Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)

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(2013 - 11 - 182)

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by

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THESIS

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2015

DECLARATION

I, hereby declare that this thesis entitled **"Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)"** is a record of research work done independently by Ms. Sruthi Lakshmi P.G under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Sruthi Lakshmi, P.G.

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LIST OF ABBREVIATIONS

%	-	per cent
@	-	at the rate of
^0C	-	Degree Celsius
CD	-	Critical difference
cm	-	centimetre
cm^3	-	centimetre cube
C:N ratio	-	Carbon Nitrogen ratio
EC	-	Emulsifiable concentrate
e.g.	-	Example
et al.	-	and co-workers
g	-	gram
g $plant^{-1}$	-	gram per plant
ha^{-1}	-	per hectare
i.e.	-	that is
K	-	Potassium
KAU	-	Kerala Agricultural University

kg	-	kilogram
kg ha^{-1}	-	kilogram per hectare
MAP	-	Month After Planting
m	-	metre
mm	-	millimetre
mg	-	milligram
mg 100 g^{-1}	-	milligram per 100 gram
millimol m^{-2} s^{-1}	-	millimol per metre square per second
mmol kg^{-1}	-	millimol per kilogram
MOP	-	Muriate of Potash
N	-	Nitrogen
NS	-	Not significant
pH	-	power of hydrogen
P	-	Phosphorus
POP	-	Package of practices
SPAD	-	Soil Plant Analysis Development

Rs.	-	Rupees
SE	-	Standard error
t	-	tonnes
t ha^{-1}	-	tonnes per hectare
UV	-	Ultra Violet
var.	-	variety
viz.	-	namely
v/v	-	volume by volume
w/v	-	weight by volume

Introduction

1. INTRODUCTION

Homestead farming, the predominant land use system of Kerala, has been practiced by farmers since time immemorial. In the multi-storey homesteads, since many trees and crops grow together, tree-crop interactions are implicit. The low productivity of crops in homesteads is often attributed to competition for nutrients, water and light. Allelopathy has been often ignored as a possible mechanism in tree-crop interaction studies.

Allelopathy refers to all biochemical interactions (stimulatory and inhibitory) among plants, including microorganisms (Molisch, 1937). Rice (1974) defined allelopathy as the influence of a plant on another plant (including microorganisms) through the release of chemical compounds into the environment. As per the latest definition of International Allelopathy Society (1996), allelopathy denotes any process involving secondary metabolites produced by plants, microorganisms, viruses, fungi that influence the growth and development of agricultural and biological systems.

In homesteads, where numerous intercrops are grown beneath the tree canopy, chances of allelopathic interactions are high. Trees are rich sources of allelochemicals that impose a kind of environmental stress on other plants growing in their vicinity known as "tree allelopathy" (Nandal *et al*., 1994). In multi-storey cropping systems, allelopathic interference may result from natural products in intercrop foliage leachings, root exudates and volatiles. These chemicals are released into the environment through leaching, root exudation, volatilization and microbial decomposition of plant residues.

Although allelochemicals emanate from all plant parts, leaves are the most potential sources (Horsley, 1977). Large quantities of leaf loppings of trees are recycled into the soil or used as mulch, and this aspect which is of great relevance especially in the present context of organic agriculture, remains uninvestigated.

The possible interactions between tree species and crop plants grown in agroforestry systems have received little attention (Nandal *et al*., 1994). Systematic evaluation of tree-crop combinations for allelopathic interactions will provide useful information to design new systems. Productivity in agroforestry systems can be enhanced by having a better understanding about tree-crop allelopathic interactions (Singh *et al*., 2012).

Phytochemicals present in trees commonly found in agroforestry systems in tropics have been reported to allelopathically retard the growth of associated crop species (Suresh and Rai, 1987 & 1988; Tawata and Hongo, 1987; Swaminathan *et al*., 1989; Jacob *et al*., 2007b).

Coconut (*Cocos nucifera* L.), cashew (*Anacardium occidentale* L.), jack (*Artocarpus heterophyllus* Lamk.), mango (*Mangifera indica* L.), tamarind (*Tamarindus indica* L.) and teak (*Tectona grandis* L.f.) are multipurpose trees commonly planted in the home gardens of Kerala. Turmeric (*Curcuma longa* Linn.) is an important tropical spice crop that can be grown on different types of soils under irrigated and rainfed conditions. In Kerala, the area under turmeric during 2013-14 was 2430 ha with a total production of 6523 tons. The estimated productivity in 2013-14 was 2573 kg ha^{-1} (GOK, 2015). Turmeric is a shade tolerant crop suited for intercropping beneath the canopy of trees in the homesteads where low to medium shade is available.

Information on the allelopathic compatibility between these multipurpose trees and turmeric is lacking. Mulching turmeric with green leaves @ 15 t ha^{-1} immediately after planting and with the same quantity after 50 days is a recommended practice (Kerala Agricultural University, 2011). However, the suitability of different tree leaves for mulching in turmeric has not been investigated till date.

Hence, considering the scope and practical utility, this research work entitled "Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)" was undertaken with the main objective to investigate the allelopathic effect of certain trees commonly planted in the homesteads of Kerala on sprouting, growth and yield of turmeric.

Riview of Literature

2. REVIEW OF LITERATURE

The present study entitled "Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)" was undertaken with the main objective of investigating the allelopathic effect of certain multipurpose trees commonly planted in the homestead gardens of Kerala on sprouting, growth and yield of turmeric. The research work undertaken on various aspects of the study such as the allelopathic effect of leaf leachates, extracts and fresh leaf loppings of various multipurpose trees on crops by have been reviewed comprehensively and presented in this chapter. Since literature related to allelopathic effects of selected trees on turmeric are not available, results of similar studies undertaken with the test trees and other multipurpose trees on a variety of crops in the tropical regions, have been included.

2.1. ALLELOPATHY-DEFINED

Molisch (1937) coined the term "Allelopathy" which refers to all biochemical interactions (stimulatory and inhibitory) among plants, including microorganisms. According to the latest definition of International Allelopathy Society (1996), allelopathy refers to any process involving secondary metabolites produced by plants, microorganisms, viruses, fungi that influence the growth and development of agricultural and biological systems.

2.2. ALLELOPATHY IN MULTISTOREY CROPPING SYSTEMS

Trees are rich sources of allelochemicals that impose a kind of environmental stress on other plants growing in their vicinity known as "tree allelopathy" (Nandal *et al*., 1994). Several phytochemicals have been identified in various parts of test trees, some of these may be inhibitory. The possible interactions between tree species and crop plants grown in agroforestry systems have received little attention (Nandal *et al*., 1994).

As trees remain a part of the agroforestry system for a longer period, and most of them produce a large amount of leaves and litter, their allelochemicals may play an important role in an overall improvement. If the due emphasis is given, allelopathy could play a major role in enhancing the production and productivity in agroforestry systems by having the better understanding about tree-crop combination (Singh *et al*., 2012).

The co-existence of perennial plants with agricultural crops and their allelopathic compatibility may be crucial to determine the success of an agroforestry system (Hossain, 2012).

Systematic evaluation of crop and woody plant combinations for allelopathic interactions will provide useful information to design new systems.

2.2.1 Mode of Allelopathic Interference in Multistorey Cropping Systems

In multi-storey cropping systems, allelopathic interference may result from natural products in intercrop foliage leachings, root exudates and volatiles. These chemicals are released into the environment through leaching, root exudation, volatilization and microbial decomposition of plant residues.

2.2.1.1. Leaching

Leaching is the removal of substances from plants by aqueous solutions such as rain, dew, mist and fog. Radioisotope labeling of plant tissue before leaching has shown that large quantities of both inorganic and many classes of organic natural products are leached from plant tissue (Tukey, 1970). Both the quantity and quality of leachable natural products differ greatly with species, physiological age of tissue, stage of plant development, plant health, light, temperature, nutritional conditions, and the intensity and volume of the leaching solution (Tukey, 1970). The secondary compounds released will be influenced by the type of crop being leached (Guenzi and McCalla, 1962; 1967). To determine the presence of allelopathic activity, the protocol for leachate preparation should be similar as possible to that prevailing naturally during symptom development (Horsley, 1991).

2.2.1.2. Root exudation

Root exudation is the release of substances into the surrounding medium by healthy, intact plant roots. A variety of natural products has been found in plant root exudates, though in comparison with leaves, the amounts of organic materials are much smaller (Rovira, 1969). Many factors can affect the quantity and quality of natural products obtained *viz.,* plant species, plant age or stage of development, temperature, light, nutritional conditions, soil micro organisms, root supporting medium, soil moisture and root damage (Rovira,1969). Similarly, exudation in soils can be expected to vary with soil physical and chemical properties. Root exudation usually increases greatly during wilting and root damage (Clayton and Lamberton, 1964). Soil microorganisms modify root-cell permeability and root metabolism and rhizosphere organisms may absorb or excrete qualitatively different natural products than plant roots. Studies of allelopathic activity of aggressor plant roots could not distinguish the natural products originating from root exudates or dead root tissue or microbial rhizosphere products (Horsley, 1991).

2.2.1.3. Volatilization

Volatilization is the release of natural products into the atmosphere. A variety of plants either secrete or excrete metabolic products into special structures such as trichomes and glands, into intercellular spaces and canals, or onto leaf surfaces. In hot, dry weather, natural products with high vapour pressure are released into the atmosphere where they may be absorbed directly by plants or adsorbed onto soil surface (Horsley,1991).

2.2.1.4. Microbial decomposition of plant residues

Plant residue mulches commonly used in multi-storey cropping systems to protect soil from erosion, conserve moisture and supply nutrients may be the source of allelochemicals that interfere with crop productivity. To improve nitrogen nutrition of crop plants plant-residue mulches, particularly of nitrogen-fixing species are commonly used which may result in allelopathic interference. Mulching and conservation tillage which leave plant residues on the soil surface or incorporate them into the soil result in the liberation of large quantities of water soluble and partially water soluble products during residues decomposition. Large quantity of crop residues left annually in the fields results in soil sickness by allelopathic means (Duke, 1985).

The plantation crops being mainly perennial crops produce a huge amount of waste biomass. It has been estimated that a coconut garden with 175 trees ha^{-1} generates biomass of 7000 kg as dry leaves, sheathes, spadices, inflorescences and coconut husks. During monsoons tannins oozing out of such heaps, creates problems of environmental pollution (Bidappa *et al*., 1996). The cut oil palm (*Elaeis guinensis*) fronds constitute a major source of organic manure yielding 10t dry matter ha^{-1} (Varghese and Rethinam, 1994). Cardamom is a shade loving crop, hence, grown underneath the trees in the forests, generally high in fertility status due to leaf fall and its decomposition (Zachariah, 1978). On an average, 5-8 t dry leaves fall annualy from shade trees in a hectare of cardamom (Korikanthimath, 1994). The wastes and surplus residues obtained from plantation crops is recycled back to the soil by various methods such as mulching, in situ incorporation and composting. The wider C:N ratio coupled with low N content, presence of soluble tannins (8-12 %), low biodegradability are some of the problems associated with coir pith (Fan *et al*., 1982). Various measures to eliminate its phytotoxicity in the field to improve the crop productivity includes, removal of phytotoxins by flooding, crop rotation and detoxification through nutrient application (Chou, 1986).

When plant tissues age and die, cell membrane integrity is lost. Allelochemicals that are compartmentalized in living cells are released into the surroundings and react with other natural products resulting in qualitative changes in some of these products. Once natural products enter the soil as incorporated soil residues additional qualitative changes occur as a result of physiochemical action of the soil and the activities of soil microorganisms (Dalton *et al*., 1983; Kimber, 1973; Martin *et al*., 1972). The secondary compounds released from litter or formed will be influenced by microbial populations present in the soil (Norstadt and McCalla, 1963).

Soil microorganisms can modify non toxic materials to phytotoxic ones (Patrick *et al*., 1964; Hassan *et al*., 1989) or reduce phytotoxicity of crop residues (Haider and Martin, 1975). Microbial metabolism of organic compounds may increase or decrease the toxicity due to release of organic carbon as CO_2, fixation into microbial biomass or transformation to other products. The soil microbial biomass has been studied in several multi storey cropping systems. Coconut-cacao mixed cropping have shown greater microbiological activity than coconut monocropping system (Nair and Rao, 1977). The microbial biomass (bacteria, fungi, actinomycetes) was higher in arecanut-based high density multispecies cropping systems than in monocropping. The nature and activity of microorganisms associated with perennial monocrop are changed with introduction of other crops (Bopaiah, 1991). In homesteads of Kerala, the soil microflora was found to vary with the cropping intensity, crop diversity, planting pattern of crops and the management practices adopted (Jacob, 1997).

Initial experiments to determine the involvement of allelochemicals arising from residue decomposition should concentrate on simulating field conditions as closely as possible. For example, the same quantity, quality and age of residue documented during symptom description should be used; soil moisture and aeration conditions should also be similar (Horsley, 1991). Experiments that use artificial media lacking active microbial populations may give results of little value in determining the cause of inhibition in field situations (Martin *et al*., 1972).

