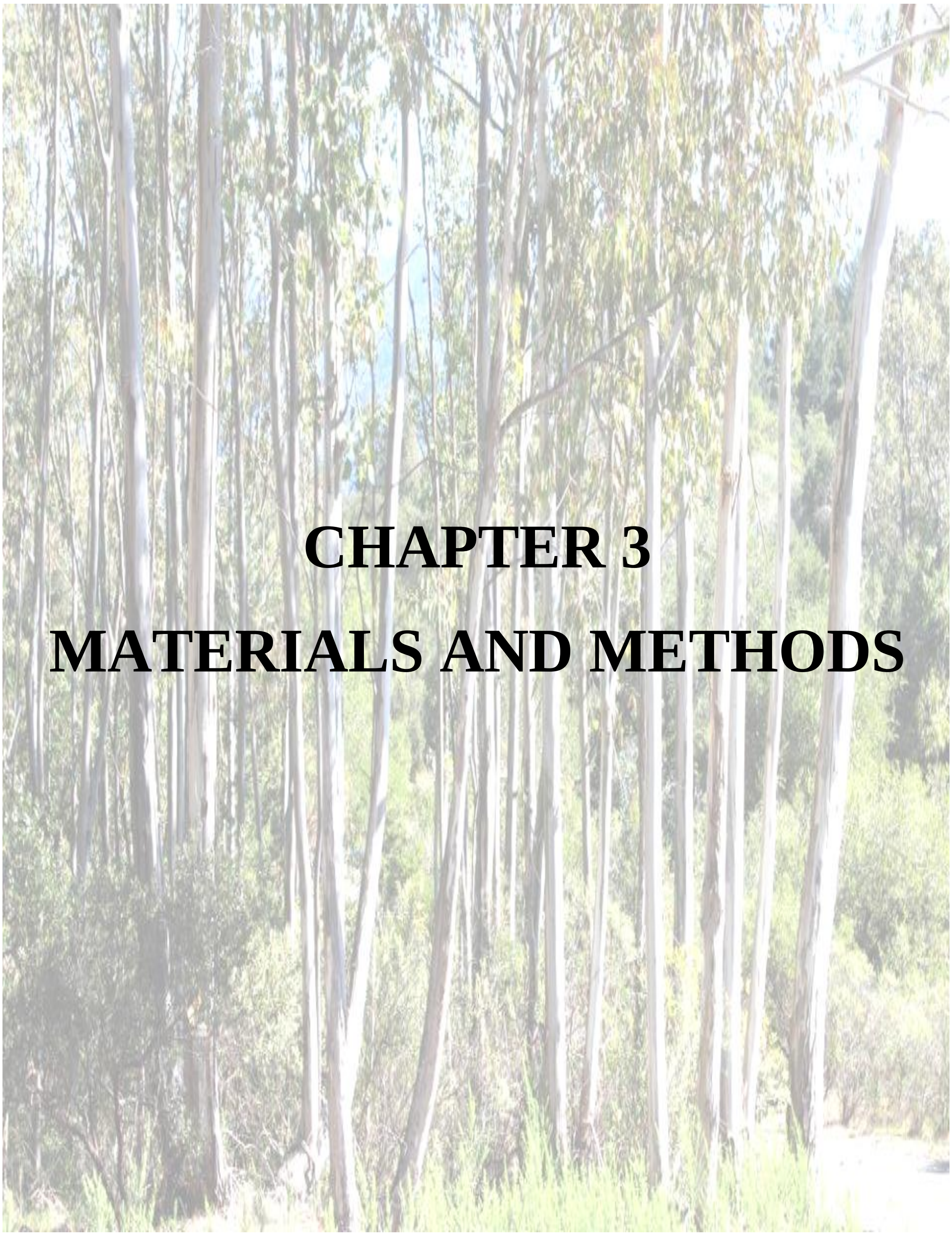
Evaluation of allelopathic effects of *Eucalyptus camaldulensis* plant on other near cultivations especially wheat was done by (Ziaebrahimi *et al.*, 2007). Effects of water extracts of *Eucalyptus* leaves examined on germination and growth of three wheat cultivar seeds and seedlings. Results showed that germination percentage strongly decreased, leaf and root lengths also affected and dry and wet weights of both roots and shoots showed similar change patterns. Activity of peroxidases increased in stress conditions and roots showed more increased enzyme activity than leaves. Activity of polyphenoloxidases increased only in one of three cultivars and again roots showed more activity of this enzyme in response to *Eucalyptus* extract. They suggest that detoxification process were conducted mainly in roots of seedlings.

Khan *et al.* (2004) stated that aqueous extracts of *Eucalyptus* leaves significantly reduced seed germination, root and shoot length, fresh and dry weight of maize compared to control treatment.

Jagger and Pender (2003) stated that *Eucalyptus* have a negative impact on agriculture production (result reduction of crop yield) also attributed to allelochemicals production.

Sasikumar *et al.* (2001) studied to identify the allelopathic compounds in the leachates of bark, fresh leaves and leaf litter of *Eucalyptus tereticornis, E. camaldulensis, E. polycarpa* and *E. microtheca* on redgram *(Cajanus cajan*). Germination was inhibited by each individual compounds tested while vigour index was significantly affected by catechol, ferulic, gallic and syringic acids, compared to control. Bioassay with leachates revealed significant reduction in germination over control in all the cased, 7 days after sowing. Dry matter production was affected by *E. camaldulensis* and *E. microtheca.* Meanwhile, vigour index was affected by *E. camaldulensis*, *E. polycarpa* and *E. microtheca.*

Allolli and Narayanareddy (2000) studied the allelopathic effects of various concentrations of plant extracts (1.0, 2.5, 5.0 and 10.0%) isolated from leaves, barks and roots of *Eucalyptus* on the germination and seedling growth of cucumber seeds. Treatment with 10% leaf extract resulted in 41% less germination and decreased shoot and root growth.



CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

In this chapter, the materials and methods have been presented which include brief description of location of the experimental site, climate, materials used and methodology followed in the experiment. Two experiments (Laboratory and Field) were conducted to achieve the objectives of the research. The details of these sections are described in the following subheads-

3.1 Location

The experiments were conducted in the Agroforestry Laboratory and Agroforestry Research Field, Department of Agroforestry and Environment, HSTU Campus, Dinajpur. The geographical location of the site was between 25º 13' latitude and 88º 23' longitude, and about 37.5m above the sea level.

Figure 3.1: Map showing Dinajpur district

3.2 Soil characteristics

The field experimental plot was situated in a medium high land belonging to the Old Himalayan Piedmont Plain Area (AEZ 01). Land was well-drained as drainage system was well developed. The soil texture was sandy loam in nature. The soil P^H was 5.1. The details soil properties are presented in Appendix-I.

3.3 Climate and Weather

The climate of the study area (laboratory experiment) was characterized by scanty rainfall during Rabi season (7^{th} October to 23^{th} October) and field experiment was also characterized by scanty rainfall during Rabi season (22^{th} December to 15^{th} March) with minimum rainfall during this period of the year.

3.4 Duration

Duration of the experimental period was from October 2016 to March 2017.

3.5 Design

The laboratory experiment design was CRD (Complete Randomized Design) with 3 replication and the field experiment design was RCBD (Randomized Complete Block Design) with 3 replication.

3.6 Seed collection

The seeds of test crops (maize, country bean and bottle gourd) were collected from Bangladesh Agriculture Development Corporation (BADC), Nashipur, Dinajpur.

3.7 The selected test crops

Maize (*Zea mays*), Country bean (*Lablab purpureus*), Bottle gourd (*Lagenaria siceraria*). These crops were selected due to their common practice in the farmers' agroforestry fields with the *E. camaldulensis* trees. Beside these, the species are locally available. Maize is used as a food for human consumption and also as a feed grain for animals. In a field study, Igboanugo (1988) found that beans could be incompatible with *Eucalyptus*, while maize may be compatible with *Eucalyptus* for agrosilvicultural practices. Country bean and Bottle gourd also used as a food for human consumption.

3.8 Laboratory experiment

3.8.1 Exudates preparation

The bark was collected from *E. camaldulensis* tree nearby area of HSTU and stem exudate of *E. camaldulensis* was collected from different sawmills of Dinajpur area. The collected bark and stem of *E. camaldulensis* was chipped and air- dried at room temperature. The air-dried materials was soaked in distilled water for five days and then filtered through Whatman No. 3 filter papers. After preparing different concentrations of the exudates, they were kept into bottles. The bottles were then brought into laboratory for further use.

3.8.2 Treatment combination

For laboratory experiment, three different concentrations of both bark and stem exudates (50%, 25%, 10%) were prepared. To prepare 50% concentration 50g air-dried material were soaked in 100ml water. Like 50% concentration, to prepare 25% concentration 25g air-dried material were soaked in 100ml water and 10g air-dried material were soaked in 100ml water to prepare 10% concentration. Finally, treatments were replicated 3 times in completely randomized design in the laboratory experiment. Distilled water was used for control treatment. Therefore, the treatment combinations were as follows:

- T_1= 50% concentration of both bark and stem exudates
- T_2=25% concentration of both bark and stem exudates
- T_3=10% concentration of both bark and stem exudates
- T_4= Control (Water) of both bark and stem

3.8.3 Pre-sowing treatment

The seeds were surface-sterilized with 0.5% Mercuric Chloride solution and repeatedly rinsed in distilled water. Ten seeds were placed in each sterile Petridis (9cm dia) lined with two Whatman No.3 filter papers and 4 ml of test extracts will be added to each Petridish as per treatments. The germination experiments were conducted in laboratory with normal temperature.

3.8.4 Germination data

Seeds were considered germinated when root length were 1-2 mm and recorded every 8-hour till seven days. Germination speeds were calculated as followed by (Zhang and Fu, 2010). The seedling of country bean, bottle gourd, and maize were removed from the Petridish after 7 days and the length of primary roots and shoots were measured. The effects of extracts on test crops were expressed in percentage (%) of control and were calculated according to T/C, where T is the “treatment” data and C is the “control” data. The effect is stimulatory when the result is greater than 100% and the effect is inhibitory when the result is less than 100%.

Germination data were collected on the germination percentage, germination speed, shoot number and days of germination initiation etc. Germination speed was calculated as under (Chiapusio *et al*., 1997):

$S= (N_1*1) + (N_2–N_1)*1/2 + (N_3- N_2)*1/3 + … + (Nn- N_{n-1}) *1/n.$

Where, N_1, N_2, N_3, …, N_{n-1}, Nn refers to the proportion of germinated seeds on the first, second , third days, …, n-1, n days.

3.9 Field Experiment

The seeds of test crops were sown in the Research field of Agroforestry and Environment, HSTU to see their root-shoot growth parameters and fine root architecture (length, diameter and number) in field condition. Plot size of each replication was 1m*1m for both bark and stem exudates.

3.9.1 Treatment combination

For field experiment, to prepare 50% concentration 50g air-dried material were soaked in 100ml water. Finally, treatments were replicated 3 times in Randomized Complete Block Design. Distilled water was used for control treatment. For bark exudates 9 plots, for stem exudates 9 plots and 3 common plot for control in each tested crops. Therefore, the treatment combinations are as follows:

- T_1= bark (50% concentration)
- T_2= stem (50% concentration)
- T_3= control (water)

3.9.2 Germination data

Seeds were considered germinated when root length were 1-2 mm and recorded every 8-hour till seven days. Germination data were collected on the germination percentage, germination speed, shoot number and days of germination initiation etc. Germination speed was calculated as under (Chiapusio *et al*., 1997):

$S= (N_1*1) + (N_2–N_1)*1/2 + (N_3- N_2)*1/3 + … + (Nn- N_{n-1}) *1/n.$

Where, N_1, N_2, N_3, …, N_{n-1}, Nn refers to the proportion of germinated seeds on the first, second , third days, …, n-1, n days.

The effects of extracts on test crops were expressed in percentage (%) of control and were calculated according to T/C, where T is the "treatment" data and C is the "control" data. The effect is stimulatory when the result is greater than 100% and the effect is inhibitory when the result is less than 100%.

3.10 Data collection

Data were collected on the following parameters- shoot height, no. of branches/leaves, root length (central/tap root length), number of first order lateral roots, collar diameter.

3.11 Morphological measurements of plants

The morphology of shoot and roots and their biomass were measured. Both above and below ground morphology and biomass of seedlings were measured. Root morphology estimation, biomass measurements and seedling quality index were done.

3.12 Root washing of seedling

Each seedling was dug to collect the root systems with minimum damage from the polybag. To ease the uprooting of seedlings, Zida *et al*. (2008) also used water around the selected seedlings. Then very gently soil, stones, debris, etc. were separated by hand from the root systems under a gentle water flow. All the attached materials are detached from the root systems by following carefully the central root and other tertiary roots by hands. Soil containing roots that could not be separated in the field were processed in the laboratory. In the laboratory, roots and soil were repeatedly submerged in water and finely sieved to retain fine roots. A sieve was used to collect any root fragments detached from the system. After collecting the sampled seedlings with whole root system, they were kept in polythene bags and then stored in a wet place near the field laboratory for further measurements.

3.13 Shoot height measurement

Shoot height is defined as the distance from the cotyledon scar to the base of the terminal bud on dormant seedlings or to the tip of the shoot on growing seedlings. In this experiment, shoot height was measured from the root collar to the base of terminal bud of the living shoot tip (Jacobs *et al*., 2005; Ritchie, 1984; Haase, 2007) by measuring tape and measuring pole.

3.14 Root collar diameter (RCD) measurement

RCD is considered as the best morphological measurement of seedling quality as reflected in outplanting performance. It is a measure of the seedling's survivability potential and also the parameter on which the seedling quality, price are based on. In this study, RCD was measured by a diameter caliper, 5 mm above the root collar of all the seedlings with an accuracy of 1 and 0.1 mm respectively (Tsakaldimi *et al.*, 2009).

3.15 Number of branches and Length of central root

Living and non living branches of the shoot were counted for all the seedlings. Length of central root was measured from the root collar zone to the last part of the taproot.

3.16 First order lateral roots

All first-order lateral roots (FOLR) were counted and measured. For this, FOLRs were separated carefully by a sharp knife. For measuring lengths and diameters, each FOLR were numbered serially. Lengths of FOLRs were measured by a measuring tape (made of steel) and diameters of FOLR were measured by a caliper (accuracy 0.1 mm). To measure lengths and diameters, FOLR were separated gently from the central roots by sharp knife and scissor. Diameters of FOLR were taken at the junction of central roots.

After measuring the length and diameter of each FOLR, they were arranged seedling-wise. Then FOLRs of a replication were again sorted and arranged into five different diameter classes such as D1 (1.0-1.5 mm), D2 (>1.5-2.0 mm), D3 (>2.0-2.5 mm), D4 (>2.0-3.0 mm) and D5 (>3.0).

3.17 Biomass measurement

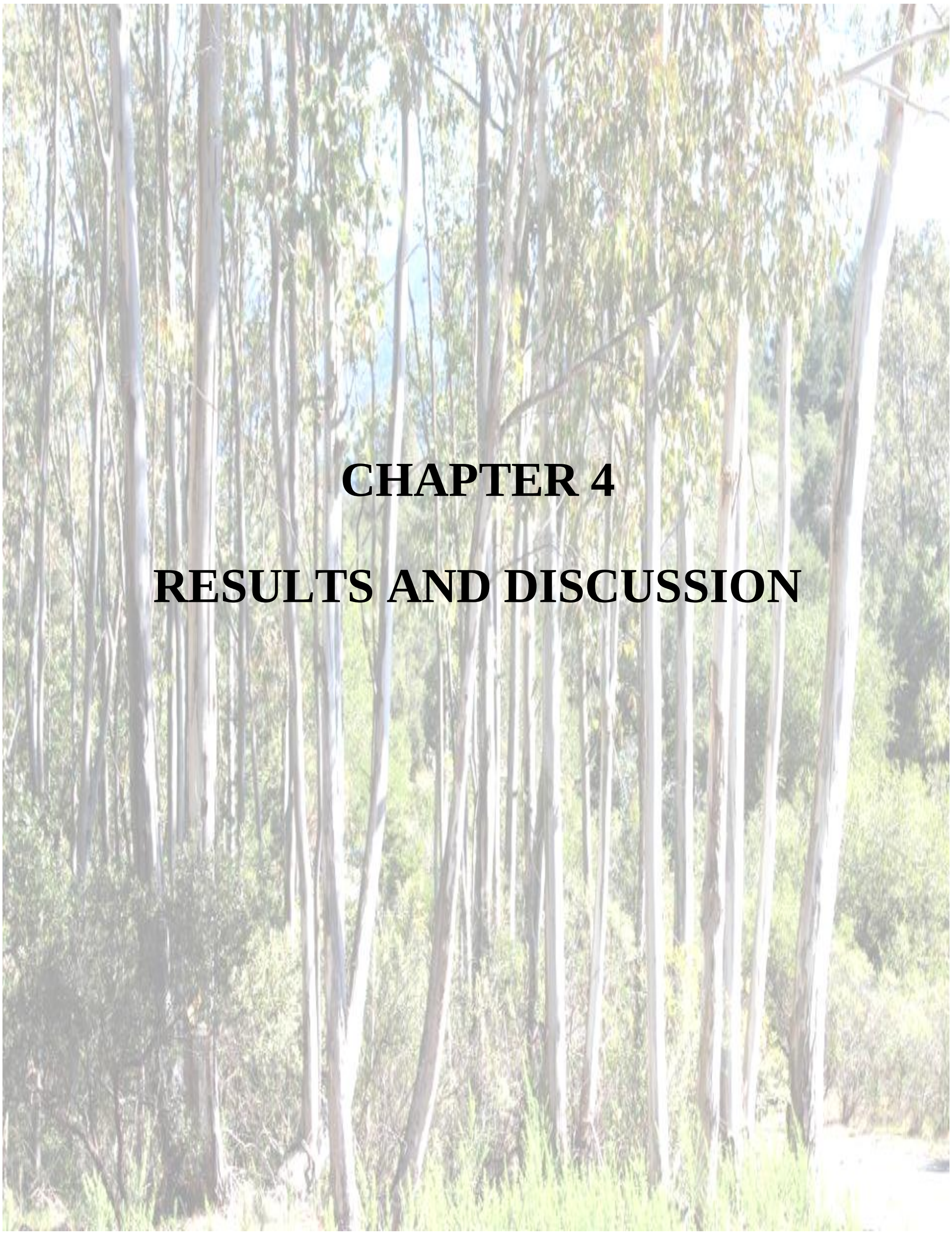
For biomass measurement, the seedlings were divided into two parts: shoot and root system. The root systems were separated from the soil through gentle wash of water using a bucket and sieve to collect any root fragments detached from the system. Branches and leaves were mixed together to get the shoot weight. Both parts were oven-dried at 80°C (Royo *et al*., 2001; Tsakaldimi *et al.*, 2009) for 72 hours until they reached in a constant weight. They were weighed through an electric balance to get shoot dry weight (g), root weight (g). Then total oven dry weight (g) was calculated. The root to shoot ratio was calculated by the root and shoot dry weights (Thompson, 1985).

3.18 Seedling quality index (QI)

The seedling quality index (QI) was calculated using the equation (Dickson *et al.*, 1960): QI=total seedling dry weight (g)/[height (cm)/diameter (mm)+shoot dry weight (g)/root dry weight (g)].

3.19 Statistical Analysis

All statistics were calculated with Statistics 10 software and Microsoft Excel 2007.



CHAPTER 4

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The results obtained from the present studies along with statistical analysis of data have been presented and discussed in this chapter. The present studies regarding effect of bark and stem exudates of *Eucalyptus camaldulensis* on some selected agricultural crops were observed. The summaries of analysis of variance for germination and growth parameters studied have been presented under following sub headings.

4.1 Effect of bark and stem exudates of *E. camaldulensis* on three agricultural crops under laboratory condition

The number of germinated seeds, germination percentage and shoot percentage was found in different treatments. Germination traits were affected by different concentration. Germination was found to start after 3 days of seed sowing.

4.1.1 Effect of bark and stem exudates of *E. camaldulensis* on Maize

4.1.1.1 Germination percentage of Maize in laboratory

The germination percentage of maize was varied notably due to three treatments compared to control (Fig. 4.1).

In case of bark exudates application, the maximum inhibition (24.74%) over control was found in Treatment T_1 (50% concentration) followed by 34.82% and 76.33% in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

In case of stem exudates application, the maximum inhibition (35.36%) over control was found in Treatment T_1 (50% concentration) followed by 42.83% and 63.76 % in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

From the figure it is clear that though both bark and stem exudates inhibited the germination of maize, but inhibition by stem exudates is less in higher concentration than bark exudates.

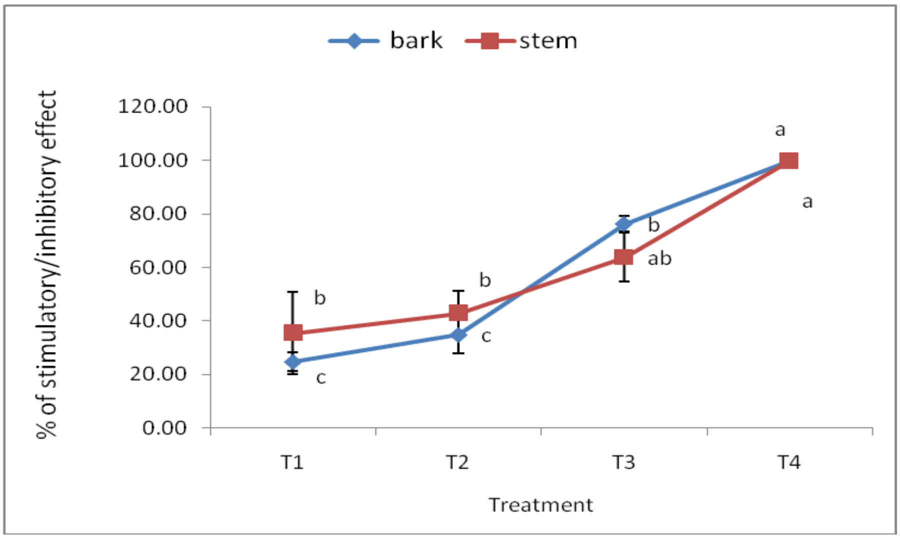
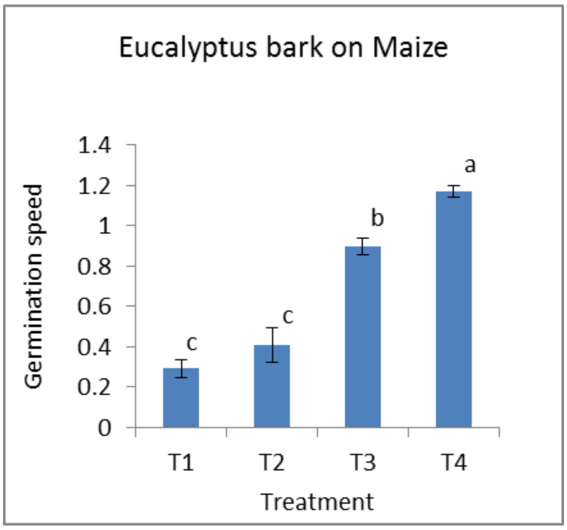
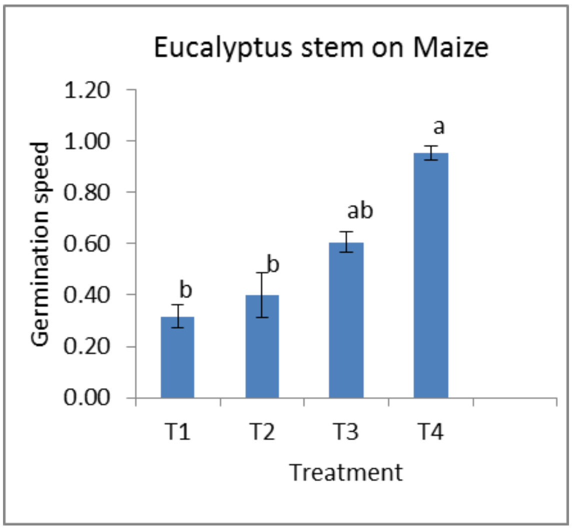


Figure 4.1: Effect of bark and stem exudates of *E. camaldulensis* on germination percentage of Maize (*Zea mays*). In a line diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.1.1.2 Germination speed of Maize in laboratory

Figure 4.2 shows the germination speed of Maize due to bark and stem exudates application. Highest germination speed was found in T_4 (Control), followed by T_3 (10%), T_2 (25%) and lowest in T_1 (50%) (Figure 1a and Figure 1b). This result shows that higher concentration of *Eucalyptus camaldulensis* have stimulatory effect on the seed germination of Maize than the control condition. The details are presented in Appendix-II (a), II (b), III (a) and III (b).