In multi-storey cropping, allelopathic interactions could most likely occur through leaching, root exudation and release of phytotoxins from decaying litter and roots. In multi-storey cropping, the rain water passing through the foliage of the tree components leaches allelochemicals and transport them to under storey crop plants. Trees are integral part of multi-storey cropping systems, hence, adds large quantity of litter through dead and falling leaves, twigs, branches, fruits and prunings of trees as manure. For example, the rubber tree during its first five years of growth adds upto 5 t of leaf litter ha^{-1} (Lin *et al*., 1996). Common trees of home gardens like jack (*Artocarpus heterophyllus*), wild jack (*Artocarpus hirsuta*), mango (*Mangifera indica*), mahogany (*Sweitania macrophylla*), bamblimass (*Citrus maxima*), nutmeg (*Myristica fragrans*), and coffee (*Coffea arabica*) annually contribute 3.51, 3.95, 2.43, 1.93, 1.73, 4.25 and 2.10 t litter ha^{-1} respectively (Jacob, 1997). Leaf litter is a potential source of phytotoxins and allelopathic interactions may occur through release of allelochemicals due to its decay or its leaching during rains or irrigation. This has several management implications in homestead agroforestry, where many intercrops are grown beneath the tree canopy. The increased amount of litter could lead to greater release of toxic chemicals into the soil, these remain active for a long time in low rainfall areas and may inhibit growth of subsequent intercrops. The crop or root residues remaining on soil surface after the harvest of intercrops or trees might serve as allelochemicals sources.

In multi-storey cropping systems, there is very high root density of component plant species (trees + crops), it seems that roots of component plant species intermingle with each other leading to allelopathic interaction through root exudates. Moreover, despite the deep rooting characteristics of trees, most of the fine feeder roots are found within the top 20 cm of the soil. For example, the rubber tree has its fine feeder roots concentrated in the top 15-30 cm soil layer and spreading up to several meters. These roots are continuously sloughed off. Substances exuding from the roots may affect adjacent species directly or may influence them indirectly through decomposition of such biomass (Jacob and Nair, 2000).

2.3. ALLELOPATIC EFFECT OF TREES ON CROPS

Ovalle and Avendano (1987) reported that trees increase understorey herbaceous productivity. The overall effect of tree on understorey vegetation depends on the balance between their positive (facilitation) and negative (competition) effects (Callaway and Walker, 1997). Rafiqul-Hoque *et al.* (2003) showed that certain trees contain higher levels of bioactive chemicals suggesting a large inhibitory potential.

In most of the cases, allelopathic effects are selective and vary with different tree crops (Stowe, 1979; Melkania, 1986). In general, leaves are most potent source of allelochemicals however, the toxic metabolites are also distributed in all other plants parts in various concentrations. The allelopathic effect may be so striking that competition for resources does not explain why in plant communities many species appear to regulate one another through the production and release of chemicals attractants, stimulators or inhibitors (Putnam and Tang, 1986).

2.3.1. Allelopathic Effect of Tree Leaf Leachates on Crops

2.3.1.1. Effect on germination

Konar and Kushari (1989) reported the allelopathic effect of certain multipurpose trees on *Costus-speciosus*. Treatment of rhizomes with leaf leachates of *Mangifera indica, Shorea robusta, Tectona grandis* increased the percentage sprouting and shortened the sprouting time, while the leaf leachate of *Eucalyptus globulus* inhibited rhizome sprouting.

Terminalia tomentosa leaf leachate inhibited germination of cowpea and rice seeds (Gayner and Jadhav, 1992).

Jacob and Nair (1998) reported significant inhibition of rice seed germination by leaf leachates of ailanthus, tamarind (*Tamarindus indica*), acacia (*Acacia auriculiformis*) and Portia. The inhibition was less by leaf leachates of mango (*Mangifera indica*), bombax and cashew (*Anacardiun occidentale*). The leaf leachates of acacia, eucalyptus, casuarina, ailanthus, tamarind, portia and cashew inhibited the germination of cowpea.

The leaf leachates of *Acacia auriculiformis, Casuarina equisetifolia, Bambusa arundinacea* and *Tectona grandis* significantly inhibited germination of tomato, aubergine and chilli (Krishna *et al*., 2003).

Morus alba, Melia azedarach and Albizzia lebbek leaf leachates inhibited seed germination of *Brassica juncea* (Abdulla *et al*., 2005).

El-Khawas and Shehata (2005) reported that the leaf leachates of *Acacia nilotica* and *Eucalyptus rostrata* inhibited germination of *Zea mays* and *Phaseolus vulgaris*. Krishna *et al*. (2005) reported the influence of allelopathic effects of *Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus* hybrid and *Mangifera indica* on the germination behaviour of kasthuri bendi (*Abelmoschus moschatus*) and sanka pushpa (*Clitoria ternatea*). The adverse effect of the four multipurpose trees differed with each medicinal plant. However, maximum adverse effect was recorded with *M. indica* while minimum adverse effects were observed in *Eucalyptus* hybrid. Sanka pushpa showed the greatest sensitivity compared to the two other species tested.

Leaf leachates of *Gliricidia sepium* and *Acacia auriculiformis* significantly decreased germination percentage and increased mean germination time of maize (*Zea mays*), (Oyun, 2006).

The leaf leachates of *Tectona grandis* inhibited the seed germination of cowpea. Gliricidia, cashew and mango showed strong inhibitory effect on germination of brinjal. Teak, jack and casuarina were also inhibited seed germination (Jacob *et al*., 2007a).

2.3.1.2. Effect on growth

Konar and Kushari (1989) reported that the leaf leachates of trees like *Mangifera indica, Shorea robusta and Tectona grandis* promoted the growth of *Costus speciosus* while the leaf leachate of *Eucalyptus globulus* inhibited the growth.

Leaf leachate of *Terminalia tomentosa* stimulated growth of cowpea (Gayner and Jadhav, 1992).

Jacob and Nair (1998) reported that the leachates of acacia, ailanthus (*matty*), tamarind and portia caused maximum suppression of plumule growth in rice. The degree of inhibition was still greater in radicle length. The leaf leachates of acacia, ailanthus, tamarind and portia proved most harmful. The inhibition was minimal from leaf leachates of bombax and jack. In cowpea, the tree leaf leachates of ailanthus and subabul caused maximum inhibition of plumule growth. The inhibition by jack leaf leachate was least. Maximum reduction of root growth in cowpea was caused by ailanthus, tamarind, cashew, albizzia and eucalyptus.

Aqueous leachates of *Eucalyptus globulus* reduced the chlorophyll content in the leaves of *Costus speciosus* and finger millet (Konar and Kushari, 1995; Padhy *et al*., 2000).

Mango leaf leachate decreased germination, root length and seedling fresh weight of Gobhi sarson (Sharma *et al*., 2000).

The leaf leachates of *Acacia auriculiformis, Casuarina equisetifolia, Bambusa arundinacea* and *Tectona grandis* significantly inhibited growth of tomato, aubergine and chilli. Response indices revealed that inhibition of radical and plumule growth was more pronounced (Krishna *et al*., 2003).

Krishna *et al*. (2005) reported the allelopathic effect of *Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus* hybrid and *Mangifera indica* on root and shoot growth of kasthuri bendi (*Abelmoschus moschatus*) and sanka pushpa (*Clitoria ternatea*). The adverse effect of the four multipurpose trees differed with each medicinal plant. However, maximum adverse effect was recorded with *M. indica* while minimum adverse effects were observed in *Eucalyptus* hybrid. Sanka pushpa showed the greatest sensitivity compared to two other species tested.

All the seedling growth parameters including seedling vigour index of maize (*Zea mays*) were decreased significantly with leaf leachates of both *Gliricidia sepium* and *Acacia auriculiformis* (Oyun, 2006).

Jacob *et al*. (2007a) reported the allelopathic effect of leaf leachates of *Artocarpus heterophyllus*, *Mangifera indica*, *Ailanthus triphysa*, *Anacardium occidentale*, *Tamarindus indica*, *Tectona grandis*, *Thespesia populnea*, *Casuarina equisetifolia*, *Gliricidia sepium* and *Strychnos nux-vomica* on the growth of cowpea, bitter guard and brinjal. The leaf leachates of gliricidia, strychnos and tamarind significantly suppressed the plumule growth of cowpea. Leaf leachate of all the trees significantly suppressed the radicle growth. *Gliricidia,* tamarind *Strychnos,* cashew and casuarina were most inhibitory to cowpea. All the leaf leachates significantly suppressed the radicle growth of brinjal. Strychnos, portia, mango and tamarind were most inhibitory. The leaf leachates of all trees (except Casuarina), severely inhibited the plumule length. Leaves of teak, portia and *gliricidia* caused maximum inhibition. Leaf leachates of *casuarina*, mango and *Strychnos* did not suppress root growth whereas, *Gliricidia*, tamarind and teak were most inhibitory. The inhibitory effects of the leaf leachate were more prominent in brinjal than cowpea and bitter gourd. Casuarina and *Strychnos* adversely decereased the plant height at 2 MAP of cowpea. Casuarina leaf leachate inhibited the leaf production. *Ailanthus*, *Casuarina* and *Gliricidia* leachates inhibited the root growth. Leaf leachate of tamarind, teak, *Casuarina* and *Strychnos* caused severe allelopathic inhibition of cowpea, hence were incompatible. Leaf leachates of *Casuarina*, *Strychnos*, tamarind, teak and *Ailanthus* significantly reduced the plant height of bitterguard. All trees except *Gliricidia*, portia and tamarind reduced the leaf production of bitter gourd at 2 MAP. *Strychnos*, mango, portia and tamarind also suppressed the root growth. Cashew, tamarind and teak significantly reduced the plant height of brinjal. Irrigation with *Ailanthus*, cashew, jack, *Strychnos*, tamarind and teak leaf leachate severely inhibited the root growth in brinjal. *Gliricidia*, portia, tamarind, teak and cashew are incompatible.

Jacob *et al.* (2010) reported that guinea grass plants treated with sapota, *matty*, wild jack, neem (*Azadirachta indica*) and tamarind (*Tamarindus indica*) leachates had greater height compared to control. Tiller production was promoted by sapota and gliricidia leachates. Leaf production was severely affected by cocoa and mahogany leachates.

The aqueous leaf leachate of *Mangifera indica* suppressed growth and development of *Capsicum annum* (Chilli), *Glycine max* (Soybean), *Zea mays* (Maize), *Oryza sativa* (Rice) and *Abelmoschus esculentus* (Bhindi) (Sahoo *et al*., 2010).

Pot culture and field studies were undertaken to assess the allelopathic compatibility between pepper (var. Panniyur 1) and twenty one multipurpose trees *viz*., *Achras sapota*, *Ailanthus triphysa*, *Anacardium occidentale*, *Artocarpus heterophyllus*, *Artocarpus hirsute*, *Azadirachta indica*, *Bombax malabaricum*, *Casuarina equisettifolia*, *Coffea arabica*, *Erythrina indica*, *Gliricidia sepium*, *Hevea brasilensis*, *Leucaena leucocephala*, *Macaranga peltata*, *Mangifera indica*, *Psidium guajava*, *Swietania macrophylla*, *Tamarindus indica*, *Tectona grandis*, *Theobroma cacao* and *Thespesia populnea*. It was inferred that, due to inhibitory effects of the leaf leachates, caution should be exercised while green manuring or mulching pepper plants continuously with leaves of the trees. From the field studies it is revealed that, besides coconut, trees such as wild jack, jack, erythrina, teak, neem and mango can be safely recommended as suitable alternate standards for trailing pepper (Jacob *et al*., 2011).

Aqueous leachates of *Acacia auriculiformis*, *Anacardium occidentale*, *Albizia lebbeck*, *Eucalyptus citriodora*, *Emblica officinalis*, *Shorea robusta* and *Tectona grandis* significantly reduced the vigour index, shoot length, root length, fresh and dry weight in gram seed (*Cicer arietinum*). Plant pigments *viz*., chlorophyll and carotenoids reduced significantly. The soluble sugar content reduced with 100 % (v/v) of leachate treatment but proline and phenol content increased in the test plant. The result revealed that *E. citriodora* and *S. robusta* extract had greater inhibitory effect on germination and vigour index (Das *et al*., 2012).

2.3.1.3. Effect on yield

Literature on the allelopathic effect of leaf leachate of trees found in tropics on crop yield is meager.

Jacob (2007a) reported that seed yield of cowpea was significantly reduced by leaf leachates of *Tamarindus indica, Tectona grandis*, *Casuarina equisetifolia* and *Strychnos nux-vomica*. The effects of *T.indica* and *T.grandis* leachate was lethal.

Field studies were conducted to assess the effect of leaf leachates of *Achras sapota, Ailanthus triphysa, Anacardium occidentale, Artocarpus heterophyllus, Artocarpus hirsute, Azadirachta indica, Bombax malabaricum, Casuarina equisettifolia, Coffea arabica, Erythrina indica, Gliricidia sepium, Hevea brasilensis, Leucaena leucocephala, Macaranga peltata, Mangifera indica, Psidium guajava, Swietania macrophylla, Tamarindus indicus, Tectona grandis, Theobroma cacao and Thespesia populnea* on yield of crops. In maize, yield was reduced by nearly 20 per cent by *A. occidentale, B. malabaricum, C. equisettifolia, G. sepium* and *T. grandis*. Despite the inhibitory effect on root growth, yield was unaffected by *A. triphysa*. In cowpea, pod formation was totally inhibited in plants grown under *A. sapota*. Substantial yield reduction was noticed in groundnut under *G. sepium* and *T. cacao*. Yield of groundnut was reduced by leaf leachates of *A. sapota*, *G. sepium* and *T. cacao* but compatible with *T. grandis* (KAU, 2009).

Jacob *et al.* (2010) reported that fodder yield of guinea grass at 3 MAP was drastically reduced by leaf leachate of mahogany and rubber. A significantly higher yield was obtained with sapota and *matty* leachates.

2.3.2. Allelopathic Effect of Tree Leaf Extracts on Crops

2.3.2.1. Effect on germination

The effects of extracts of dried powdered leaves of *Tectona grandis* were tested on the germination of rice (*Oryza sativa*) and cowpeas (*Vigna unguiculata*). Germination was significantly reduced in the early stages (Jadhav and Gaynar, 1994).

Water extracts of rubber (*Hevea brasiliensis)* leaves at lower concentrations promoted germination of tea (*Camellia sinensis*) and inhibited at higher concentrations (Pan Rong *et al*., 1997).

Kamara *et al*. (2000) reported the most drastic reductions of maize seed germination caused by *Gliricidia sepium*, *Tetrapleura tetraptera*, *Senna siamea* and *Leucaena leucocephala*.

A study was conducted to evaluate the allelopathic effect of leaf extracts from *Azadirachta indica, Acacia arabica* (*Acacia nilotica*), *Eucalyptus tereticornis, Tamarindus indica, Tectona grandis, Samanea saman* and *Syzygium cumini* on seed germination of sorghum and rice. All tree leaf extracts promoted germination in sorghum while only *A. indica* and *A. arabica* increased germination in rice (Channal *et al*., 2000).

Syzygium cumini, Acacia arabica (*Acacia nilotica*), *Tamarindus indica, Eucalyptus tereticornis, Tectona grandis, Samanea saman* and *Azadirachta indica* extracts were tested for their allelopathic effects on green gram and pigeon pea. In green gram, the percent germination was reduced due to *T. grandis* and *E. tereticornis* while it increased with treatment from other tree extracts and was highest with *A. indica*, followed by *A. arabica* and *T. indica*. Generally, lower concentration of all tree leaf extracts enhanced germination, (except *S. cumini, A. arabica* and *T. indica*) (Channal *et al*., 2002a).

Studies on the allelopathic effect of tree leaf extracts of *Syzygium cumini, Acacia arabica* (*Acacia nilotica*), *Tectona grandis, Eucalyptus tereticornis, Tamarindus indica, Samanea saman* and *Azadirachta indica* each on sunflower and soyabean indicated that germination of sunflower was increased by *T. grandis, T. indica* and *S. saman* , while it was suppressed by *E. tereticornis* and *A. arabica*. Soyabean germination was increased by *A. arabica, T. grandis, S. saman* and *A. indica* at both concentrations, while it was decreased by *T. indica* (Channal *et al*., 2002b).

Leaf extracts of *Populus deltoids* inhibited seed germination of green gram (Mandal *et al*., 2005).

The aqueous leaf extracts of *Acacia leucopholea* showed inhibitory effects on seed germination of *Arachis hypogaea* (groundnut) and *Sorghum vulgare* (sorghum) (Jayakumar and Manikandan, 2005)

Tectona grandis and *Leucaena leucocephala* leaf extracts inhibited the seed germination of maize (Sahoo *et al*., 2007).

Extracts from *Spina Christi* (*Ziziphus spina-christi*), *Sesbania sesban* and *Tamarindus indica* significantly reduced germination of seeds of maize (*Zea mays*) and sorghum *(Sorghum bicolor*). Extracts forced maize seeds to germinate earlier, while the opposite was observed for sorghum seeds (Mubarak, 2009).

The aqueous extracts of eucalyptus (*Eucalyptus camaldulensis*) inhibited wheat seed germination (Khan *et al*., 2009).

Dry leaves extract of *Dalbergia sissoo* completely inhibited the germination of pearlmillet and rice and caused significant reduction in maize also (Akhtar *et al*., 2010).

The aqueous leaf extracts of *Mangifera indica* had both stimulatory and inhibitory action on germination and initial growth parameters of *Capsicum annum* (chilli), *Glycine max* (soybean), *Zea mays* (maize), *Oryza sativa* (rice) and *Abelmoschus esculentus* (bhindi). 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 bhindi (Sahoo *et al*., 2010).

Leaf extracts of *Senna siamea, Albizia lebbeck, Azadirachta indica, Cedrela odorata, Leucaena leucocephala, Gliricidia sepium, Eucalyptus grandis, Terminalia superba and Tectona grandis* significantly reduced germination of *Abelmoschus esculentus* seeds (Abugre *et al*., 2011).

Aqueous extract of *Acacia auriculiformis*, *Anacardium occidentale*, *Albizia lebbeck*, *Eucalyptus citriodora*, *Emblica officinalis*, *Shorea robusta* and *Tectona grandis* reduced the frequency of seed germination of *Cicer arietinum* (Das *et al*., 2012).

Tectona grandis leaf extract inhibited germination of *Vigna mungo* (Evangeline *et al*., 2012).

Mango leaf extract significantly inhibited germination of cress (*Lepidum sativum*), lettuce (*Lactuca sativa*) and alfalfa (*Medicago sativa*). The inhibitory activities of the extracts were proportional to the extract concentrations (Khan *et al*., 2013).

Leaf extract of old mango leaves enhanced the germination of wheat moderately (Saleem *et al*., 2013).

Moringa olifera leaves aqueous extract inhibited the seed germination of chickpea (Mangal *et al*., 2013).

Azadirachta indica leaf extract decreased the rate of germination of *Abelmoschus esculentus* (Vaithiyanathana, 2014).

2.3.2.2. Effect on growth

Leaf extract of bamboo inhibited growth of ground nut (Eyini *et al*., 1989).

Ailanthus altissima leaf extract inhibited growth of Garden cress (Heisey, 1990).

The effects of extract of dried powdered leaves of *Tectona grandis* were tested on the seedling growth of rice (*Oryza sativa*) and cowpea (*Vigna unguiculata*). Plumule and radicle growth in rice were inhibited. In cowpeas, plumule growth was more inhibited than radicle growth and radicle growth was stimulated by short soaking time (Jadhav and Gaynar, 1994).

Water extracts of rubber (*Hevea brasiliensis)* leaves at lower concentrations promoted growth of tea (*Camellia sinensis*) seedlings and inhibited at higher concentrations (Pan Rong *et al*., 1997).

Aqueous extracts of dry teak leaves inhibited root and shoot growth of rice seedlings (Mandal *et al*., 1998).

Kamara *et al*. (2000) reported that *Terminalia superba*, *Tetrapleura tetraptera*, *Gliricidia sepium* and *Senna siamea* significantly reduced maize root growth at the lowest extract concentration, while shoot length was most significantly reduced by *Gliricidia sepium*, *Leucaena leucocephala*, *Alchornea coordifolia* (*A. cordifolia*), *Terminalia superba*, and *Tetrapleura tetraptera*.

The allelopathic effect of leaf extracts from *Azadirachta indica, Acacia arabica* (*Acacia nilotica*), *Eucalyptus tereticornis, Tamarindus indica, Tectona grandis, Samanea saman* and *Syzygium cumini* on vigour index, seedling length, and seedling dry matter of sorghum and rice was evaluated through pot culture/bioassay experiment. Seedling length of sorghum was considerably decreased by *S. cumini, T. grandis* and *E. tereticornis* and in rice by *E. tereticornis* and *T. indica*. Seedling length was markedly increased in sorghum by *A. arabica* and in rice by *A. indica, S. saman* and *A. arabica*. Leaf extracts of *A. arabica, S. saman* and *A. indica* enhanced vigour index in sorghum while *A. arabica* and *S. saman* increased vigour index in rice. Vigour index was markedly decreased in sorghum by *E. tereticornis* and *S. cumini* and in rice by *S. cumini, T. indica* and *E. tereticornis*. Leaf extracts decreased the seedling dry matter in sorghum and rice irrespective of concentrations (Channal *et al*., 2000).

Syzygium cumini, Acacia arabica [*Acacia nilotica*], *Tamarindus indica, Eucalyptus tereticornis, Tectona grandis, Samanea saman* and *Azadirachta indica* extracts were tested for their allelopathic effects on green gram and pigeon pea. Seedling length was decreased when treated with extracts of all tree species except *S. cumini, S. saman* and *A. indica*. The same trend was observed in vigour index. Seedling dry matter was not reduced by any leaf extract. In pigeon pea seedling length, vigour index and seedling dry matter were increased by *A. arabica, T. indica, E. tereticornis, S. saman* and *A. indica*. Generally, lower concentration of all tree leaf extracts enhanced seedling length (except *S. cumini, A. arabica* and *T. indica*), vigour index (except *S. cumini, T. indica, S. saman* and *A. indica*) and seedling dry matter (except *S. saman*) (Channal *et al*., 2002a).

Studies on the allelopathic effect of tree leaf extracts of *Syzygium cumini, Acacia arabica* (*Acacia nilotica*), *Tectona grandis, Eucalyptus tereticornis, Tamarindus indica, Samanea saman* and *Azadirachta indica* on sunflower and soyabean revealed that seedling length of sunflower was significantly increased by *S. cumini, A. indica, A. arabica* and *S. saman*, while that of soyabean was increased by all tree leaf extracts. Almost all the leaf extracts enhanced vigour index in sunflower, while only *T. grandis, A. arabica* and *A. indica* increased the vigour index in soyabean. A *.arabica, E. tereticornis, T. indica* and *A. indica* markedly decreased seedling dry matter in sunflower, while all leaf extracts except *E. tereticornis* decreased the seedling dry matter of soyabean (Channal *et al*., 2002b).

Tamarind leaf extract strongly inhibited radicle and hypocotyl growth of radish and lettuce (Parvez *et al*., 2003).

The aqueous leaf extracts of *Acacia leucopholea* inhibited shoot length, root length, leaf area of *Arachis hypogaea* (groundnut) and *Sorghum vulgare* (sorghum) (Jayakumar and Manikandan., 2005)

Prosopis juliflora and *Eucalyptus camaldulensis* leaf extracts inhibited seedling length of *Triticum aestivum* and *Brassica campestris* (Khan *et al*., 2005).

Leaf extracts of *Populus deltoids* reduced shoot and root length of green gram (Mandal *et al*., 2005).

Jacob *et al*. (2007b) reported the effects of the leaf extracts of *Ailanthus triphysa*, cashew, *Casuarina equisetifolia, Gliricidia sepium, Artocarpus heterophyllus, Strychnos nux-vomica, Mangifera indica, Thespesia populnea, Tamarindus indica* and *Tectona grandis* on bitter gourd (*Momordica charantia*) and brinjal (*Solanurn melongena*). Among the trees, *C. equisetifolia, T. populnea, T. indica* and *T. grandis* leaf extracts reduced the number of leaves of bitter gourd (*Mamordica charantia*) @ 2MAP. In brinjal, all extracts except those of *Ailanthus triphysa* and cashew reduced plant height at one MAP. The number of leaves were also reduced by the trees except *A. triphysa*, cashew and *M. indica*. At 4 MAP, *T. indica* extract alone reduced plant height. Leaf production was reduced by most of the extracts.

Leaf extract of *Acacia nilotica* significantly increased the radicle length of maize and sorghum seedlings. Higher survival of maize and sorghum seedlings was noticed when treated with extracts of *Khaya senegalensis*, *Peltophorum pterocarpum*, *Prosopis africana*, *Eucalyptus camaldulensis* and *Spina christi*. In both crops *A. nilotica* had least effect on the hypocotyl length (Mubarak, 2009).

Leaf extracts of *Eucalyptus camaldulensis* significantly reduced fresh and dry weight of wheat seedlings. The inhibitory effects increased with increase in extract concentration (Khan *et al*., 2009).

Allelopathic effects of *Dalbergia sissoo* fresh and dry leaves extract on growth of maize (*Zea mays*), pearlmillet (*Pennisetum glaucum*) and rice (*Oryza sativa*) were investigated. Fresh and dry leaves extracts had no inhibitory effect on growth of pearlmillet and rice. Rather it slightly promoted growth. Dry leaf extract enhanced the maize dry matter production. Dry leaf water extract was more effective than fresh leaves (Akhtar *et al*., 2010). Plumule and radicle extension of seedlings of *Zea mays* (Maize), *Vigna unguiculata* (Cowpea), *Lycopersicon esculentum* (Tomato) and *Abelmoschus esculentus* (Okra) were significantly reduced by the leaf extracts of *Senna siamea, Albizia lebbeck, Azadirachta indica, Cedrela odorata, Leucaena leucocephala, Gliricidia sepium, Eucalyptus grandis, Terminalia superba and Tectona grandis* with the exception of *Zea mays* where plumule and radicle development was increased by *E. grandis* leaf extracts (Abugre *et al*., 2011).