(a) **(b)**

Figure 4.2: Effect of bark (a) and stem (b) exudates of *E. camaldulensis* on germination speed of Maize (*Zea mays*). In a bar diagram, different letter (s) show statististically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

Plate 1: Germination of Maize seeds in different treatments

4.1.1.3 Morphology of Maize in laboratory

In case of bark exudates application, plant height of Maize (*Zea mays*) seedlings was statistically varied differently among the treatments. Plant height was highest in T_4 (24.78cm) and lowest in T_1 (20.50cm). Collar diameter was also affected by the bark exudate. Collar diameter was highest in T_4 (2.76mm) and lowest in T_1 (2.29mm). Central root length was highest in T_4 (23.13cm) and lowest in T_1 (18.67cm).Number of first order lateral root was varied differently among the treatments. Highest number of roots was recorded in T_4 (10) and lowest in T_1 (6.33) (Table 4.1).

Table 4.1: Effect of different concentrations of bark exudates of *E. camaldulensis* on the plant morphological characteristics of *Zea mays* under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	20.50±0.28 c	2.29±0.03 d	18.67 ±0.20 c	6.33±0.60 b
T_2	20.83±0.31 c	2.4±0.0 c	18.78±0.21 c	7.44±0.33 b
T_3	23.12±0.11 b	2.56±0.02 b	20.79±0.14 b	7.7±0.21 b
T_4	24.78±0.14 a	2.76±0.02 a	23.13±0.12 a	10±0.23 a
CV%	2.78	2.76	2.44	14

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter (s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

In case of stem exudates application, plant height of Maize (*Zea mays*) seedlings was statistically varied differently among the treatments. Plant height was highest in T_4 (24cm) and lowest in T_2 (21.83cm). Collar diameter was also affected by stem exudate. Collar diameter was highest in T_4 (2.60mm) and lowest in T_2 (2.43mm). Central root length was highest in T_4 (23.95cm) and lowest in T_1 (21.07cm). Number of first order lateral root was varied differently among the treatments. Highest number of roots was recorded in T_4 (14.50) and lowest in T_1 (6.86) (Table 4.2).

Table 4.2: Effect of different concentrations of stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Zea mays* under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	22.43±0.31 bc	2.44±0.02 b	21.07±0.61 b	6.86±0.26 c
T_2	21.83±0.36 c	2.43±0.02 b	21.61±0.49 b	11±0.23 b
T_3	23.40±0.14 ab	2.54±0.02 a	22.50±0.14 ab	13±0.67 b
T_4	24±0.24 a	2.60±0.01 a	23.95±0.41 a	14.50±0.26 a
CV%	3.53	2.75	5.6	11.2

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter (s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.1.1.4 Biomass allocation of Maize in laboratory

In case of bark exudates application, shoot and root dry biomass of Maize (*Zea mays)* varied among different treatment. The highest value of shoot dry biomass was in treatment T_4 (0.87g) and the lowest value was in treatment T_1 (0.47g). The highest value of root dry biomass was in treatment T_4 (0.19g) and the lowest value was in treatment T_1 (0.12g).Total dry biomass was recorded highest in treatment T_4 (1.07g) and the lowest value was in treatment T_1 (0.59g). Shoot/root ratio did not vary significantly among different treatments. Quality index was found highest in treatment T_4 (0.04) and the lowest value was in treatment T_1 (0.02) in different treatments (Table 4.3).

Table 4.3: Effect of different concentrations of bark exudates of *E. camaldulensis* on the biomass allocation of *Zea mays* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.47±0.01 d	0.12±0.01 c	0.59±0.01 d	3.97±0.18 a	0.02±0.0 b
T_2	0.56±0.00 c	0.14±0.01 bc	0.69±0.02 c	4.29±0.54 a	0.03±0.0 ab
T_3	0.83±0.01 b	0.17±0.01 ab	1.00±0.00 b	5.01±0.29 a	0.04±0.0 a
T_4	0.87±0.01 a	0.19±0.00 a	1.07±0.01 a	4.53±0.05 a	0.04±0.0 a
CV%	2.01	11.62	2.2	12.47	12.56

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4 = Only water (control). In a column, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test.

In case of stem exudates application, shoot and root dry biomass of Maize (*Zea mays)* varied among different treatment. The highest value of shoot dry biomass was in treatment T_4 (0.65g) and the lowest value was in treatment T_1 (0.31g). The highest value of root dry biomass was in treatment T_4 (0.23g) and the lowest value was in treatment T_1 (0.15g).Total dry biomass was recorded highest in treatment T_4 (0.88g) and the lowest value was in treatment T_1 (0.45g). Shoot/root ratio did not vary much significantly among different treatments. Quality index was found highest in treatment T_4 (0.03) and the lowest value was in treatment T_1 and T_2 (0.02) in different treatments (Table 4.4).

Table 4.4: Effect of different concentrations of Stem exudates of *E. camaldulensis* on the biomass allocation of *Zea mays* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.31±0.00 c	0.15±0.02 c	0.45±0.02 c	2.18±0.31 ab	0.02±0.00 b
T_2	0.37±0.03 bc	0.16±0.00 c	0.54±0.03 bc	2.25±0.20 ab	0.02±0.00 b
T_3	0.41±0.00 b	0.22±0.00 b	0.62±0.00 b	1.87±0.04 b	0.02±0.00 ab
T_4	0.65±0.03 a	0.23±0.01 b	0.88±0.03 a	2.86±0.05 a	0.03±0.00 a
CV%	8.43	8.75	6.85	14.31	12.37

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test.

4.1.2 Effect of bark and stem exudates of *E. camaldulensis* on Country Bean

4.1.2.1 Germination Percentage of Country Bean in laboratory

The germination percentage of Country Bean was varied notably due to three treatments compared to control (Fig. 4.3).

In case of bark exudates application, the maximum inhibition (31%) over control was found in Treatment T_1 (50% concentration) followed by 47% and 55% in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

In case of stem exudates application, the maximum inhibition (37.33%) over control was found in Treatment T_1 (50% concentration) followed by 62.33% and 74.33 % in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

From the figure it is clear that though both bark and stem exudates inhibited the germination of country bean, but inhibition by stem exudates is less in higher concentration than bark exudates.

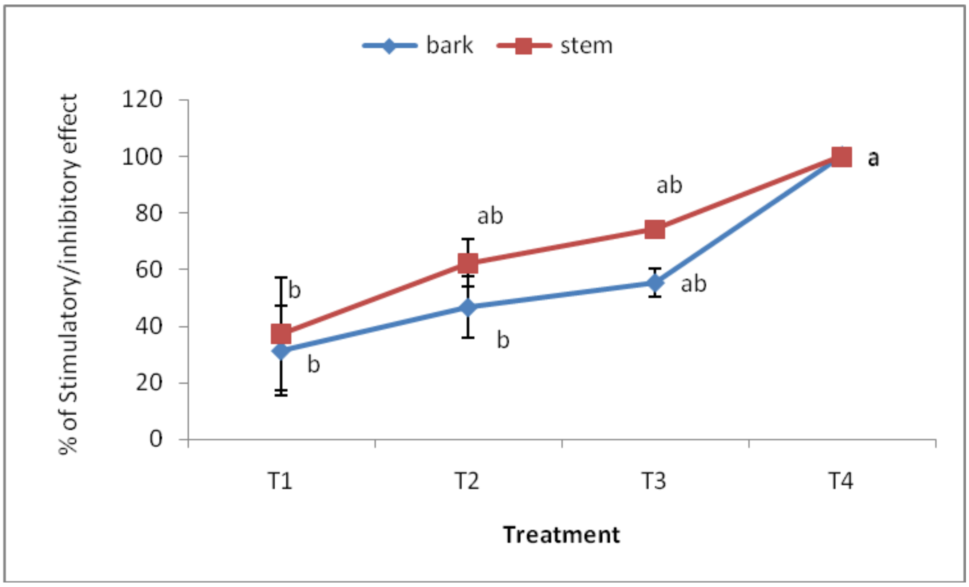
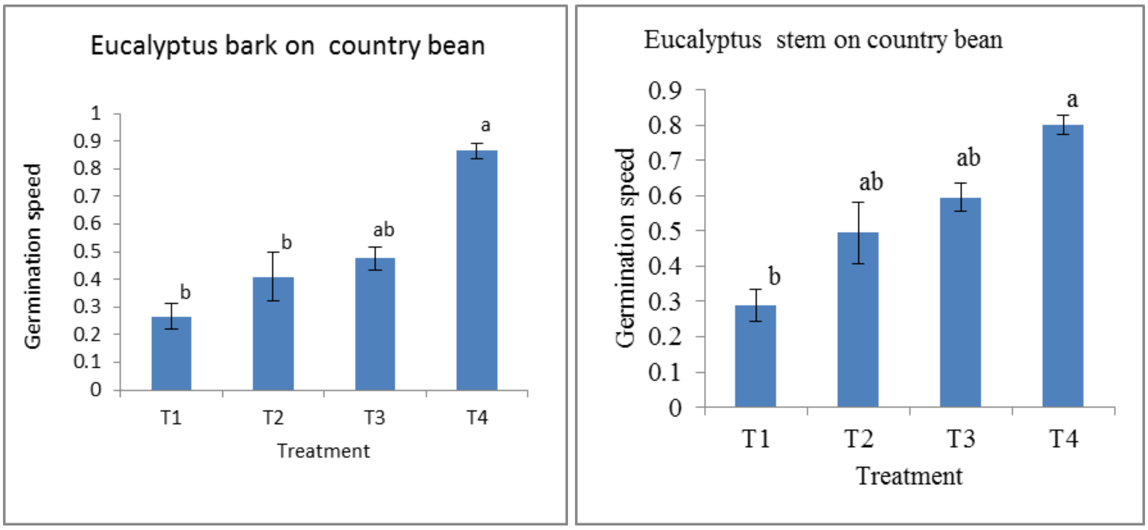


Figure 4.3: Effect of bark and stem exudates of *E. camaldulensis* on germination percentage of Country Bean (*Lablab purpureus*). In a line diagram, different letter (s) show statististically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.1.2.2 Germination speed of Country Bean in laboratory

Figure 4.4 shows the germination speed of Country Bean due to bark and stem exudates application. Highest germination speed was found in T_4 (Control), followed by T_3 (10%), T_2 (25%) and lowest in T_1 (50%) (Figure 1a and Figure 1b) in both bark and stem exudates. This result shows that higher concentration of *E. camaldulensis* have inhibitory effect on the seed germination of Country Bean than the control condition. The details are presented in Appendix- IV (a), IV(b), V(a)and V(b).



(a) (b)

Figure 4.4: Effect of bark(a) and stem(b) exudates of *E. camaldulensis* on germination speed of Country Bean (*Lablab purpureus*). In a bar diagram, different letter (s) show statististically significant at $P \leq 0.05$ by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

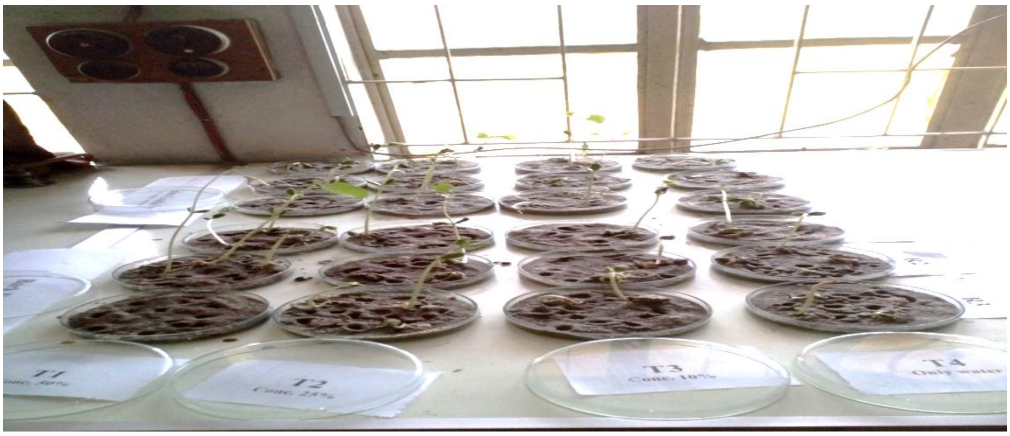


Plate 2 : Germination of Country Bean seeds in different treatments

4.1.2.3 Morphology of Country Bean in laboratory

In case of bark exudates application, plant height of Country Bean (*Lablab purpureus)* seedlings was statistically varied among the treatments. Plant height was highest in T_4 (14.33cm) and lowest in T_1 (10.00cm). Collar diameter was also affected by the bark exudates. Collar diameter was highest in T_4 (2.48mm) and lowest in T_1 (2.02mm). Central root length was highest in T_4 (4.38cm) and lowest in T_1 (2.31cm). Number of first order lateral root was varied among the treatments. Highest number of roots was recorded in T_4 (9.00) and lowest in T_1 (4.43) (Table 4.5).

Table 4.5: Effect of different concentrations of bark exudates of *E. camaldulensis* on the plant morphological characteristics of *Lablab purpureus* L. under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	10.64 ±0.66 b	2.02±0.01 c	2.31±0.09 b	4.43±0.20 b
T_2	11.12±0.44 b	2.35±0.08 ab	2.6±0.31 b	4.88±0.39 b
T_3	10. 00±0.82 b	2.20±0 bc	2.6±0.43 b	8.00±1.04 a
T_4	14.33±0.83 a	2.48±0.02 a	4.38±0.05 a	9.00±0.44 a
CV%	16.31	5.85	20.23	20.73

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter (s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

In case of stem exudates application, plant height of Country Bean (*Lablab purpureus*) seedlings was statistically varied differently among the treatments. Plant height was highest in T_4 (11.67cm) and lowest in T_1 and T_2 (10.17cm). Collar diameter was also affected by stem exudate. Collar diameter was highest in T_4 (3.28mm) and lowest in T_1 (2.05mm). Central root length was highest in T_4 (5.00cm) and lowest in T_1 (2.20cm). Number of first order lateral root was varied among the treatments. Highest number of roots was recorded in T_4 (7.00) and lowest in T_1 (2.83) (Table 4.6).

Table 4.6: Effect of different concentrations of stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Lablab purpureus* L. under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	10.17±0.10 c	2.05±0.03 b	2.2±0.09 b	2.83±0.98 b
T_2	10.17±0.08 c	2.10±0.32 ab	3.07±0.69 b	4.00±0.75 ab
T_3	10.96±0.15 b	2.58±0.23 ab	3.56±0.01 b	5.12±.29 ab
T_4	11.67±0.33 a	3.28±0.17 a	5.00±0.00 a	7.00±0.00 a
CV%	3.47	25.94	31.07	38.10

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at P≤0.05 by Tukey's Range Test.

4.1.2.4 Biomass allocation of Country Bean

In case of bark exudates application, shoot and root dry biomass of Country Bean (*Lablab purpureus*) varied among different treatment. The highest value of shoot dry biomass was in treatment T_4, T_3 (0.38g) and the lowest value was in treatment T_1 (0.33g). The highest value of root dry biomass was in treatment T_4 (0.35g) and the lowest value was in treatment T_1 (0.23g). Total dry biomass was recorded highest in treatment T_4 (0.73g) and the lowest value was in treatment T_1 (0.57g). Shoot/root ratio varied statistically among different treatments. Quality index did not vary significantly among different treatments (Table 4.7).

Table 4.7: Effect of different concentration of bark exudates of *E. camaldulensis* on the biomass allocation of *Lablab purpureus* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.33±0.00 b	0.23±0.00 c	0.57±0.00 d	1.42±0.01 c	0.05±0.00 a
T_2	0.37±0.00 a	0.32±0.00 b	0.7±0.00 c	1.17±0.00 c	0.06±0.00 a
T_3	0.38±0.00 a	0.34±0.00 a	0.72±0.00 b	1.11±0.01 b	0.06±0.00 a
T_4	0.38±0.00 a	0.35±0.00 a	0.73±0.00 a	1.08±0.02 a	0.05±0.00 a
CV%	0.86	1.4	0.6	1.79	0

*T_1= 50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at P≤0.05 by Tukey's Range Test.

In case of stem exudates application, shoot and root dry biomass of Country Bean (*Lablab purpureus*) varied among different treatment. The highest value of shoot dry biomass was in treatment T_4 (0.17g) and the lowest value was in treatment T_1 (0.13g). The highest value of root dry biomass was in treatment T_4 (0.12g) and the lowest value was in treatment T_1 (0.06g).Total dry biomass was recorded highest in treatment T_4 (0.29g) and the lowest value was in treatment T_1 (0.19g). Shoot/root ratio was found statistically similar in different treatments. Quality index did not vary significantly among different treatments (Table 4.8).

Table 4.8: Effect of different concentration of Stem exudates of *E.camaldulensis* on the biomass allocation of *Lablab purpureus* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.13±0.00 d	0.06±0.02 b	0.19±0.02 c	2.63±0.72 a	0.01±0.00 a
T_2	0.14±0.00 c	0.09±0.01 ab	0.23±0.01 bc	1.61±0.24 a	0.02±0.00 a
T_3	0.15±0.00 b	0.11±0.00 a	0.27±0.00 ab	1.43±0.04 a	0.02±0.00 a
T_4	0.17±0.01 a	0.12±0.00 a	0.29±0.00 a	1.36±0.01 a	0.02±0.00 a
CV%	0.78	18.79	7.54	37.48	15.75

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.1.3 Effect of bark and stem exudates of *E. camaldulensis* on Bottle Gourd

4.1.3.1 Germination Percentage of Bottle Gourd in laboratory

The germination percentage of Bottle Gourd was varied notably due to three treatments compared to control (Fig. 4.5).

In case of bark exudates application, the maximum inhibition (54.33%) over control was found in Treatment T_1 (50% concentration) followed by 67.33% and 81.67% in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

In case of stem exudates application, the maximum inhibition (45.67%) over control was found in Treatment T_1 (50% concentration) followed by 65% and 62.67 % in treatment T_2 (25% conc.) and T_3 (10% conc.) respectively.

From the figure it is clear that though both bark and stem exudates inhibited the germination of Bottle Gourd, but inhibition by bark exudates is less in higher concentration than stem exudates.

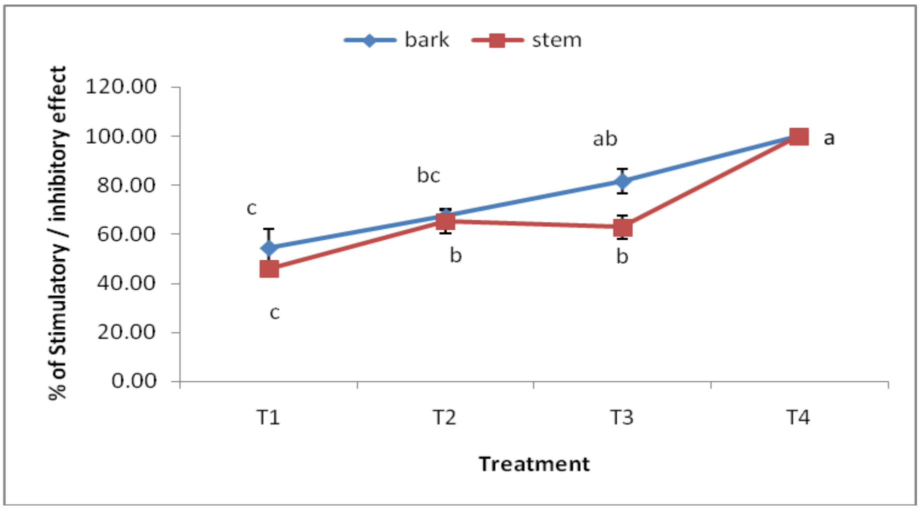
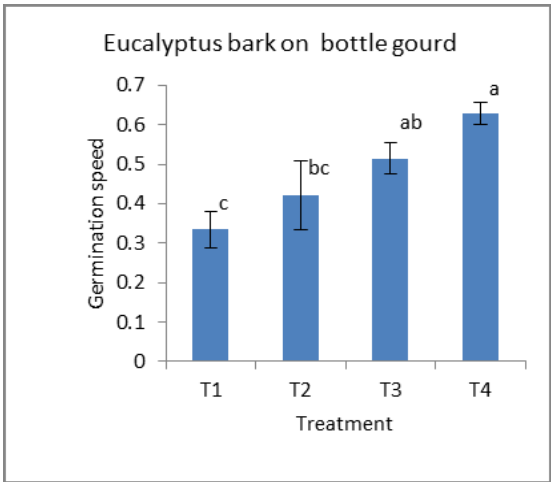
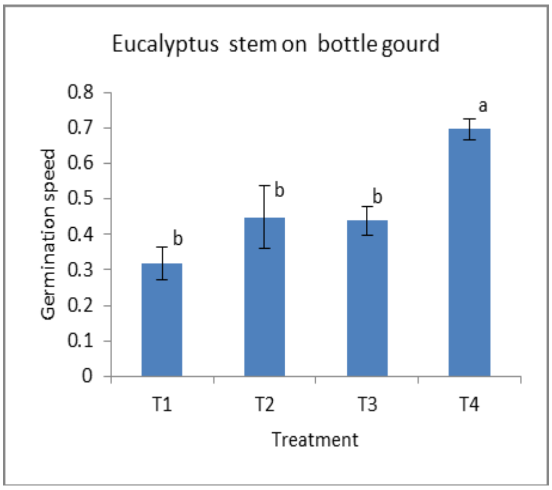


Figure 4.5: Effect of bark and stem exudates of *E. camaldulensis* on germination percentage of Bottle Gourd. In a line diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.1.3.2 Germination speed of Bottle Gourd in laboratory

Figure 4.6 shows the germination speed of Bottle Gourd due to bark and stem exudates application. Highest germination speed was found in T_4 (Control), followed by T_3 (10%), T_2 (25%) and lowest in T_1 (50%) (Figure 1a and Figure 1b) in both bark and stem exudates. This result shows that higher concentration of *Eucalyptus camaldulensis* have inhibitory effect on the seed germination of Bottle Gourd than the control condition. The details are presented in Appendix- VI (a), VI (b), VII (a) and VII (b).





(a) (b)

Figure 4.6: Effect of bark (a) and stem (b) exudates of *E. camaldulensis* on germination speed of Bottle Gourd (*Lagenaria siceraria*). In a bar diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

Plate 3: Germination of Bottle Gourd seeds in different treatments

4.1.3.3 Morphology of Bottle Gourd in laboratory

In case of bark exudates application, plant height of Bottle Gourd (*Lagenaria siceraria*) seedlings was statistically varied among the treatments. Plant height was highest in T_4 (17.28cm) and lowest in T_1 (10.64cm). Collar diameter was also affected by the bark exudate. Collar diameter was highest in T_4 (3.29mm) and lowest in T_1 (3.07mm). Central root length was highest in T_4 (6.78cm) and lowest in T_1 (3.21cm). Number of first order lateral root was statistically similar among different treatments (Table 4.9).

Table 4.9: Effect of different concentrations of bark exudates of *E.camaldulensis* on the plant morphological characteristics of *Lagenaria siceraria* under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	10.64±0.38 c	3.07±0.04 b	3.21±0.57 c	3.64±0.52 a
T_2	14.66±0.26 b	3.15±0.03 ab	5.11±0.18 b	3.67±0.23a
T_3	14.35±0.21 b	3.18±0.03 ab	5.05±0.20b	3.60±0.33 a
T_4	17.28±0.28 a	3.29±0.05 a	6.78±0.28 a	4.28±0.28 a
CV%	5.64	3.79	17.83	26.59

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

In case of stem exudates application, plant height of Bottle Gourd (*Lagenaria siceraria*) seedlings was statistically varied differently among the treatments. Plant height was highest in T_4 (16.06cm) and lowest in T_1 (10.15cm). Collar diameter was also affected by stem exudate. Collar diameter was highest in T_4 (3.29mm) and lowest in T_1 (2.42mm). Central root length was highest in T_4 (4.87cm) and lowest in T_1 (3.36cm). Number of first order lateral root was statistically similar among different treatments (Table 4.10).