Tectona grandis leaf extract inhibited seedling growth of *Vigna mungo* (Evangeline *et al*., 2012).

Mango leaf extracts significantly inhibited seedling growth of cress (*Lepidum sativum*), lettuce (*Lactuca sativa*) and alfalfa (*Medicago sativa*). The inhibiton was directly proportional to the extract concentrations (Khan *et al*., 2013). Saleem *et al*. (2013) suggested thast old leaf extract of mango could be used to enhance wheat growth.

Lower concentrations of dry leaf extract of *T. grandis* significantly promoted seedling growth in black gram (*Vigna mungo*) and green gram (*Vigna radiata*). Higher concentrations severely reduced seedling dry weight of the crops (Manimegalai, 2013).

Mangal *et al*. (2013) reported that aqueous leaf extract of *Moringa olifera* contains water soluble allelochemicals which could inhibit the seedling growth and biochemical contents of chickpea crop.

The growth and developmental parameters of rice seedlings were significantly reduced by leaf extracts of *Casuarina equisetifolia*. But, at lower concentration the seedling growth was slightly enhanced (Leela *et al*., 2013).

The crude leaf extract of tamarind reduced radicle growth in lettuce more adversely than hypocotyl (Syed *et al*., 2014).

2.3.2.3*. *Effect on yield and yield attributes

Sundramoorthy and Kalra (1991) reported a reduction in yield of pearl millet, sesame and cluster bean by the aqueous leaf extracts of *Acacia tortilis*.

The aqueous leaf extracts of *Acacia leucopholea* reduced the yield of *Arachis hypogaea* and *Sorghum vulgare* (Jayakumar and Manikandan, 2005).

Akkaya *et al*. (2006) suggested that higher amounts of leaf extracts of pine (*Pinus* sp.) and walnut (*Juglans regia*) leaves may decrease wheat (*Triticum aestivum*) grain yield, while lower amounts may contribute to grain yield.

Young leaf extracts of mango induced some reduction in grain weight of wheat (Saleem *et al*., 2013).

2.3.3. Allelopathic Effect of Fresh Tree Leaf Loppings and Leaf Litter on Crops

2.3.3.1. Effect on germination

Jacob and Nair (1999) reported that leaf litter of Acacia *auriculiformis, Casuarina equisetifolia, Albizia lebbeck, Leucaena leucocephala, Artocarpus heterophyllus, Mangifera indica* and *Tamarindus indicus* significantly inhibited germination of rice.

The leaf litter of *Eucalyptus camaldulensis* adversely affected germination of wheat (Khan *et al*., 2008).

Bhatt and Singh (2009) reported that leaf litter of *Aquilaria malaccensis* (Syn. *A. agallocha), Michelia champaca, Tectona grandis and Trema orientalis* reduced the germination of rice, maize, green gram, rice bean, ground nut and cabbage.

2.3.3.2. Effect on growth

Jacob and Nair (1999) reported that leaf litter of *Acacia auriculiformis, Casuarina equisetifolia, Albizia lebbeck, Leucaena leucocephala, Artocarpus heterophyllus, Mangifera indica* and *Tamarindus indica* significantly inhibited growth of rice.

Divya and Yassin (2003) reported the reduction in dry matter production of cowpea, sesame, horse gram and sorghum when mulched with crushed dry leaves of *Azadirachta indica*.

Leucaena leucocephala and *Tectona grandis* leaf litter had inhibitory effect on the growth of maize (Sahoo *et al*., 2007).

The leaf litter of *Eucalyptus camaldulensis* adversely affected growth of wheat (Khan *et al*., 2008).

Bhatt and Singh (2009) reported that leaf litter of *Aquilaria malaccensis* (Syn. *A. agallocha*)*, Michelia champaca, Tectona grandis and Trema orientalis* reduced growth and dry matter production of rice, maize, green gram, rice bean, ground nut and cabbage.

2.3.3.3*. *Effect on yield and yield attributes

Ramamoorthy and Paliwal (1993) reported that mulching with leaves of *Gliricidia sepium* increased the yield of *Sorghum vulgare*.

The grain yield of maize increased with increasing levels of applied mulch of *L. leucocephala* (Larbi *et. al*., 1993). A five year field experiment to evaluate the effect of *Leucaena* dead mulches revealed that it improved yield of maize (Caamal *et. al*., 2001).

Kamara (1998) reported highest yields of maize (*Zea mays*) when mulched with leaves of *Gliricidia sepium* and *Leucena leucocephala*.

Sidhu and Dhillon (1998) recorded that grain yields of wheat (*Triticum aestivum*) generally increased with increasing leaf litter rates of *Eucalyptus tereticornis* in plots without NPK fertilizer, but decreased with leaf litter incorporation in plots with fertilizer.

Mango litter biomass increased the yield of forage crops. A combination of 75 per cent N through urea fertilizer + 25 per cent N through tree litter biomass gave higher yield of forage crops (sorghum, sudangrass (*Sorghum sudanense*) and maize) than when N was applied as urea alone or litter alone (Lal, 1999).

Divya and Yassin (2003) reported the suppression of grain yield of cowpea, sesame, horse gram and sorghum when mulched with crushed dry leaves of *Azadirachta indica*.

Leucaena leucocephala and *Tectona grandis* leaf litter had negative effect on the yield of maize (Sahoo *et al.,* 2007).

The leaf litter of *Eucalyptus camaldulensis* adversely affected yield of wheat (Khan *et al*., 2008).

The effect of leaf loppings of *Achras sapota*, *Ailanthus triphysa*, *Anacardium occidentale*, *Artocarpus heterophyllus*, *Artocarpus hirsute*, *Azadirachta indica*, *Bombax malabaricum*, *Casuarina equisettifolia*, *Coffea arabica*, *Erythrina indica*, *Gliricidia sepium*, *Hevea brasilensis*, *Leucaena leucocephala*, *Macaranga peltata*, *Mangifera indica*, *Psidium guajava*, *Swietania macrophylla*, *Tamarindus indicus*, *Tectona grandis*, *Theobroma cacao* and *Thespesia populnea* on yield of crops was investigated through field studies. Leaf loppings of all trees except *Casuarina* and *M. indica* reduced the seed yield of cowpea. The greatest yield reduction was caused by *A. occidentale* (84%), followed by *T. grandis*, *H. brasilensis* and *T. cacao.* All trees except *A. sapota* and *M. indica* significantly reduced groundnut yield. *H. brasilensis* leaves reduced yield considerably. The yield reduction in groundnut caused by *L. leucocephala*, *A. occidentale* and *C. arabica* was notable. Leaf loppings of all the trees significantly reduced maize yield. Development of grains on the cob was severely affected. The yield supression caused by *T. populnea* and *T. cacao* was as high as 80 per cent (KAU, 2009).

Combined application of tree litter of ipil-ipil (*Leucaena leucocephala*) and recommended fertilizer dose produced good rice yield (Arifin *et al*., 2012)

2.4 ALLELOPATHIC EFFECT OF TREES ON PHYSIOLOGICAL PROCESS IN PLANTS

Leaf extracts of bamboo reduced chlorophyll development and protein content of groundnut (Eyini *et al*., 1989).

The diosgenin concentration in *Costus speciosus* rhizomes increased on treating with *Mangifera indica* leaf leachate and decreased with *Eucalyptus globulus* leachate but was unaffected by *Shorea robusta* and *Tectona grandis* leachates (Konar and Kushari, 1989).

Experiments were conducted to assess the effect of aqueous leaf extracts of *Eucalyptus globulus, Melia azedarach* and *Moringa oleifera* on mineral uptake by sorghum. The uptake of Zn, Ca and Mg were more affected than K, P, Fe or Mn by extract exposure and the extracts reduced uptake of these minerals. *E. globulus* caused the greatest reduction in Ca absorption while *M. oleifera* and *E. globulus* caused marked reductions in Mg uptake (Pawar and Chavan, 1999).

The allelopathic potential of aqueous leaf extract of *Eucalyptus camaldulensis* was investigated on mitotic index in the root apical meristem of *Allium cepa*, Hill reaction in isolated spinach (*Spinacia oleracea*) chloroplast and radicle growth and peroxidase activity in *Lepidium sativa, Avena fatua, Zea mays* and *Lycopersicon esculentum*. The presence of different concentrations of aqueous leaf extract decreased the mitotic index. Aqueous extract decreased the mitotic index and number of cells in prophase, metaphase and anaphase, affected Hill reaction, decreased the enzyme activity significantly, inhibited peroxidase activity in *L. sativum* and suppressed the radicle growth in all the plant species. These results suggest that *Eucalyptus* species suppresses the growth of other plant species by affecting several biochemical and physiological processes (Moradshahi *et al*., 2003)

Phenolic allelochemicals have been observed in both natural and managed ecosystems, where they cause a number of ecological and economic problems such as decline in crop yield due to soil sickness, regeneration failure of natural forests and replanting problems in orchards. Phenolic allelochemical structures and modes of action are diverse and may offer potential lead compounds for the development of future herbicides or pesticides. Allelopathic effects of phenolics includes changes in membrane permeability, inhibition of plant nutrient uptake, inhibition of cell division and elongation, effects on plant photosynthesis and respiration, effects on various enzyme functions, synthesis of plant endogenous hormones and protein synthesis. (Li *et al*., 2010).

The yield of essential oils and total phenolics and the anti-oxidant activities of basil seedlings increased with increasing concentrations of aqueous leaf extracts of walnut (*Juglans regia*) whereas the relative water content, leaf water potential, as well as the total chlorophyll and carotenoid content of basil leaves decreased significantly (Dadi *et al*.,2013).

Tamarind leaf extract (crude extract) hindered the normal physiological growth process resulting in weak and curly seedlings and necrosis of their tips in lettuce seedlings (Syed *et al*., 2014).

2.5 ALLELOCHEMICALS IN TREES

Tyman and Morris (1967) described the composition of cashew nut shell liquid (CNSL) as anacardic acid (71.7%), cardol (18.7%), cardanol (4.7%), novel phenol (2.7%) and two unknown minor ingredients (2.2%).

Chou and Kuo (1986) identified 10 phytotoxins such as mimosine, quercetin, gallic, protocatechuic, p-hydroxybenzoic, p-hydroxyphenylacetic, vanillic, ferulic, caffeic and p-coumaric acids in subabul (*Leucaena leucocephala*). Their amount was significantly higher in young leaves than in mature leaves.

Duke (1992) reported the presence of several phytochemicals in trees. *Ailanthus altissima* contains ailanthin, ailanthinone, ailanthone, beta-sitosterol, gallic-acid, isoquercetin, isoquercitrin, linuthin, quassiin, quercetin, scopoletin and tannin. *Anacardium occidentale* contains alpha-linolenic acid, anacardic acid, anacardol, beta-sitosterol, capric acid, caprylic acid, cardanol, cardol, gadoleic acid, gallic acid, lauric acid, limonene, naringenin, palmitic acid, squalene, tannin and threonine. *Artocarpus heterophyllus* contains betulinic acid and tannin. Alanine, alpha-pinene, beta-pinene, gallic acid, gallotannic acid, isoleucine, isomangiferolic acid, kaempferol, lauric acid, limonene flower, linoleic acid, linolenic acid, mangiferic acid, mangiferine, mangiferol, mangiferolic acid, mangiferonic acid, myristic acid, p-coumaric acid, palmitic acid, quercetin, tannin and threonine are present in *Mangifera indica*. Alpha terpineol, cinnamaldehyde, ethyl cinnamate, galacturonic acid, geranial essential oil, geraniol essential oil, limonene, linoleic acid, myristic acid, oleic acid, palmitic acid, pantothenic acid, phenol, pipecolinic acid, tannin and tartaric acid is found in *Tamarindus indica*. *Tectona grandis* contains betulin and betulinic acid. *Strychnos nux-vomica* has arachidic acid, brucine, chlorogenic acid, cycloartenol, linoleic acid, myristic acid, palmitic acid, strychnicine and strychnine. *Gliricidia sepium* contains gallic acid, protocatechuic acid, p-hydroxybenzoic acid, gentisic acid, beta-resorcyclic acid, vanillic acid, syringic acid, p-coumaric acid, m-coumaric acid, o-coumaric acid, ferulic acid, sinapinic acid (trans and cis forms), coumarin, and myricetin. Kaempferol-3-alpha-rhamnoside, quercetin-3-alpha-araboside, luteolin-3', 4'-dimethoxy-7 beta-rhamnoside, kaempferol-3-betadirhamnoside, quercetin-3-beta-glucoside is present in *Casuarina equisetifolia*.