Table 4.10: Effect of different concentrations of stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Lagenaria siceraria* under laboratory condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	10.15±0.39 c	2.42±0.20 b	3.36±0.23 b	3.43±0.48 a
T_2	11.44±0.26 b	3.23±0.05 a	3.74±0.34 b	3.67±0.16 a
T_3	11.00±0.34 bc	3.02±0.01 a	3.64±0.14 b	3.85±0.14 a
T_4	16.06±0.22 a	3.29±0.02 a	4.87±0.22 a	3.87±0.12 a
CV%	6.92	8.98	18.85	19.02

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.1.3.4 Biomass allocation of Bottle Gourd in laboratory

In case of bark exudates application, shoot and root dry biomass of Bottle Gourd (*Lagenaria siceraria*) varied among different treatment. The highest value of shoot dry biomass was in treatment T_4 (0.34g) and the lowest value was in treatment T_1 (0.21g). The highest value of root dry biomass was in treatment T_4 (0.24g) and the lowest value was in treatment T_1 (0.17g). Total dry biomass was recorded highest in treatment T_4 (0.57g) and the lowest value was in treatment T_1 (0.39g). Shoot/root ratio was vary among different treatments. Quality index was found statistically similar in different treatments (Table 4.11).

Table 4.11: Effect of different concentrations of bark exudates of *E. camaldulensis* on the biomass allocation of *Lagenaria siceraria* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.21±0.00 d	0.17±0.00 d	0.39±0.00 d	1.23±0.01 bc	0.03±0.00 a
T_2	0.24±0.00 c	0.20±0.00 c	0.44±0.00 c	1.2±0.00 c	0.03±0.00 a
T_3	0.29±0.00 b	0.23±0.00 b	0.52±0.00 b	1.29±0.01 b	0.03±0.00 a
T_4	0.34±0.00 a	0.24±0.00 a	0.57±0.00 a	1.44±0.03 a	0.03±0.00 a
CV%	1.18	1.24	0.85	1.84	0

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

In case of stem exudates application, shoot and root dry biomass of Bottle Gourd (*Lagenaria siceraria*) varied among different treatment. The highest value of shoot dry biomass was in treatment T_4 (0.25g) and the lowest value was in treatment T_1 (0.19g). The highest value of root dry biomass was in treatment T_4 (0.19g) and the lowest value was in treatment T_1 (0.12g). Total dry biomass was recorded highest in treatment T_4 (0.44g) and the lowest value was in treatment T_1 (0.31g). Shoot/root ratio vary significantly among different treatments. Quality index was found statistically similar in different treatments (Table 4.12).

Table 4.12: Effect of different concentrations of Stem exudates of *E. camaldulensis* on the biomass allocation of *Lagenaria siceraria* under laboratory condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	0.19±0.00 c	0.12±0.00 d	0.31± 0.00 c	1.58±0.01 a	0.03±0.00 a
T_2	0.22±0.00 b	0.15±0.00 c	0.38±0.00 b	1.44±0.01 b	0.03±0.00 a
T_3	0.24±0.00 ab	0.18±0.00 b	0.42±0.00 a	1.28±0.02 c	0.03±0.00 a
T_4	0.25±0.01 a	0.19±0.01 a	0.44±0.01 a	1.29±0.03 c	0.02±0.00 a
CV%	3.01	0.5	2.11	2.5	17.65

*T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.2 Effect of bark and stem exudates of *E. camaldulensis* on three agricultural crops under field condition

The number of germinated seeds, germination percentage and shoot percentage was calculated in different treatments. Germination traits were affected by different treatments. Germination was found to start after 13 days of seed sowing.

4.2.1 Effect of bark and stem exudates of *E. camaldulensis* on Maize

4.2.1.1 Germination Percentage of Maize in field

The germination percentage of maize varied notably due to two treatments compared to control (Fig. 4.7). The maximum inhibition (40%) over control was found in stem exudates (T_2) followed by (52%) inhibition over control bark exudates (T_1) application. From the figure it is clear that stem exudates inhibited the germination of maize than bark exudates. The details are presented in Appendix- VIII.

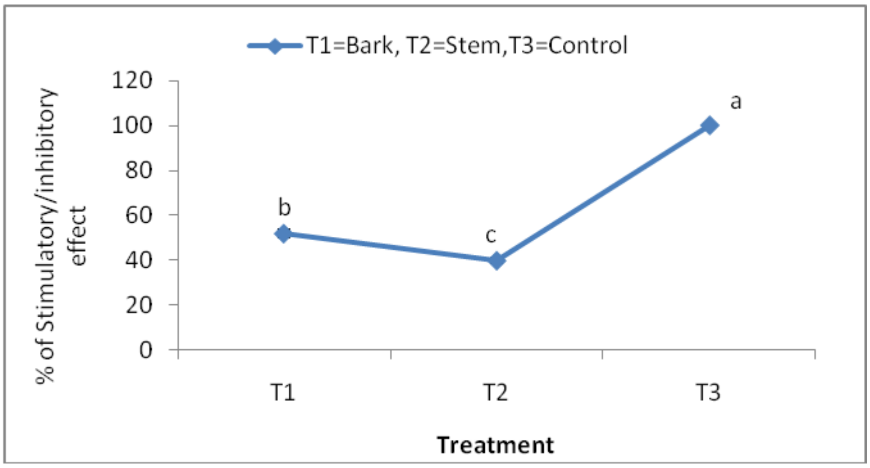


Figure 4.7: Effect of bark (T_1) and stem (T_2) exudates of *E. camaldulensis* on germination percentage of Maize (*Zea mays*). In a line diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.1.2 Germination speed of Maize in field

Figure 4.8 shows the germination speed of Maize due to bark and stem exudates application. Highest germination speed was found in T_3 (Control), followed by T_1 (bark exudates), T_2 (stem exudates). This result shows that *E. camaldulensis* have inhibitory effect on the seed germination of Maize than the control condition and *Eucalyptus* bark exudates has less inhibitory effect on Maize than stem exudates. The details are presented in Appendix- IX.

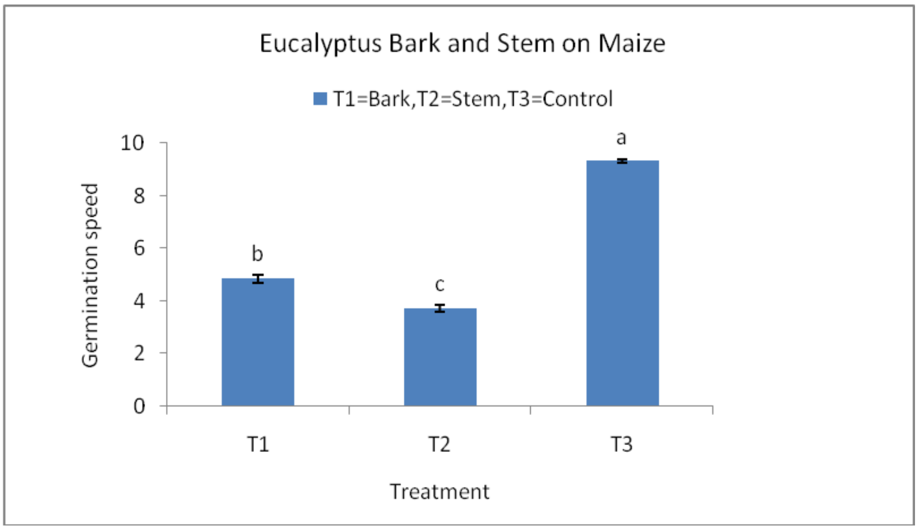


Figure 4.8: Effect of bark (T_1) and stem (T_2) exudates of *E. camaldulensis* on Germination speed of Maize. In a bar diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1= 50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.1.3 Morphology of Maize in field

Plant height of Maize (*Zea mays*) seedlings was statistically varied among the different treatments. Plant height was highest in T_3 (117cm) and lowest in T_2 (92.20cm). Collar diameter was also affected by the bark and stem exudates. Collar diameter was highest in T_3 (25mm) and lowest in T_2 (14.74mm). Central root length was highest in T_3 (41cm) and lowest in T_2 (23.63cm). Number of first order lateral root was varied differently among the treatments. Highest number of first order lateral roots was recorded in T_3 (36) and lowest in T_2 (17) (Table 4.13).

Table 4.13: Effect of different concentration of Bark and Stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Zea mays* under field condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	108.8±0.28 b	18±0.58 b	34±0.58 b	24.67±0.33 b
T_2	92.20±1.1 c	14.74±0.15 c	23.63±0.32 c	17±0.58 c
T_3	117±1.2 a	25±0.58 a	41±0.58 a	36±0.58 a
CV%	1.53	4.31	2.67	3.41

*T_1= Bark, T_2=Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.2.1.4 Biomass allocation of Maize in field

Shoot and root dry biomass of Maize (*Zea mays*) varied among different treatment. The highest value of shoot dry biomass was in treatment T_3 (51g) and the lowest value was in treatment T_2 (37g). The highest value of root dry biomass was in treatment T_3 (18g) and the lowest value was in treatment T_2 (5g). Total dry biomass was recorded highest in treatment T_3 (69g) and the lowest value was in treatment T_2 (42g). Shoot/root ratio and Quality index vary significantly among different treatments (Table 4.14).

Table 4.14: Effect of different concentrations of Bark and Stem exudates of *E. camaldulensis* on the biomass allocation of *Zea mays* under field condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	42.54±0.81 b	10.98±0.02 b	53.52±0.79 b	3.88±0.08 b	0.47±0.01 b
T_2	37±0.58 c	5±0.58 c	42±1.15 c	7.58±.78 a	0.42±0.02 c
T_3	51±0.58 a	18±0.58 a	69±1.15 a	2.84±0.06 b	0.58±0.00 a
CV%	2.64	7.21	3.31	16.42	3.9

*T_1=Bark, T_2=Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.2.2 Effect of bark and stem exudates of *E. camaldulensis* on Country Bean

4.2.2.1 Germination Percentage of Country Bean in field

The germination percentage of Country Bean varied notably due to two treatments compared to control (Fig. 4.9). The maximum inhibition (19.67%) over control was found in stem exudates (T_2) followed by (34.33%) inhibition over control bark exudates (T_1) application. From the figure it is clear that stem exudates inhibited the germination of Country Bean than bark exudates. The details are presented in Appendix-X.

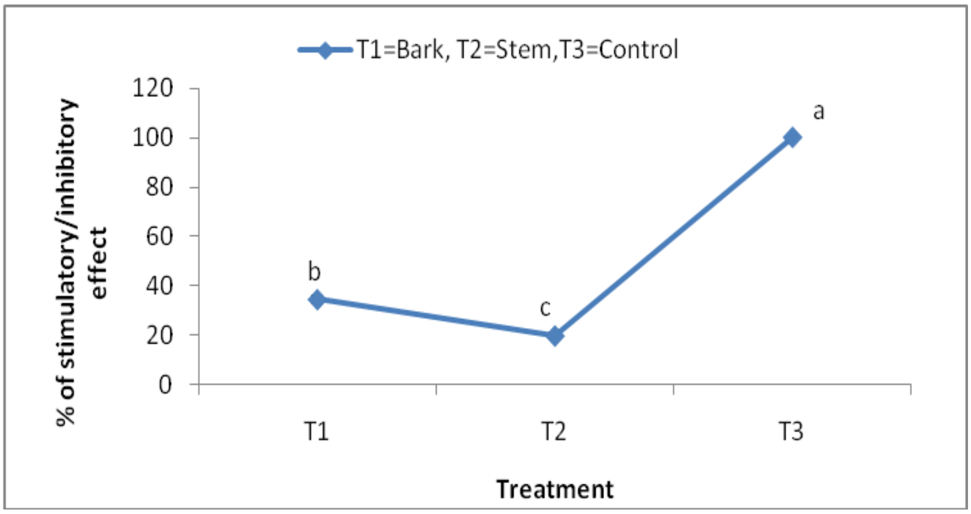


Figure 4.9: Effect of bark and stem exudates of *E. camaldulensis* on germination percentage of Country Bean. In a line diagram, different letter (s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.2.2 Germination speed of Country Bean in field

Figure 4.10 shows the germination speed of Country Bean due to bark and stem exudates application. Highest germination speed was found in T_3 (Control), followed by T_1 (bark exudates), T_2 (stem exudates). This result shows that *Eucalyptus camaldulensis* have inhibitory effect on the seed germination of Country Bean than the control condition and *Eucalyptus* bark exudates has less inhibitory effect on Country Bean than stem exudates. The details are presented in Appendix-XI.

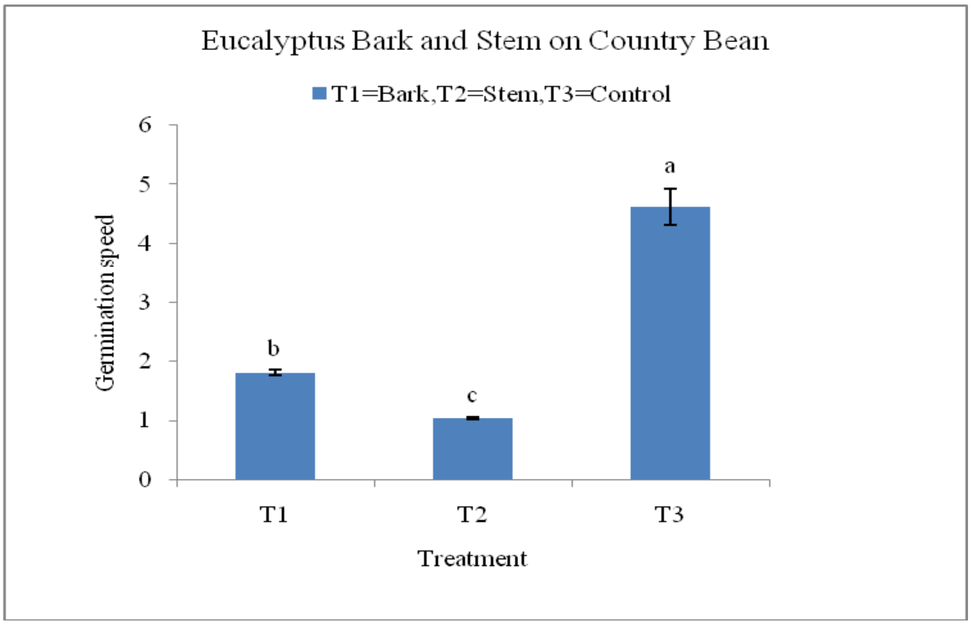


Figure 4.10: Effect of bark (T_1) and stem (T_2) exudates of *E. camaldulensis* on germination speed of Country Bean .In a bar diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.2.3 Morphology of Country Bean in field

Plant height of Country Bean seedlings was statistically varied among the different treatments. Plant height was highest in T_3 (114cm) and lowest in T_2 (74.53cm). Collar diameter was also affected by the bark and stem exudates. Collar diameter was highest in T_3 (5.91mm) and lowest in T_2 (5.23mm). Central root length was highest in T_3 (23cm) and lowest in T_1 (15.33cm). Number of first order lateral root was varied differently among the treatments. Highest number of roots was recorded in T_3 (15.33) and lowest in T_2 (5.33) (Table 4.15).

Table 4.15: Effect of different concentrations of Bark and Stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Lablab purpureus* under field condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	96.79±0.64 b	5.34±0.01 ab	15.33±0.88 c	5.33±0.33 c
T_2	74.53±0.61 c	5.23±0.11 b	19±0.58 b	11±0.58 b
T_3	114±1.00 a	5.91±0.19 a	23±0.58 a	15.33±0.33 a
CV%	1.4	4.18	6.29	7.06

*T_1=Bark, T_2=Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.2.2.4 Biomass allocation of Country Bean in field

Shoot and root dry biomass of Country Bean varied among different treatment. The highest value of shoot dry biomass was in treatment T_3 (50.5g) and the lowest value was in treatment T_2 (23.33g). The highest value of root dry biomass was in treatment T_3 (2.1g) and the lowest value was in treatment T_2 (0.72g). Total dry biomass was recorded highest in treatment T_3 (52.6g) and the lowest value was in treatment T_2 (24.05g). Shoot/root ratio and Quality index vary significantly among different treatments (Table 4.16).

Table 4.16: Effect of different concentrations of Bark and Stem exudates of *E. camaldulensis* on the biomass allocation of *Lablab purpureus* under field condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	30.83±0.17 b	1.1±0.06 b	31.93±0.12 b	28.2±1.61 ab	0.26±0.00 b
T_2	23.33±0.58 c	0.72±0.01 c	24.05±0.33 c	32.41±0.53 a	0.22±0.00 c
T_3	50.5±0.29 a	2.1±0.06 a	52.6±0.35 a	24.08±0.53 b	0.38±0.01 a
CV%	1.35	6.26	1.37	6.28	2.6

*T_1= Bark, T_2= Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.2.3 Effect of bark and stem exudates of *E. camaldulensis* on Bottle Gourd

4.2.3.1 Germination Percentage of Bottle Gourd in field

The germination percentage of Bottle Gourd varied notably due to two treatments compared to control (Fig. 4.11). The maximum inhibition (40%) over control was found in stem exudates (T_2) followed by (50%) inhibition over control bark exudates (T_1) application. From the figure it is clear that stem exudates inhibited the germination of Bottle Gourd than bark exudates. The details are presented in Appendix- XII.

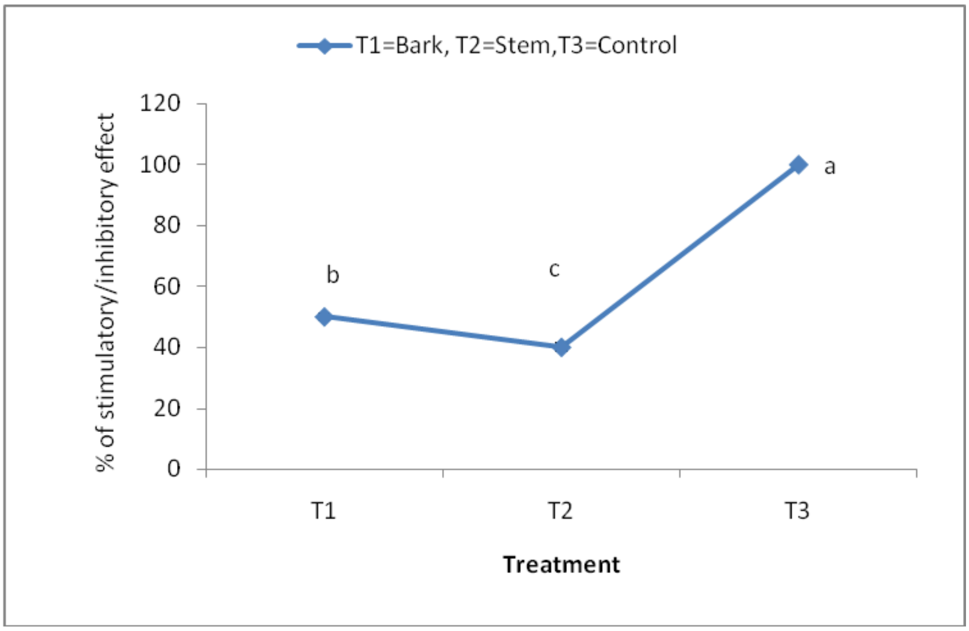


Figure 4.11: Effect of bark and stem exudates of *E. camaldulensis* on germination percentage of Bottle Gourd. In a line diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.3.2 Germination speed of Bottle Gourd in field

Figure 4.12 shows the germination speed of Bottle Gourd due to bark and stem exudates application. Highest germination speed was found in T_3 (Control), followed by T_1 (bark exudates), T_2 (stem exudates). This result shows that *Eucalyptus camaldulensis* have inhibitory effect on the seed germination of Bottle Gourd than the control condition and *Eucalyptus* bark exudates has less inhibitory effect on Bottle Gourd than stem exudates. The details are presented in Appendix-XIII.

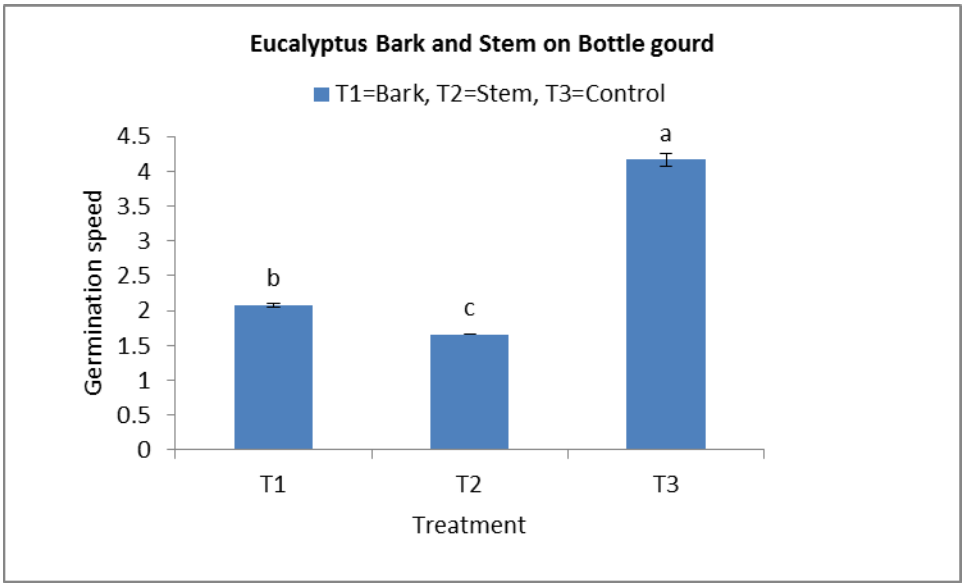


Figure 4.12: Effect of bark (T_1) and stem (T_2) exudates of *E. camaldulensis* on Germination Speed of Bottle Gourd. In a bar diagram, different letter (s) show statistically significant at P≤0.05 by Tukey's Range Test. (T_1=50% concentration, T_2= 25% concentration, T_3= 10% concentration, T_4= Only water).

4.2.3.3 Morphology of Bottle Gourd in field

Plant height of Bottle Gourd seedlings was statistically varied among the different treatments. Plant height was higher in T_3 (21.67cm) and lowest in T_1 (12.33cm). Collar diameter was also affected by the bark and stem exudates. Collar diameter was highest in T_3 (6.9mm) and lowest in T_1 (3.55mm). Central root length was highest in T_3 (13cm) and lowest in T_1 (7.33cm). Number of first order lateral root was varied differently among the treatments. Highest number of roots was recorded in T_3 (12) and lowest in T_1 (7) (Table 4.17).

Table 4.17: Effect of different concentrations of Bark and Stem exudates of *E. camaldulensis* on the plant morphological characteristics of *Lagenaria siceraria* under field condition

Treatment*	Plant height (cm)	Collar diameter (mm)	Central root length (cm)	No. of First order lateral roots
T_1	12.33±0.33 c	3.55±0.05 c	7.33±0.33 b	7±0.58 b
T_2	16.43±0.23 b	4.37±0.03 b	8±0.58 b	8.33±0.33b
T_3	21.67±0.88 a	6.9±0.58 a	13±0.58 a	12±0.58 a
CV%	5.78	1.82	9.34	9.68

*T_1= Bark, T_2= Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at P≤0.05 by Tukey's Range Test.

4.2.3.4 Biomass allocation of Bottle Gourd in field

Shoot and root dry biomass of Bottle Gourd varied among different treatment. The highest value of shoot dry biomass was in treatment T_3 (5.73g) and the lowest value was in treatment T_2 (2.30g). The highest value of root dry biomass was in treatment T_3 (2.17g) and the lowest value was in treatment T_2 (0.17g).Total dry biomass was recorded highest in treatment T_3 (7.9g) and the lowest value was in treatment T_2 (2.47g). Shoot/root ratio and Quality index vary significantly among different treatments (Table 4.18).

Table 4.18: Effect of different concentrations of Bark and Stem exudates of *E. camaldulensis* on the biomass allocation of *Lagenaria siceraria* under field condition

Treatment*	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot/root ratio	Quality Index
T_1	4.29±0.06 b	1.19±0.05 b	5.48±0.09 b	3.62±0.14 b	0.35±0.01 a
T_2	2.30±0.06 c	0.17±0.02 c	2.47±0.05 c	13.85±1.68 a	0.08±0.01 b
T_3	5.73±0.15 a	2.17±0.09 a	7.9±0.06 a	2.66±0.18 b	0.33±0.01 a
CV%	4.09	8.69	2.26	25.3	5.94

*T_1= Bark, T_2= Stem, T_3= Only water (control). In a column, different letter(s) show statistically significant at $P \leq 0.05$ by Tukey's Range Test.