Ramamoorthy and Paliwal (1993) identified fifteen toxic compounds, including gallic acid, protocatechuic acid, *p*-hydroxybenzoic acid, gentisic acid, β-resorcyclic acid, vanillic acid, syringic acid, 3-coumaric acids, ferulic acid, sinapinic acids, coumarin and myricetin from *Gliricidia sepium*.

Ailanthone and chaparrinone were identified as the active constituents in *Ailanthus altissima* (Lin *et al*., 1996).

From the leaves of *Acacia leucopholea* different phenolic acids *viz*., hydroquinone, salicylic acid, trans-cinnamic acid, gentisic acid, vanillic acid, protocatechuic acid, p-coumaric acid and trans-ferulic acid were identified. Different functional groups of tannins were also identified (Jayakumar and Manikandan, 2005).

Jacob *et al.* (2007b) reported that leaf extracts of ailanthus contains triterpenes, cashew contains terpenoids triterpenes and saponins, jack contains flavonoids and terpenoids, mango contains terpenoids and triterpenes, tamarind contains flavonoids and terpenoids and teak contains triterpenes.

Macias *et al*. (2010) isolated a new compound, abeograndinoic acid, from *T. grandis*, which has an unusual carbon skeleton. A further 21 known terpenoids including four sesquiterpenoids, eight diterpenes and nine triterpenes were also isolated. Two new quinones (an isoprenoid quinone, and a dimeric anthraquinone) named naphthotectone and anthratectone respectively were isolated from bioactive leaf extracts of *Tectona grandis.*

Total phenolic content was higher in new mango leaves as compared to old ones. The compounds identified in mango leaves were 4-hydroxybenzaldehyde, *m*-coumaric, *p*-coumaric, 4-hydroxy benzoic, vanillic, caffeic, gallic and protocatechuic acids (Saleem *et al*., 2013).

Syed *et al*., 2014 reported that oxalic and tartaric acids are the major allelochemicals in tamarind (*Tamarindus indica*) leaves.

Jessing *et al*. (2014) reported that *Artemisia annua* produces Artemisinin.

From the above review it is evident that leaf leachates, leaf extracts, leaf loppings and leaf litter of trees exert significant allelopathic effect on crops. The effects may be on germination, growth or yield. The effects are mostly inhibitory while some instances of stimulatory influences are also reported. The manifestation of the inhibitory effects is mainly a consequence of the multifarious physiological processes in plants, that may be affected. It is also revealed that several phytochemicals are present in plants which may be causing these allelopathic effects.

Materials and Methods

3. MATERIALS AND METHODS

The investigation entitled "Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)" was carried out at the College of Agriculture, Padannakkad during the period from April 2014 to January 2015. The main objective was to investigate the allelopathic effect of certain trees commonly planted in the homesteads of Kerala on sprouting, growth and yield of turmeric.

The study involved two bioassays, which were carried out in the laboratory and two pot culture experiments, which were undertaken in the open field adjacent to the main building of the College of Agriculture, Padannakkad, Kerala Agricultural University (KAU) Kerala. The materials used and the methods adopted for the conduct of the experiments are described in this chapter.

3.1. EXPERIMENTAL SITE

The studies were undertaken in the laboratory and open area (pot culture experiments) adjacent to the main building of the College of Agriculture, Padannakkad situated at 12^0 $20^,$ 30'' N latitude, 75^0 04' 15'' E longitude and an altitude of less than 20 m above mean sea level.

3.2. WEATHER CONDITIONS

Monthly averages of maximum and minimum temperatures, relative humidity, rainfall received and evaporation during the study period are given in Appendix.1. The mean maximum temperature ranged between 29.22^0 C to 34.51^0 C and minimum temperature ranged between 19.34^0 C to 24.56^0 C during the crop season. The mean maximum and minimum relative humidity ranged between 82.5% to 93.56% and 57.90% to 84.6% respectively during the cropping period. A total rainfall of 3481.75 mm was recorded during the crop season (Fig.1).

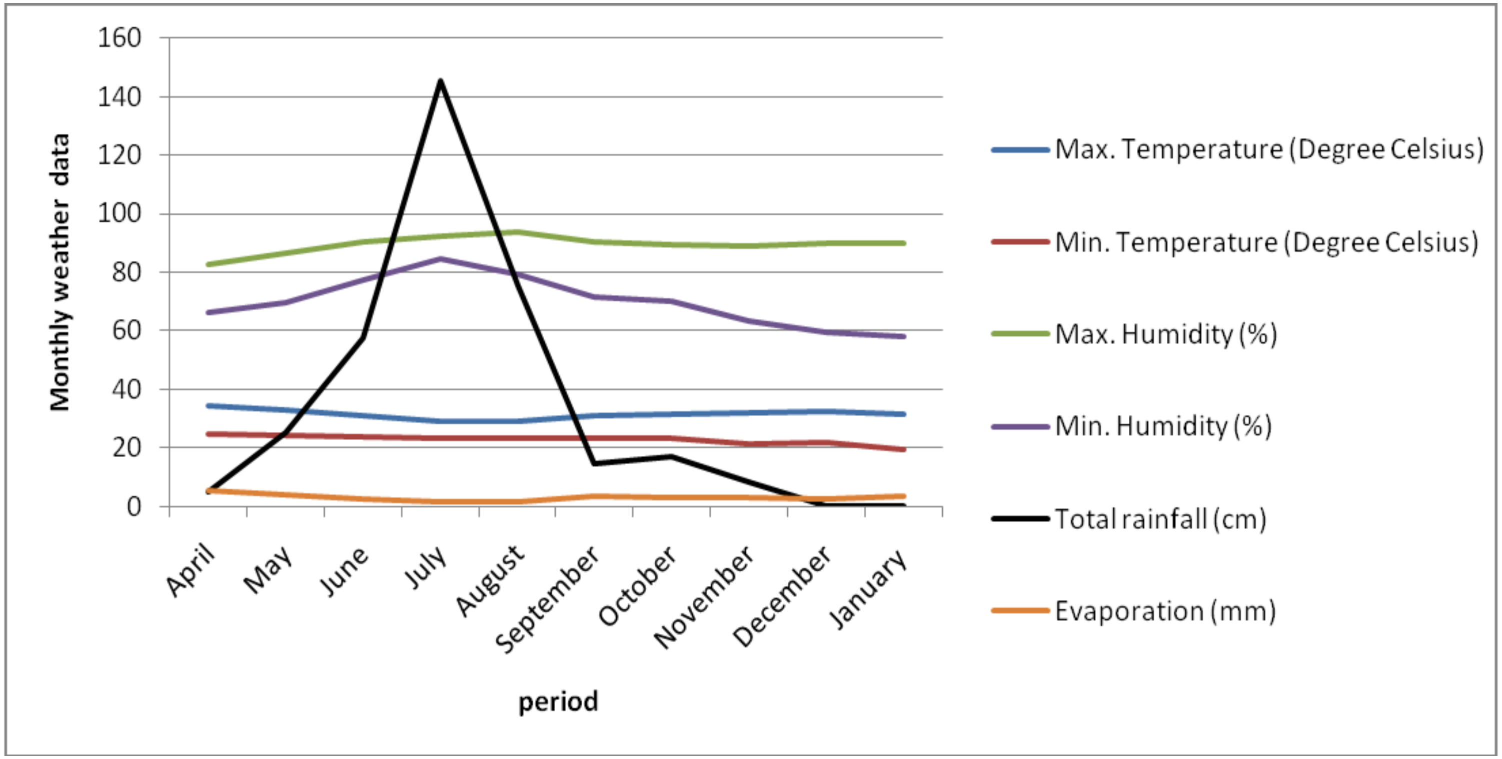

Fig.1. Monthly weather data during the cropping period

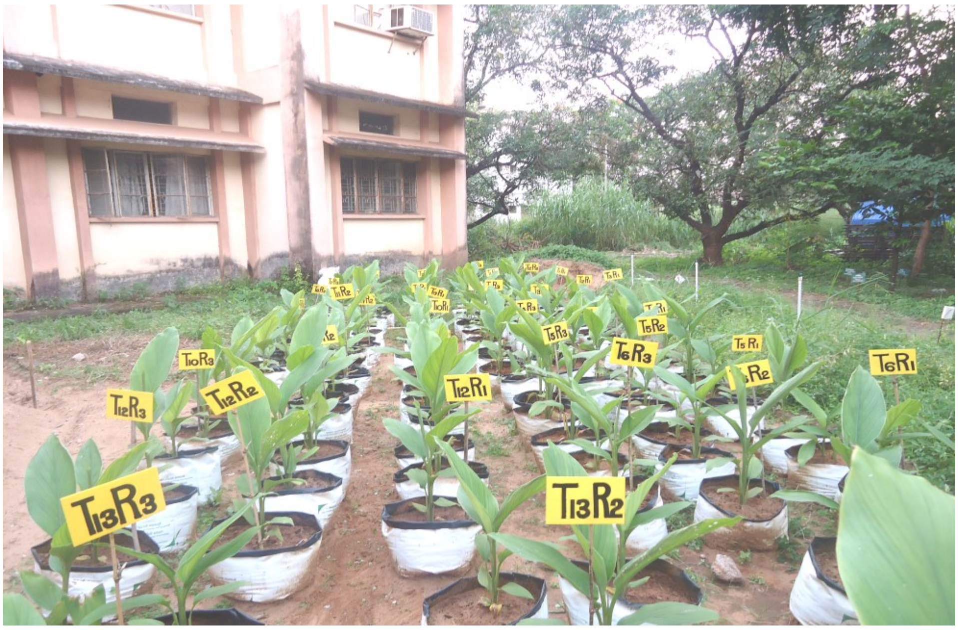

Plate 1. General layout of the experimental field (Pot culture I)

Plate 2. General layout of the experimental field (Pot culture II)

3.3. TEST CROP

Seed rhizomes of turmeric *var*. Sobha were obtained from instructional farm, College of Horticulture, Vellanikkara. Sobha, a clonal selection from local type, was released from College of Horticulture, KAU, Vellanikkara, Thrissur in 1991. The characters of the variety includes, medium duration (240-270 days), big mother rhizome with medium bold and closer internodes and inner core of rhizomes dark orange. Dryage is 19.38 per cent with 7.39 per cent curcumin content, 9.65 per cent oleoresin and 4.24 per cent essential oil.

3.4. TEST TREES

The details of test trees are as follows.

Table 1. Details of test trees used for the experiments.

Sl.No.	Common name	Scientific name	Vernacular name
1	Coconut	*Cocos nucifera* L.	Thengu
2	Cashew	*Anacardium occidentale* L.	Kashumavu
3	Jack	*Artocarpus heterophyllus* Lamk.	Plavu
4	Mango	*Mangifera indica* L.	Mavu
5	Tamarind	*Tamarindus indica* L.	Pulimaram
6	Teak	*Tectona grandis* L.f.	Thekku

The allelopathic effect of the trees on turmeric was assessed through four separate experiments as detailed below.

3.5. EXPERIMENT I (BIOASSAY I)

This experiment was carried out with the objective of assessing the allelopathic influence of leaf leachates of test trees on sprouting and early establishment of turmeric.

3.5.1 Season

The experiment was conducted during April 2014 to May 2014.

3.5.2. Materials

3.5.2.1. Crop and variety

Turmeric variety 'Sobha' was raised for the experiment. The characteristics of the variety are detailed under section 3.3.

3.5.2.2. Source of seed material

Rhizomes of turmeric variety 'Sobha' were purchased from the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur.

3.5.2.3. Containers

Protrays with cells of 3.5 cm diameter were used for planting turmeric rhizomes.

3.5.2.4. Preparation of growing media

Growing media was prepared using soil exposed to sunlight for one week, sand and cow dung in the ratio 1:1:1.

3.5.2.5. Manures and fertilizers

The general recommendation for turmeric is organic manure @ 40 t ha^{-1} and $N:P_2O_5:K_2O$ @ 30:30:60 kg ha^{-1} as per the Package of Practices Recommendations for Kerala (Kerala Agricultural University, 2011). The quantity of organic manure (full dose) and fertilizers to supply the basal dose of 30 kg P_2O_5 and 30 kg K_2O was worked out for 1 kg growing media and applied at the time of planting. The quantity of cow dung, Rajphos and MOP for 1 kg growing media was 20 g, 75 mg and 25 mg respectively.

3.5.3. Methods

3.5.3.1. Design and layout

The experiment was laid out in completely randomized design and comprised of 13 treatments as detailed in section 3.5.3.2. All the treatments were replicated thrice.

3.5.3.2. Treatment details

3.5.3.2.1. Treatments

The first bioassay comprised of 13 treatments as detailed below.