4.3 Discussion

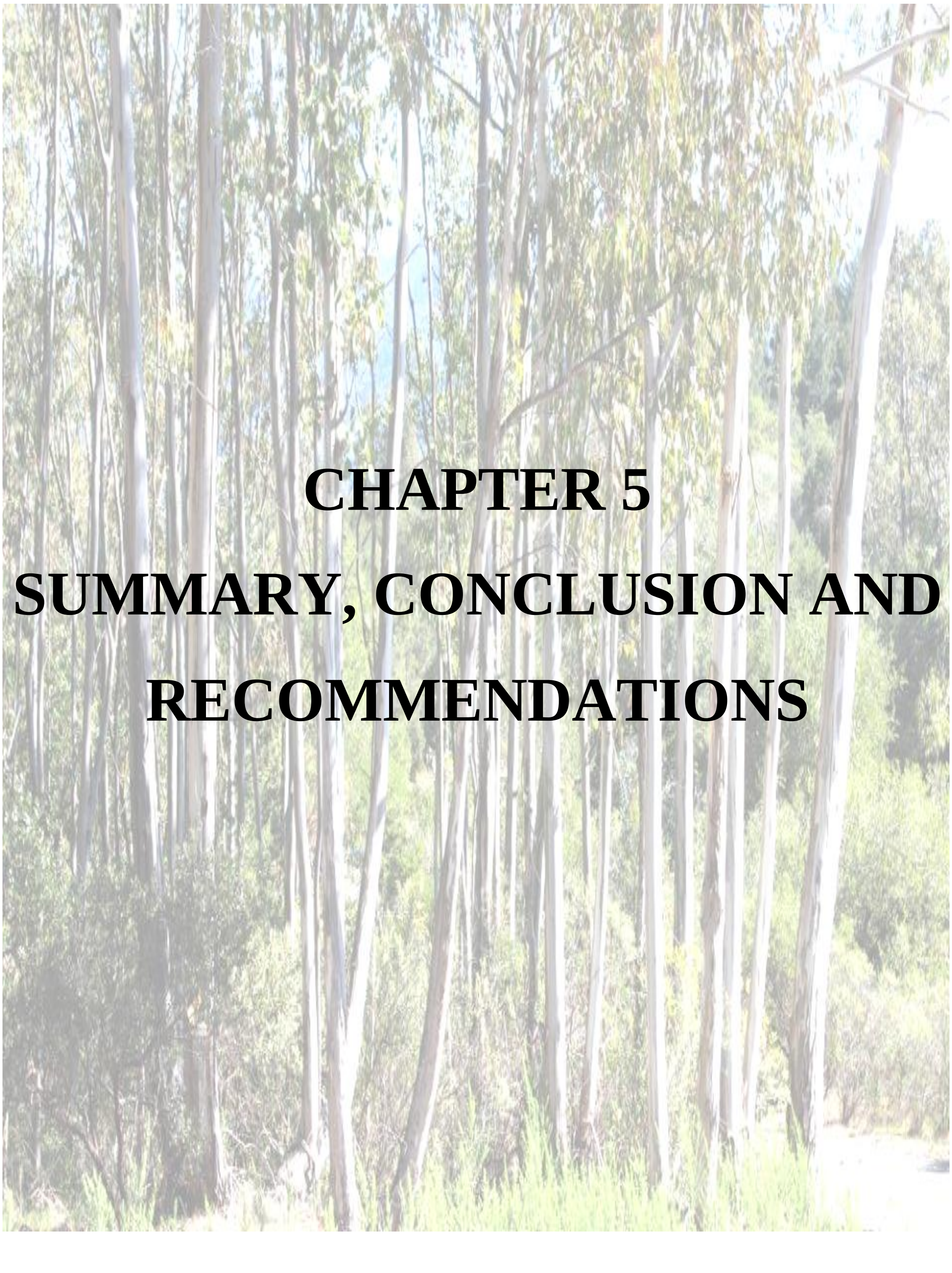
The results showed that the both bark and stem exudates of *Eucalyptus camaldulensis* inhibited the seed germination and seedling growth of three test crops i.e. Maize, Country bean and Bottle gourd. Therefore, both bark and stem exudates of *E. camaldulensis* exerted allelopathic effects on seed germination of crop species. However, the allelopathic effects of *E. camaldulensis* were either inhibitory or stimulatory depending on test species. The results are consistent with the reports on allelopathic effects in literatures (Zang and Fu, 2010; Malik, 2004).

Results of laboratory experiment showed that 50% concentration of both bark and stem exudates of *E. camaldulensis* inhibited more in germination of three tested crops compared to other concentrations. Bark exudates of *E. camaldulensis* showed germination percentage 24.74% in Maize, 31% in Country bean and 54.33% in Bottle gourd over control. On the other hand, stem exudates of *E. camaldulensis* showed germination percentage 35.36% in Maize, 37.33% in Country bean and 45.67% in Bottle gourd over control. The results are in consistent with the results of many researchers (Prajapati and Tandel, 2013; Saberi *et al*., 2013). For example, Ghanuni *et al* (2015) who conducted research on the allelopathic effect of *Eucalyptus* leaf on peanuts and found significant germination and seedling growth reduction. Gurmu (2015) suggested that leaves powder of *Eucalyptus* induced significant inhibitory effect on germination and seedling growth of each crops compared to the control treatments. Wasihun (2012) studied on Maize and Bean in laboratory condition and found more germination inhibition and growth reduction in bean than maize.

In case of field experiments, both bark and stem exudates of *E. camaldulensis* also inhibited the germination of the three tested crop. Application of 50% concentration of *E. camaldulensis* bark exudates showed germination percentage 52.0% in Maize, 34.33% in Country bean and 50.0 % in Bottle gourd over control and 50% stem exudates showed germination percentage 40% in Maize, 19.67% in Country bean and 40% in Bottle gourd over control. Prajapati and Tandel (2013) also worked on the effect of *Eucalyptus* leaf powder on crops and found germination reduction in the open nursery condition. Fikreyesus *et al* (2011) worked on the leaf, root and bark of *Eucalyptus* and found significant inhibitory effect on the germination and shoot- root morphology of tomato plants.

Morphological parameters like plant height (cm), collar diameter (mm),central root length (cm), no. of first order lateral roots showed significantly higher growth in control over bark and stem exudates in all the tested crops at the laboratory and field experiments. Similar results were recorded for biomass allocation like shoot dry weight (g), root dry weight (g), total dry weight (g), shoot/root ratio and quality index. The results showed that the inhibitory effect increased with increasing concentrations. This result was in agreement with many researchers (Fikreyesus *et al.*, 2011; Saberi *et al.*, 2013; Djanaguiraman *et al.*, 2002). Greater concentration of allelochemicals might inhibit the seed germination by suppressing the synthesis of gibberellins and indole acetic acid (Moradshahi, 2003). The inhibitory effect was proportional to the concentrations of the extracts and the higher concentration had the strongest inhibitory effect (Fikreyesus et al., 2011). In the field experiment, inhibition by bark exudates is less compared to stem exudates of respective crops. This might be due to more allelopathic effect of stem exudates over bark exudates of *E. camaldulensis* on the tested crops.

From the overall result it can be concluded that in addition to the allelopathic effect of leaf and root of *E. camaldulensis*, bark and stem have also allelopathic effect on the agricultural crops which inhibited more in laboratory compared to field condition (Khan *et al*., 2008). Alrababah (2009) found that the yields of agriculture crops were reduced in field, perhaps due to allelopathic effects of trees on the crop through the release of phytotoxic phenolics from leaf litter and the accumulation of these phytotoxins in the soil. As a common practice, if fallen stem, bark and branches of *Eucalyptus* timely collected for fuel wood purposes, it might be a good management strategy to alleviate the allelopathic effects of *Eucalyptus camaldulensis* on understorey crop species especially in the agroforestry system.



CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

A study was conducted at the laboratory and departmental research field of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Bangladesh during October 2016 to March 2017 to find out the bark and stem exudates of *Eucalyptus camaldulensis* on the germination, root architecture and shoot growth of three agricultural crops like Maize, Country bean and Bottle gourd.

There were two experiments. Experiment 1 was laboratory experiment and experiment 2 was field experiment. The experiments were laid out in complete randomized design. Experiment 1was conducted in petridish and experiment 2 was conducted in field. There were four treatments including control viz. T_1 (50% concentration), T_2 (25% concentration), T_3 (10% concentration) and T_4 (only water; Control). All statistics were calculated with Statistics 10 software and MS Excel 2007.

Results of laboratory experiment showed that 50% concentration of both bark and stem exudates of *E. camaldulensis* inhibited more in germination of three tested crops compared to other concentrations. Bark exudates of *E. camaldulensis* showed germination percentage 24.74% in Maize, 31% in Country bean and 54.33% in Bottle gourd over control. On the other hand, stem exudates of *E. camaldulensis* showed germination percentage 35.36% in Maize, 37.33% in Country bean and 45.67% in Bottle gourd over control.

Results of field experiments showed that the germination of the three tested crops are also inhibited by both bark and stem exudates of *E. camaldulensis*. Application of 50% concentration of *E. camaldulensis* bark exudates showed germination percentage 52.0% in Maize, 34.33% in Country bean and 50.0 % in Bottle gourd over control and 50% stem exudates showed germination percentage 40% in Maize, 19.67% in Country bean and 40% in Bottle gourd over control.

Due to the effect of bark and stem exudates of *E. camaldulensis* plant height (cm), collar diameter (mm),central root length (cm), no. of first order lateral roots of three tested crops showed significantly lower compared to control at both the laboratory and field experiments. Similar results were recorded for biomass allocation like shoot dry weight (g), root dry weight (g), total dry weight (g), shoot/root ratio and quality index. The results showed that the inhibitory effect increased with increasing concentrations.

5.2 Conclusion

From the present study it should be concluded that germination of Maize, Country bean and Bottle gourd seeds will be affected by different concentrations of bark and stem exudates of *E. camaldulensis*. Higher concentrations of exudates had strongest inhibitory effect on the tested crops. Therefore, if *Eucalyptus* is incorporated with a wider spacing for agroforestry practice, inhibitory effect might be reduced by reducing the concentration of its litterfall. Overall, findings of this study will help farmers and decision makers to choose this tree in the field of agroforestry for higher yield from a piece of land.

5.3 Recommendations

The recommendations that can be put forward from the present study are as follows:

- In the experiment water was used as the solvent
- The experiment was conducted in laboratory and field, but further it should be done in farmers' field to validate the result.
- The allelopathic effect of bark and stem fallen from the *Eucalyptus camaldulensis* tree may be minimized by regular collection for household purposes.
- The allelopathic effect can be minimized by planting low- density of *Eucalyptus camaldulensis* tree. Crops like maize, bean and bottle gourd should not be planted very close to *Eucalyptus* trees to get the maximum germination of the associated crops.

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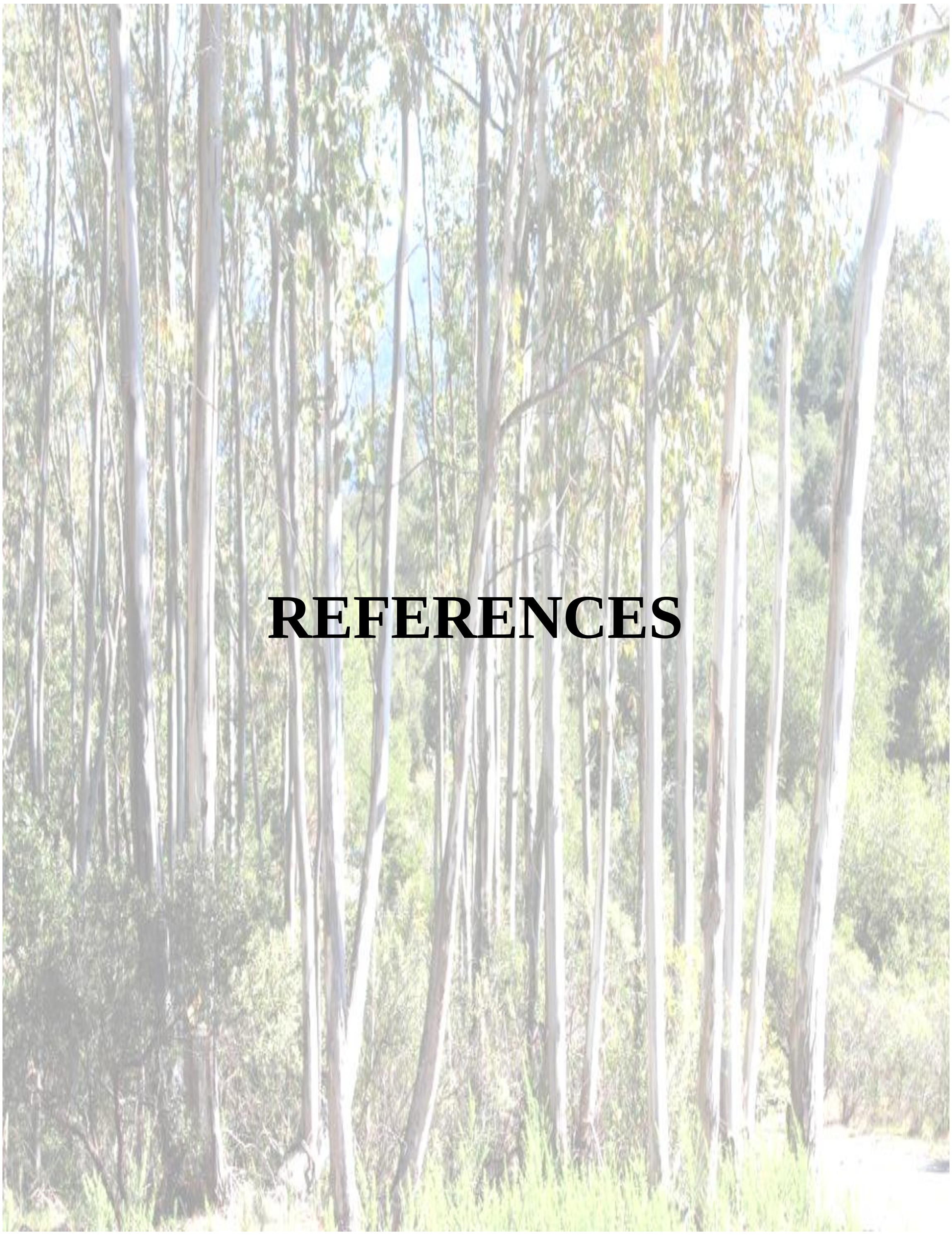

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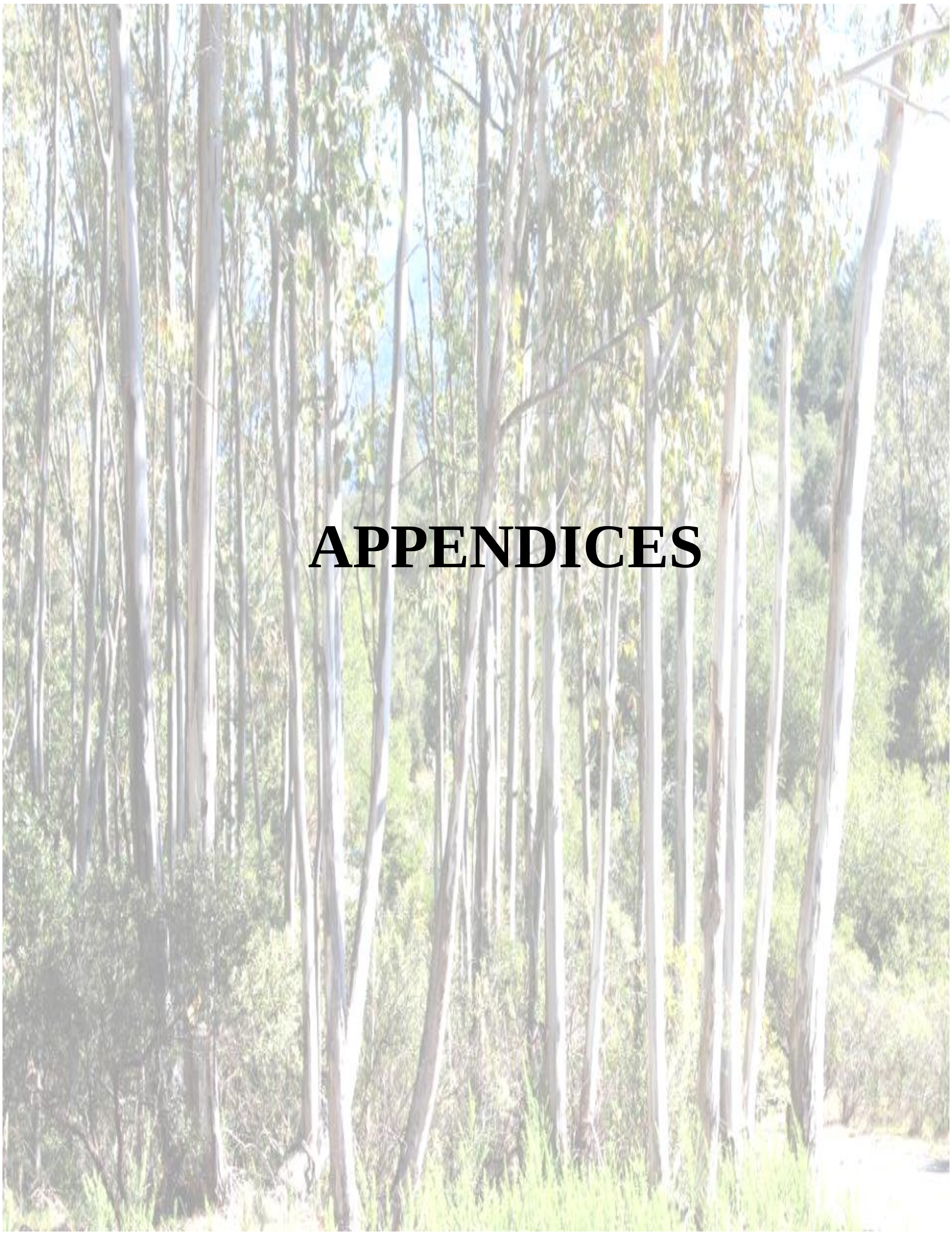

APPENDICES

APPENDICES

Appendix-I: The physical and chemical properties of soil in Agroforestry and Environment farm HSTU, Dinajpur

Soil characters	Physical and chemical properties
Texture	
Sand (%)	65
Silt (%)	30
Clay (%)	5
Textural class	Sandy loam
CEC (meq/ 100g)	8.07
pH	5.35
Organic matter (%)	1.06
Total nitrogen (%)	0.10
Sodium (meq/ 100g)	0.06
Calcium (meq/ 100g)	1.30
Magnesium (meq/ 100g)	0.40
Potassium (meq/ 100g)	0.26
Phosphorus (µg/g)	24.0
Sulphur (µg/g)	3.2
Boron (µg/g)	0.27
Iron (µg/g)	5.30
Zinc (µg/g)	0.90

Source: Soil Resources Development Institute, Dinajpur (2016)

Appendix-II (a): Descriptive Statistics of Germination speed of Maize influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0	0.08	.05	27.34	.20	.34
T_2	3	0	0.15	.09	36.94	.31	.58
T_3	3	1	0.07	.04	7.92	.84	.98
T_4	3	1	0.05	.03	4.18	1.12	1.21

Appendix-II (b): Analysis of Variance of Germination speed of Maize influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	1.54	0.51	56.00	0.00
Error	8	0.07	0.01		

Appendix-III(a): Descriptive Statistics of Germination speed of Maize influenced by *Eucalyptus camaldulensis* stem (In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0.3167	0.2309	0.1333	72.928	0.05	0.45
T_2	3	0.3983	0.1041	0.0601	26.128	0.292	0.5
T_3	3	0.6057	0.147	0.0848	24.264	0.45	0.742
T_4	3	0.9527	0.1147	0.0662	12.042	0.867	1.083

Appendix-a1III(b): Analysis of Variance of Germination speed of Maize influenced by *Eucalyptus camaldulensis* stem (In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	0.724	0.241	9.760	0.005
Error	8	0.198	0.025		

Appendix-IV(a): Descriptive Statistics of Germination speed of Country Bean influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0.27	0.24	0.14	88.61	0.00	0.45
T_2	3	0.41	0.18	0.11	44.88	0.25	0.61
T_3	3	0.48	0.05	0.03	10.75	0.42	0.51
T_4	3	0.86	0.06	0.04	7.16	0.79	0.90

Appendix-IV(b): Analysis of Variance of Germination speed of Country Bean influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	0.588	0.196	8.180	0.008
Error	8	0.192	0.024		

Appendix-V(a): Descriptive Statistics of Germination speed of Country Bean influenced by *Eucalyptus camaldulensis* stem (In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0.29	0.27	0.16	93.26	0.00	0.53
T_2	3	0.49	0.11	0.06	21.67	0.42	0.62
T_3	3	0.60	0.05	0.03	9.01	0.54	0.65
T_4	3	0.80	0.06	0.03	7.51	0.75	0.87

Appendix-V(b): Analysis of Variance of Germination speed of Country Bean influenced by *Eucalyptus camaldulensis* stem (In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	0.407	0.136	5.990	0.019
Error	8	0.181	0.023		

Appendix-VI(a): Descriptive Statistics of Germination speed of Bottle gourd influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0.33	0.04	0.02	12.73	0.29	0.38
T_2	3	0.42	0.02	0.01	5.13	0.40	0.44
T_3	3	0.52	0.08	0.05	16.04	0.44	0.60
T_4	3	0.63	0.08	0.04	12.17	0.54	0.69

Appendix-VI(b): Analysis of Variance of Germination speed of Bottle gourd influenced by *Eucalyptus camaldulensis* bark (In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	0.144	0.048	12.860	0.002
Error	8	0.030	0.004		

Appendix-VII(a): Descriptive Statistics of Germination speed of Bottle gourd influenced by *Eucalyptus camaldulensis* stem(In Laboratory)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	0.32	0.06	0.03	17.52	0.26	0.37
T_2	3	0.45	0.03	0.02	6.68	0.42	0.48
T_3	3	0.44	0.09	0.05	19.52	0.37	0.53
T_4	3	0.70	0.07	0.04	9.87	0.62	0.74

Appendix-VII(b): Analysis of Variance of Germination speed of Bottle gourd influenced by *Eucalyptus camaldulensis* stem(In Laboratory)

Source of variation	Degrees of Freedom	Sum Square Values	Mean Square Values	F Value	P value
Treatment	3	0.225	0.075	18.680	0.001
Error	8	0.032	0.004		

Appendix-VIII: Descriptive Statistics of germination percentage of Maize influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	52	2.65	1.53	5.09	49	54
T_2	3	40	2.00	1.15	5.00	38	42
T_3	3	100	0.00	0.00	0.00	100	100

Appendix-IX: Descriptive Statistics of Germination speed of Maize influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	4.85	0.26	0.15	5.42	4.55	5.03
T_2	3	3.74	0.24	0.14	6.49	3.50	3.99
T_3	3	9.32	0.11	0.07	1.22	9.23	9.45

Appendix-X: Descriptive Statistics of germination percentage of Country Bean influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	34.33	1.53	0.88	4.45	33	36
T_2	3	19.67	0.58	0.33	2.94	19	20
T_3	3	100.00	0.00	0.00	0.00	100	100

Appendix-XI: Descriptive Statistics of Germination speed of Country Bean influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	1.81	0.09	0.05	4.77	1.75	1.91
T_2	3	1.03	0.03	0.02	3.24	1.00	1.07
T_3	3	4.63	0.53	0.31	11.48	4.15	5.20

Appendix-XII: Descriptive Statistics of germination percentage of Bottle gourd influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	50	1.73	1.00	3.46	48	51
T_2	3	40	2.00	1.15	5.00	38	42
T_3	3	100	0.00	0.00	0.00	100	100

Appendix-XIII: Descriptive Statistics of Germination speed of Bottle gourd influenced by *Eucalyptus camaldulensis* bark and stem (In Field)

Treatment	N	Mean	SD	SE Mean	C.V.	Minimum	Maximum
T_1	3	2.08	0.04	0.03	2.13	2.03	2.12
T_2	3	1.66	0.01	0.01	0.59	1.65	1.67
T_3	3	4.17	0.17	0.10	4.00	4.00	4.33

Appendix-XIV: Some plates on my research experiment

Plate 4: Collection of bark from *Eucalyptus* tree

Plate 5: Different concentrations of bark and stem exudate preparation

Plate 6: Seeds were sown in petridishes in agroforestry laboratory

Plate 7: Morphological measurements of maize seedlings

Plate 8: Seeds were sown in agroforestry field



Plate 9 : Germination of tested speices in different treatments


Plate 10 : Morphological measurements of maize and country bean seedlings

Plate 11: Measurement of collar diameter

Plate 12 : Drying of tested speices

Plate 13 : Biomass measurements of tested seedlings