Table 2. Treatment details of Experiment I (Bioassay I)

Treatments	Concentration of leaf leachate (w/v)
T_1	Coconut 1:10
T_2	Cashew 1:10
T_3	Jack 1:10
T_4	Mango 1:10
T_5	Tamarind 1:10
T_6	Teak 1:10
T_7	Coconut 1:15
T_8	Cashew 1:15
T_9	Jack 1:15
T_{10}	Mango 1:15
T_{11}	Tamarind 1:15
T_{12}	Teak 1:15
T_{13}	Control

3.5.3.2.2. Collection of leaves

Leaves were collected directly from fully mature trees. Leaves were selected from different parts of the tree (lower, middle and top portions) to get a representative sample of the entire tree canopy. Leaves that were dry or in senescent stage and ready to shed were avoided.

3.5.3.2.3. Cleaning

Contaminants like adhering soil/dust particles etc. were removed from the leaves by carefully wiping with a cloth.

3.5.3.2.4. Drying and storing of sample

As the material collected was of varying moisture content they were air dried (in shade) to uniform moisture content. Whenever the material was to be stored for later use, it was kept in polythene bags in refrigerator (for use as fresh).

3.5.3.2.5. Preparation of leachate

Leachate was prepared from the intact leaves without subjecting it to destruction according to the standard procedures (Jacob *et al*., 2006). To determine the presence of allelopathic activity, the protocol for leachate preparation should be as similar to that prevailing under natural conditions. Hence, distilled water (ambient temperature) was used as solvent, as in nature allelochemicals are released into the environment in a water soluble form. Moreover, this ensured a natural release of toxins. Aqueous leachate was prepared by soaking the fresh leaves in distilled water in the ratio 1:10 (w/v) and 1:15 (w/v) respectively. The leaves were soaked for 24 h, as it is expected to leach out most of the allelochemicals. The ratio 1:15 was tried to explore the possibility of alleviation of allelopathic effects, if any, through dilution.

3.5.3.2.6. Filtration

The leachates were filtered through muslin (*kora*) cloth.

3.5.3.2.7. Measurement of pH and Osmolality of leachates

The pH and osmolality of the leaf leachates were measured using pH meter and vapour pressure osmometer (WESCOR, Germany) respectively. The pH of the leaf leachates was adjusted to range between 6-7 by adding either alkali (KOH) or acid (HCl) as required.

3.5.3.2.8. Storing of leachates

The prepared leachates were stored in refrigerator to prevent decay and breakdown by bacteria.

3.5.3.2.9. Setting up of the bioassay with leaf leachate

Protrays with cells of 3.5 cm diameter were filled with the growing media and uniformly sized healthy seed rhizomes of turmeric were planted. Uniform and adequate moisture was maintained in all the treatments during the period of study by adding equal quantity of the leachate, daily or on alternate days.

The control consisted of protray cells set up similarly but watered with distilled water. All the treatments and control in bioassays were replicated thrice. Each replication comprised of ten protray cells. The observations were recorded at one month after planting (1 MAP).

3.6. EXPERIMENT II (BIOASSAY II)

This experiment was carried out with the objective of assessing the allelopathic influence of leaf extracts of test trees on sprouting and early establishment of turmeric.

3.6.1 Season

The experiment was conducted during April 2014 to May 2014.

3.6.2. Materials

Same as for bioassay I (sections ***3.5.2.1.*** to ***3.5.2.5.)***

3.6.3. Methods

3.6.3.1. Design and layout

The experiment was laid out in completely randomized design and comprised of 13 treatments as detailed in section 3.6.3.2. All the treatments were replicated thrice.

3.6.3.2. Treatment details

3.6.3.2.1. Treatments

The second experiment comprised of 13 treatments as detailed below.

Table 3. Treatment details of Experiment II (Bioassay II)

Treatments	Concentration of leaf extract (w/v)
T_1	Coconut 1:10
T_2	Cashew 1:10
T_3	Jack 1:10
T_4	Mango 1:10
T_5	Tamarind 1:10
T_6	Teak 1:10
T_7	Coconut 1:15
T_8	Cashew 1:15
T_9	Jack 1:15
T_{10}	Mango 1:15
T_{11}	Tamarind 1:15
T_{12}	Teak 1:15
T_{13}	Control

3.6.3.2.2. Collection of leaves

Same as described under section 3.5.3.2.2

3.6.3.2.3. Cleaning

Same as described under section 3.5.3.2.3

3.6.3.2.4. Drying and storing of sample

Same as described under section 3.5.3.2.4

3.6.3.2.5. Preparation of leaf extract

Leaf extract was prepared from the intact leaves subjecting it to destruction according to the standard procedures (Jacob *et al*., 2006). Aqueous extracts were prepared by blending the tree leaves with distilled water in the ratio 1:10 (w/v) and 1:15 (w/v) respectively.

3.6.3.2.6. Filtration

The extracts were filtered through muslin (*kora*) cloth.

3.6.3.2.7. Measurement of pH and Osmolality of leachates

Same as described under section 3.5.3.2.7

3.6.3.2.8. Storing

Same as described under section 3.5.3.2.8

3.6.3.2.9. Setting up of the bioassay with leaf extract

Protrays with cells of 3.5 cm diameter were used for all the treatments. Cells of the portrays were filled with the growing media and uniformly sized healthy seed rhizomes of turmeric were planted.

Uniform and adequate moisture was maintained in all the treatments during the period of study by adding equal quantity of the extract daily or on alternate days. The control consisted of protray cells set up similarly but watered with distilled water. All the treatments and control were replicated thrice. Each replication comprised of ten protray cells. Observations were recorded at 1 MAP.

3.7. EXPERIMENT III (POT CULTURE 1)

This experiment was undertaken to study the effect of irrigating with fresh tree leaf leachates of test trees on growth and yield attributes of turmeric.

3.7.1. Season

The experiment was conducted during April 2014 to January 2014

3.7.2. Materials

3.7.2.1. Crop and variety

Turmeric variety 'Sobha' released from the Kerala Agricultural University was raised for the experiment.

3.7.2.2. Source of seed material

Rhizomes of turmeric variety 'Sobha' were purchased from the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur.

3.7.2.3. Containers

The container used for raising the crop was UV (ultra violet) stabilized grow bags of 25 cm height and 30 cm diameter capable of holding upto 15 kg of growing media.

3.7.2.4. Preparation of growing media

Growing media was prepared using soil exposed to sunlight for one week, sand and cow dung in the ratio 1:1:1.

3.7.2.5. Manures and fertilizers

Organic manure and nutrients (N: P_2O_5: K_2O) were applied, as per the Package of Practices Recommendations for Kerala (Kerala Agricultural University, 2011).

3.7.3. Methods

3.7.3.1. Design and layout

The experiment was laid in completely randomized design and comprised of 13 treatments as detailed in section 3.7.3.2. All the treatments were replicated thrice.

3.7.3.2. Treatment details

3.7.3.2.1. Treatments

The third experiment comprised of 13 treatments as detailed below

Table 4. Treatment details of Experiment III (Pot culture I)

Treatments	Concentration of leaf leachate (w/v)
T_1	Coconut 1:10
T_2	Cashew 1:10
T_3	Jack 1:10
T_4	Mango 1:10
T_5	Tamarind 1:10
T_6	Teak 1:10
T_7	Coconut 1:15
T_8	Cashew 1:15
T_9	Jack 1:15
T_{10}	Mango 1:15
T_{11}	Tamarind 1:15
T_{12}	Teak 1:15
T_{13}	Control

3.7.3.2.2. Collection of leaves

Same as described under section 3.5.3.2.2

3.7.3.2.3. Cleaning

Same as described under section 3.5.3.2.3

3.7.3.2.4. Drying and storing of sample

Same as described under section 3.5.3.2.4

3.7.3.2.5. Preparation of leaf leachate

Same as described under section 3.5.3.2.5. However, in order to stimulate natural conditions the pH of the leaf leachates were not adjusted to range between 6-7.

3.7.3.2.6. Filtration

Same as described under section 3.5.3.2.6

3.7.3.2.7. Storing

The prepared leachates were stored in refrigerator to prevent decay and breakdown by bacteria.

3.7.3.2.8. Setting up of the pot culture with leaf leachate

The study was conducted using UV (ultra violet) stabilized grow bags of 25 cm height and 30 cm diameter capable of holding upto 20 kg of growing media. The grow bags were filled with potting mixture containing sand, soil and cow dung in the ratio 1:1:1 exposed to sunlight for one week to eliminate any allelochemicals, if present. Organic manure and nutrients ($N:P_2O_5:K_2O$) were applied, as per the Package of Practices Recommendations for Kerala (Kerala Agricultural University, 2011). The healthy seedlings of turmeric of uniform growth (at 2 leaf stage) were planted in grow bags. The tree leaf leachates were prepared using distilled water as described earlier in 3.7.3.2.5 and uniformly applied to each grow bag (@ 100 ml per pot) immediately after planting and subsequently twice in a week. On all other days the grow bags were irrigated with tap water to maintain adequate moisture, throughout the experimental period. A control was maintained, in which the plants were irrigated with tap water. All the treatments were replicated thrice and each replication comprised of four grow bags.

3.7.4. Details of cultivation

3.7.4.1. Nursery

Turmeric seedlings were raised in protrays with cells of 3.5 cm diameter filled with growing media prepared using sand, soil and cow dung in the ratio 1:1:1 to get uniform and healthy seedlings for the pot culture studies. Rhizomes were sown on 2nd April 2014.

3.7.4.2. Transplanting

Uniformly grown healthy seedlings of turmeric were uprooted from the pro trays after one month and transplanted to the grow bags as described under section 3.7.2.3.

3.7.4.3. Manures and fertilizers

Organic manure and nutrients ($N:P_2O_5:K_2O$) were applied as per the Package of Practices Recommendations for Kerala (Kerala Agricultural University, 2011). The recommended rates of organic manure (40 t ha^{-1}) and $N:P_2O_5:K_2O$ (30:30:60 kg ha^{-1}) were calculated for each grow bag containing 15 kg potting mixture. The organic manure was applied as basal dose (300 g for each grow bag). Full dose of P_2O_5 and half dose of K_2O were applied as basal, 2/3 dose of N applied at 30 DAP and 1/3 N and 1/2 K were applied at 60 DAP. A total of 0.489 g urea, 1.125 g Rajphos and 0.75 g MOP were applied in each grow bag as split doses.

3.7.4.4. After cultivation

The weeds were removed from the grow bags by hand weeding as and when they appeared. The plants were irrigated when required.

3.7.4.5. Plant protection

There was incidence of leaf blight and leaf blotch of turmeric and shoot borer (*Conogethes punctiferalis*) in the early stages. Spraying of Bordeaux mixture (1%) was done at regular intervals for controlling the diseases. The shoot borer was effectively controlled by spraying Malathion 50 EC @ 2 ml litre^{-1}.

3.7.4.6. Harvesting

The harvest was done after 9 months (2nd January 2015).

3.8. EXPERIMENT IV (POT CULTURE II)

This experiment was carried out to assess the effect of mulching with fresh tree leaf loppings of test trees on the growth and yield attributes of turmeric.

3.8.1 Season

The experiment was conducted during April 2014 to January 2015.

3.8.2. Materials

3.8.2.1. Crop and variety

Turmeric variety 'Sobha' released from the Kerala Agricultural University was raised for the experiment.

3.8.2.2. Source of seeds

Rhizomes of turmeric variety ‘Sobha’ were purchased from the Department of Plantation Crops and Spices, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur.

3.8.2.3. Containers

The container used for raising the crop was UV (ultra violet) stabilized grow bags of 25 cm height and 30 cm diameter capable of holding up to 15 kg of growing media.

3.8.2.4. Preparation of growing media

Growing media was prepared using various components such as soil, sand and cow dung in the ratio 1:1:1, exposed to sunlight for one week.

3.8.2.5. Manures and fertilizers

Organic manure and nutrients ($N:P_2O_5:K_2O$) were applied, as per the Package of Practices Recommendations for Kerala (Kerala Agricultural University, 2011).

3.8.3. Methods

3.8.3.1. Design and layout

The experiment was laid out in completely randomized design and comprised of 7 treatments as detailed in section 3.8.3.2. All the treatments were replicated thrice.

3.8.3.2. Treatment details

3.8.3.2.1. Treatments

The experiment comprised of 7 treatments as detailed below

Table 5. Treatment details of Experiment IV (Pot culture II)

Treatments	Tree leaves used for mulching
T_1	Coconut
T_2	Cashew
T_3	Jack
T_4	Mango
T_5	Tamarind
T_6	Teak
T_7	Control (News paper)

3.8.3.2.2. Collection of leaves

Same as described under section 3.5.3.2.2

3.8.3.2.3. Setting up of pot culture with fresh leaf loppings

The study was conducted using UV (ultra violet) stabilized grow bags of 25 cm height and 30 cm diameter capable of holding upto 15 kg of growing media. The grow bags were filled with potting mixture containing sand, soil and cow dung in the ratio 1:1:1 exposed to sunlight for one week to eliminate any allelochemicals, if present. In each bag healthy turmeric rhizomes of uniform size were planted. Fresh leaf loppings were applied as mulch @ 15 t ha^{-1} immediately after planting. The same quantity was applied after 50 days (Kerala Agricultural University, 2011). The equivalent quantity of tree leaf loppings applied in a single grow bag used for the study was 112.5 g. A control was also maintained and mulching was done with news paper. All the treatments were replicated thrice and each replication comprised of four grow bags.

3.8.4. Details of cultivation

3.8.4.1. Manures and fertilizers

Same as described under section 3.7.4.3

3.8.4.2. After cultivation

Same as described under section 3.7.4.4

3.8.4.3. Plant protection

There was incidence of leaf blight and leaf blotch of turmeric and shoot borer (*Conogethes punctiferalis*) in the early stages. Spraying of Bordeaux mixture (1%) was done at regular intervals for controlling the diseases. The shoot borer was effectively controlled by spraying Malathion 50 EC @ 2 ml litre^{-1}.

3.8.4.4. Harvesting

The harvest was done after 9 months (3rd January 2015).

3.9. OBSERVATIONS

3.9.1. Bioassay

3.9.1.1. Percentage sprouting

Percentage sprouting was calculated by comparing the total number of rhizomes germinated in each treatment and the total number of rhizomes planted.

3.9.1.2. Days to sprouting

The number of days required for the germination of seed rhizomes was observed and expressed in days.

3.9.1.3. Shoot length

Height of the plant was measured from base to the growing tip (top most leaf bud) one month after planting (1 MAP) and the mean values computed and expressed in cm.

3.9.1.4. Root length (1MAP)

The seedlings were uprooted at 1 MAP and the maximum length of the roots was measured and mean length expressed in cm.

3.9.1.5. Number of roots

The seedlings were uprooted at 1 MAP and the total number of roots were counted.

3.9.1.6. Response index

The magnitude of inhibition versus stimulation in the bioassays was compared through the Response Index (RI), determined as follows, where T is the treatment mean (number of seeds germinating or mean plumule / radicle length of germinated seeds) and C is the control mean **(**Williamson and Richardson, 1988).

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If T > C the RI = 1 -(C/T)
If T = C then RI = 0
If T < C then RI = (T/C) - 1

A positive Rl indicates stimulation while negative denotes inhibition.

3.9.1.7. pH of leachates and extracts

pH of leachates and extracts were measured using pH meter with glass electrode (Jackson, 1958).

3.9.1.8. Osmolality of leachates and extracts

Osmolality of leachates and extracts were measured using vapour pressure osmometer (WESCOR, Germany).

3.9.1.9. Phenol content of leachates and extracts

Phenol content of leachates and extracts were estimated using Folin-Ciocalteu method (Malick and Singh, 1980).

3.9.1.10. Tannin content of leachates and extracts

Phenol content of leachates and extracts were assessed using Folin-Denis reagent (Schanderl, 1970)

3.9.2. Pot culture

3.9.2.1. Growth characters

3.9.2.1.1. Plant height

The height of the plants were measured at bimonthly intervals from 2 MAP from the base of the pseudostem to the tip of the topmost leaf and height was expressed in cm.

3.9.2.1.2. Number of tillers

The number of tillers were determined by counting the number of aerial shoots arising around a single plant at bimonthly intervals from two MAP.

3.9.2.1.3. Number of leaves

Number of leaves were determined by counting the number of leaves from all the tillers at bimonthly intervals from 2 MAP.

3.9.2.2. Rhizome characters

3.9.2.2.1. Rhizome spread

The horizontal spread of rhizome was measured at the time of harvest and expressed in cm.

3.9.2.2.2. Rhizome thickness

The diameter of the rhizome was measured by using a thread through the centre portion and expressed in cm.

3.9.2.3. Root characters

3.9.2.3.1. Root length

The root length was recorded at the time of harvest by measuring the maximum length of roots and mean length expressed in cm.

3.9.2.3.2. Root spread

Root spread was measured at the time of harvest by spreading the root system on a marked paper and measuring the spread of the root system at its broadest part. It is expressed in cm.

3.9.2.3.3. Root weight per plant

Roots were separated from individual plants at the time of harvest and dried in hot air oven at 70-80 ^{0}C and its weight taken and expressed in g plant^{-1}.

3.9.2.3.4. Root volume per plant

Root volume per plant was determined at the time of harvest by displacement method and expressed in cm^{3} plant^{-1}.

3.9.2.4. Physiological parameters

3.9.2.4.1. SPAD reading

SPAD value was recorded using chlorophyll meter (Konica Minolta Model SPAD 502) which represents the greenness of the leaf and thereby is an indication of the chlorophyll content in the leaf.

3.9.2.4.2. Canopy temperature

Canopy temperature was measured using steady state porometer (Spectro Analytical) and expressed as ^{0}C

3.9.2.4.3. Stomatal conductance

Stomatal conductance was measured using steady state porometer (Spectro Analytical) and expressed as milli mol m^{-2} s^{-1}.

3.9.2.5. Yield and Yield components

3.9.2.5.1. Rhizome yield

The yield of fresh rhizome from each treatment was recorded at the time of harvest (9 MAP) and expressed as g $plant^{-1}$.

3.9.2.5.2. Top yield

The yield of above ground portion from individual treatments was recorded at 9 MAP on dry weight basis and expressed as g $plant^{-1}$.

3.9.2.5.3. Dry turmeric

100 g of fresh rhizomes were taken from each treatment and dried in an hot air oven at 70-80^0 C. The weight was then taken and expressed as recovery percentage on dry weight basis.

3.9.2.6. Chemical analysis

3.9.2.6.1. Nutrient (major) content of the fresh tree leaves

Nutrient (major) content of the fresh tree leaves in terms of total N, P and K was analyzed using standard analytical methods as follows.

Table 6. Analytical methods used for the chemical characterization of plant sample

Chemical parameter	Method	Reference
Total N (%)	Modified Microkjeldhal method	Jackson, 1958
Total P (%)	Colorimetrically determined by wet digestion of the sample and developing colour by ascorbic acid method and read in a spectrophotometer.	Bray and Kurtz, 1945
Total K (%)	Flame photometry	Jackson, 1958

3.9.3. Statistical analysis

The data obtained from the experiment were subjected to analysis of variance for completely randomized design using Statistical Analysis Software (SAS) (Hatcher, 2003). The data after statistical analysis were used for comparison and interpretation of the results.

Results

4. RESULTS

An investigation was conducted to assess the allelopathic effect of certain trees commonly planted in the homesteads of Kerala on sprouting, growth and yield of turmeric.

Four experiments as detailed below were conducted to realize the objectives envisaged.

Experiment I (Bioassay I): To study the effect of fresh tree leaf leachates
Experiment II (Bioassay II): To study the effect of fresh tree leaf extracts
Experiment III (Pot culture III): To study the effect of irrigating with fresh tree leaf leachates
Experiment IV (Pot culture IV): To study the effect of mulching with fresh tree leaf loppings

The data on various observations were statistically analyzed and are presented in this chapter.

4.1. EXPERIMENT I (BIOASSAY I)

The experiment was undertaken with the objective of assessing the allelopathic influence of leaf leachates on sprouting and early establishment of turmeric (*Curcuma longa* Linn.).

4.1.1. Sprouting

The data on percentage sprouting is presented in Table 7. All treatments except T_1, T_7 and T_8 had remarkable effect on sprouting. The treatments T_2, T_3, T_4, T_5, T_6, T_9, T_{11} and T_{12} severely inhibited the sprouting of seed rhizomes of turmeric while T_8 and T_{10} were on par with control. Among the treatments, T_5 was most inhibitory. Response indices revealed that the treatments T_3, T_5 and T_6 caused 50, 57 and 50 per cent inhibition respectively.

4.1.2. Days to sprouting

There was significant variation between treatments on days to sprouting recorded at 1 MAP (Table 7). The treatments T_7, T_8 and T_{10} caused earlier germination of seed rhizomes. All other treatments were on par with control.

Table 7. Effect of tree leaf leachate on percentage sprouting and days to sprouting of turmeric seed rhizomes

Treatment	Percentage sprouting (%)	Response index	Days to sprouting	Response index
T_1 Coconut 1:10	86.66	0.00	8.53	0.11
T_2 Cashew 1:10	56.66	-0.34	8.83	0.08
T_3 Jack 1:10	43.33	-0.50	9.76	-0.01
T_4 Mango 1:10	60.00	-0.30	9.13	0.05
T_5 Tamarind 1:10	40.00	-0.57	9.50	0.01
T_6 Teak 1:10	43.33	-0.50	10.23	-0.05
T_7 Coconut 1:15	90.00	0.03	7.20	0.25
T_8 Cashew 1:15	86.66	0	7.50	0.22
T_9 Jack 1:15	63.33	-0.26	8.13	0.15
T_{10} Mango 1:15	70.00	-0.19	7.56	0.21
T_{11} Tamarind 1:15	43.33	-0.50	10.33	-0.06
T_{12} Teak 1:15	46.66	-0.46	9.80	-0.01
T_{13} Control	86.66	0.00	9.66	0.00
SEm (±)	8.164	-	0.857	-
CD (0.05)	16.787	-	1.762	-

4.1.3. Shoot length

The shoot length was recorded at 1 MAP (Table 8). Seedlings under T_8 (22.23 cm) had greater shoot length while T_2 and T_{10} were on par with control. All other treatments inhibited the shoot growth. The treatment T_6 inhibited shoot length the most followed by T_3, T_1, T_5 and T_7. Dilution did not alleviate the inhibitory effects as evident in T_9. The inhibition caused by T_3 and T_6 was 53 and 67 per cent respectively.

4.1.4. Root length

There was notable difference in root length between treatments (Table 8). All the leaf leachates except T_7 and T_8 significantly inhibited the root growth of turmeric. T_4, T_5 and T_{11} caused most severe inhibition of root growth (62 %).

4.1.5. Number of roots

There was significant difference between treatments with respect to number of roots of turmeric seedlings (Table 8). The treatments T_2 and T_8 were on par with control. All other treatments notably reduced the number of roots. The least number of roots was observed under T_6 (4.2) followed by T_{12}, T_4 and T_5. Dilution did not alleviate the inhibitory effect as evident in T_{12}, T_{10} and T_{11}.

Table.8. Effect of tree leaf leachates on shoot length, root length and number of roots of turmeric seedlings

Treatment	Shoot length (cm)	Response index	Root length (cm)	Response index	Number of roots	Response index
T_1 Coconut 1:10	13.43	-0.33	1.36	-0.24	5.63	-0.19
T_2 Cashew 1:10	19.03	-0.05	1.16	-0.35	6.70	-0.04
T_3 Jack 1:10	9.30	-0.53	0.93	-0.48	5.66	-0.19
T_4 Mango 1:10	17.16	-0.14	0.66	-0.62	4.30	-0.38
T_5 Tamarind 1:10	15.66	-0.22	0.66	-0.62	5.00	-0.28
T_6 Teak 1:10	6.43	-0.67	0.86	-0.51	4.20	-0.4
T_7 Coconut 1:15	15.56	-0.22	1.83	0.01	5.43	-0.22
T_8 Cashew 1:15	22.23	0.09	1.70	-0.05	6.36	-0.09
T_9 Jack 1:15	16.20	-0.19	0.86	-0.51	5.66	-0.19
T_{10} Mango 1:15	19.66	-0.002	0.83	-0.53	5.90	-0.15
T_{11} Tamarind 1:15	16.96	-0.15	0.66	-0.62	5.13	-0.26
T_{12} Teak 1:15	13.33	-0.33	0.76	-0.57	4.33	-0.38
T_{13} Control	20.10	0.00	1.80	0.00	7.00	0.00
SEm (±)	0.995	-	0.118	-	0.396	-
CD (0.05)	2.048	-	0.245	-	0.816	-

4.1.6. pH of leachates

The pH of leaf leachates was recorded and is presented in Table 9. All leaf leachates were acidic and tamarind leaf leachate had the lowest pH of 4.5 and 4.6 for 1:10 and 1:15 concentrations respectively.

4.1.7. Osmolality of leachates

The osmolality of the leaf leachates is abridged in Table 9. All the observed values were in the normal range and not significantly greater than tap water and hence not likely to cause any exosmosis.

Table 9. pH, osmolality, phenol and tannin content of leaf leachate of trees

Tree	pH		Osmolality (mmols kg^{-1})		Phenol content (mg 100 g^{-1})		Tannin content (mg 100 g^{-1})	
	1:10	1:15	1:10	1:15	1:10	1:15	1:10	1:15
Coconut	5.2	5.5	287	245	0.48	0.46	66	58
Cashew	5.6	5.6	247	248	1.0	0.28	72	56
Jack	5.3	6.1	239	239	0.52	0.52	66	36
Mango	5.1	5.1	292	271	1.5	1.2	94	84
Tamarind	4.5	4.6	283	260	1.3	1.0	77	60
Teak	5.5	5.4	275	268	2.9	2.6	101.4	100
Tap Water	6.3	6.3	255	255	-	-	-	-

4.1.8. Phenol content of leachates

The phenol content in the leaf leachates is presented in Table 9. At both 1:10 and 1:15 concentrations, the highest phenol content was observed with teak leaf leachate (2.9 and 2.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango.

4.1.9. Tannin content of leachates

The tannin content in the leaf leachates is presented in Table 9. The teak leaf leachate had highest tannin content (101.4 and 100 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango.

4.2. EXPERIMENT II (BIOASSAY II)

The second experiment was undertaken with the objective of assessing the allelopathic influence of leaf extracts on sprouting and early establishment of turmeric (*Curcuma longa* Linn.)

4.2.1. Sprouting

The treatments markedly influenced sprouting (Table 10). The treatments T_2, T_8, T_3 and T_9 were on par with control. The all other leaf extracts reduced the sprouting and among them T_4 caused most severe inhibition (73 %) followed by T_6 (57 %).

4.2.2. Days to sprouting

There was no notable difference between the treatments on days to sprouting (Table 10). Even though not significant, relatively earlier sprouting was observed in T_1 and T_7 while T_6 delayed sprouting.

Table 10. Effect of tree leaf extract on percentage sprouting and days to sprouting of turmeric seed rhizomes

Treatment	Percentage Sprouting (%)	Response index	Days to sprouting	Response index
T_1 Coconut 1:10	50.00	-0.42	8.20	0.15
T_2 Cashew 1:10	80.00	-0.07	10.30	0.06
T_3 Jack 1:10	76.66	-0.11	9.30	0.03
T_4 Mango 1:10	23.33	-0.73	9.86	-0.02
T_5 Tamarind 1:10	56.66	-0.34	9.46	0.02
T_6 Teak 1:10	36.66	-0.57	11.40	-0.15
T_7 Coconut 1:15	66.66	-0.23	8.03	0.16
T_8 Cashew 1:15	86.66	0	10.26	-0.05
T_9 Jack 1:15	76.66	-0.11	9.43	0.02
T_{10} Mango 1:15	63.33	-0.26	9.40	0.02
T_{11} Tamarind 1:15	63.33	-0.26	8.76	0.09
T_{12} Teak 1:15	46.66	-0.46	10.23	-0.05
T_{13} Control	86.66	0.00	9.66	0.00
SEm (±)	7.040	-	1.10	-
CD (0.05)	14.476	-	NS	-

4.2.3. Shoot length

The shoot length was recorded at 1 MAP and is presented in Table 11. All the treatments except T_1, T_8 and T_9 inhibited the shoot growth of turmeric seedlings. The treatment T_6 inhibited shoot growth most severely followed by T_4 and T_5 and the corresponding response indices were 50, 47 and 44 percent inhibition respectively.

Table.11. Effect of tree leaf extract on shoot length, root length and number of roots of turmeric seedlings

Treatment	Shoot length (cm)	Response index	Root length (cm)	Response index	Number of roots	Response index
T_1 Coconut 1:10	19.16	-0.04	0.40	-0.77	4.86	-0.30
T_2 Cashew 1:10	15.03	-0.25	0.50	-0.72	7.86	0.11
T_3 Jack 1:10	13.90	-0.30	0.70	-0.61	7.06	0
T_4 Mango 1:10	10.53	-0.47	1.13	-0.37	11.93	0.41
T_5 Tamarind 1:10	11.16	-0.44	0.66	-0.62	5.30	-0.24
T_6 Teak 1:10	10.00	-0.50	0.66	-0.62	6.36	-0.09
T_7 Coconut 1:15	17.46	-0.13	0.90	-0.50	7.80	0.10
T_8 Cashew 1:15	19.20	-0.04	1.10	-0.38	11.83	0.40
T_9 Jack 1:15	18.26	-0.09	1.06	-0.40	11.60	0.39
T_{10} Mango 1:15	16.86	-0.16	1.23	-0.31	11.96	0.41
T_{11} Tamarind 1:15	14.23	-0.29	0.53	-0.70	9.86	0.29
T_{12} Teak 1:15	17.16	-0.14	0.66	-0.62	6.10	-0.12
T_{13} Control	20.10	0.00	1.80	0.00	7.00	0.00
SEm (±)	1.128	-	0.154	-	0.603	-
CD (0.05)	2.321	-	0.317	-	1.242	-

4.2.4. Root length

The root length was recorded at 1 MAP and presented in Table 11. All the treatments inhibited root growth. The most severe inhibition was caused by T_1 (77%) followed by T_2 (72%) and T_{11} (70 %) which were all on par.

4.2.5. Number of roots

The number of roots was recorded at 1 MAP (Table 11). When compared to control, appreciably higher number of roots was recorded in T_4, T_8, T_9 and T_{10} which were on par, while the least was observed in T_1 and T_5, which were on par. The treatments T_4, T_8, T_9 and T_{10} stimulated the root production by 41, 40, 39 and 41 percent respectively.

4.2.6. pH of extracts

The pH of leaf extracts is presented in Table 12. All the tree leaf extracts were acidic and tamarind leaf extract had lowest pH of 4.5, at both concentrations.

Table 12. pH, osmolality, phenol and tannin content of leaf extracts of trees

Tree	pH		Osmolality (mmol kg^{-1})		Phenol content (mg 100 g^{-1})		Tannin content (mg 100 g^{-1})	
	1:10	1:15	1:10	1:15	1:10	1:15	1:10	1:15
Coconut	5.1	5.1	294	281	3.2	2.0	106.8	106.8
Cashew	5.4	5.4	278	277	1.9	1.3	105	97.4
Jack	5.6	5.5	277	276	1.8	1.2	105.6	96
Mango	5.2	5.2	279	287	6.0	4.6	107	104.2
Tamarind	4.5	4.5	283	275	3.0	1.4	105.8	94
Teak	5.1	5.3	288	281	4.0	1.8	106.2	105.6
Tap water	6.3	6.3	255	255	-	-	-	-

4.2.7. Osmolality of extracts

The osmolality of the leaf extracts is abridged in Table 12. All the observed values were in the normal range and not significantly greater than tap water and hence, not likley to cause any exosmosis.

4.2.8. Phenol content of leaf extracts

The phenol content in the leaf extracts is presented in Table 12. At both 1:10 and 1:15 concentration, the highest phenol content was observed with mango leaf extracts (6.0 and 4.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively).

4.2.9. Tannin content of leaf extracts

The tannin content in the leaf extracts is presented in Table 12. The teak leaf extract had highest tannin content (106.2 and 105.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango.

4.3. EXPERIMENT III (POT CULTURE I)

The third experiment was undertaken with the objective of assessing the effect of fresh tree leaf leachate on growth and yield attributes of turmeric (*Curcuma longa* Linn.).

4.3.1. Growth characters

4.3.1.1. Plant height at bimonthly interval from 2 MAP

The data on plant height at 2, 4 and 6 MAP are presented in Table 13. The treatment T_4 had plants with lesser plant height at 2 MAP but further dilution removed the inhibition. Plants under T_1, T_7 and T_{12} were taller at 4 MAP. The plant height was greater under T_1 and T_7 at 6 MAP also.

4.3.1.2. Number of tillers

The number of tillers recorded at 2, 4 and 6 MAP is presented in Table 13. There was no significant difference between the treatments.

4.3.1.3. Number of leaves

The data on number of leaves of turmeric were recorded at 2, 4 and 6 MAP (Table 13). There was no appreciable difference between the number of leaves at 2 MAP. The treatment T_6 had lesser number of leaves at 4 MAP whereas all other treatments were on par with control. At 6 MAP, T_6 and T_{11} had lesser number of leaves. At 4 MAP and 6 MAP, T_6 inhibited leaf production.

Table 13. Effect of tree leaf leachate on plant height, number of tillers and number of leaves of turmeric

Treatment	Plant height (cm)			Number of tillers			Number of leaves		
	2 MAP	4 MAP	6 MAP	2 MAP	4 MAP	6 MAP	2 MAP	4 MAP	6 MAP
T_1 Coconut 1:10	39.86	112.96	142.00	0	0.66	2.00	6.10	8.53	10.06
T_2 Cashew 1:10	38.40	86.06	110.93	0	1.00	2.33	5.96	10.20	11.53
T_3 Jack 1:10	38.63	88.06	124.86	0	1.43	1.66	5.50	10.73	11.73
T_4 Mango 1:10	32.83	97.43	119.93	0	0.33	1.33	5.96	8.53	10.00
T_5 Tamarind 1:10	44.93	89.86	118.93	0	1.00	1.66	5.53	8.20	9.86
T_6 Teak 1:10	37.40	93.63	120.53	0	0.66	1.33	5.73	7.63	9.20
T_7 Coconut 1:15	41.30	123.66	138.70	0	1.16	2.33	5.73	10.50	12.07
T_8 Cashew 1:15	49.10	92.96	119.66	0	1.50	2.33	5.86	11.73	12.96
T_9 Jack 1:15	35.26	101.16	113.96	0	1.66	2.66	6.10	10.40	11.86
T_{10} Mango 1:15	45.96	95.73	121.03	0	1.66	2.00	6.20	10.73	12.26
T_{11} Tamarind 1:15	41.43	93.53	118.03	0	1.00	1.33	5.63	8.20	9.73
T_{12} Teak 1:15	42.40	105.63	123.26	0	1.50	1.66	5.63	8.86	10.86
T_{13} Control	42.53	92.73	119.80	0	2.00	2.33	6.10	9.96	11.83
SEm (±)	4.002	6.238	5.075	-	0.577	0.489	0.309	0.992	1.017
CD (0.05)	8.228	12.827	10.436	-	NS	NS	NS	2.041	2.092

MAP: Month After Planting

4.3.2. Rhizome characters

4.3.2.1. Rhizome spread

The rhizome spread of turmeric recorded at the time of harvest is presented in Table 14. There was no remarkable difference between the treatments. However, T_8 recorded highest rhizome spread followed by T_7 and T_1. The least spread value was in T_{13}.

4.3.2.2. Rhizome thickness

The rhizome thickness of turmeric was recorded at the time of harvest (Table 14). There was no notable difference between the treatments.

Table 14. Effect of tree leaf leachate on rhizome characters of turmeric

Treatment	Rhizome spread (cm)	Rhizome thickness (cm)
T_1 Coconut 1:10	17.33	2.36
T_2 Cashew 1:10	14.66	2.90
T_3 Jack 1:10	16.76	2.50
T_4 Mango 1:10	14.03	2.46
T_5 Tamarind 1:10	15.93	2.86
T_6 Teak 1:10	15.53	3.00
T_7 Coconut 1:15	17.60	2.33
T_8 Cashew 1:15	17.76	2.90
T_9 Jack 1:15	14.93	3.10
T_{10} Mango 1:15	16.26	2.53
T_{11} Tamarind 1:15	16.66	2.86
T_{12} Teak 1:15	16.26	2.96
T_{13} Control	13.96	2.76
SEm (±)	1.421	0.307
CD (0.05)	NS	NS

4.3.3. Root characters

4.3.3.1. Root length

The data on root length is presented in Table 15. There was no significant difference between the treatments. Even though, not remarkably different, T_1 recorded the highest root length while lowest value was in T_5.

Table 15. Effect of tree leaf leachate on root characteristics of turmeric

Treatment	Root length (cm)	Root spread (cm)	Root weight per plant (g)	Root volume per plant (cm^3)
T_1 Coconut 1:10	34.66	23.23	1.43	10.60
T_2 Cashew 1:10	28.66	22.60	1.63	14.20
T_3 Jack 1:10	26.93	22.26	1.43	10.53
T_4 Mango 1:10	28.13	24.83	1.33	9.83
T_5 Tamarind 1:10	26.43	19.06	1.07	7.10
T_6 Teak 1:10	27.83	16.03	0.86	9.83
T_7 Coconut 1:15	32.83	24.60	1.60	15.43
T_8 Cashew 1:15	29.20	23.86	1.50	13.30
T_9 Jack 1:15	32.16	19.93	1.53	12.96
T_{10} Mango 1:15	28.63	26.06	1.86	16.53
T_{11} Tamarind 1:15	28.40	21.40	1.46	9.43
T_{12} Teak 1:15	27.96	25.73	1.03	8.53
T_{13} Control	29.96	21.90	1.66	11.16
SEm (±)	3.295	1.621	0.209	1.684
CD (0.05)	NS	3.333	0.430	3.464

4.3.3.2. Root spread

The root spread of turmeric was recorded at the time of harvest (Table 15). The treatment T_6 had lesser root spread while T_{10} (26.06 cm) and T_{12} (25.73 cm) had appreciably greater root spread when compared to control.

4.3.3.3. Root weight per plant

The treatments had notable influence on root weight of turmeric (Table 15). The treatments T_6, T_{12} and T_5 had lesser root weight while all other treatments were on par with control.

4.3.3.4. Root volume per plant

The data on root volume of turmeric recorded at the time of harvest is presented in Table 15. Plants under T_5 had appreciably lesser root volume (7.10 cm^3) while those under T_7 (15.43 cm^3) and T_{10} (16.53 cm^3) had more.

4.3.4. Physiological parameters

4.3.4.1. SPAD reading

The SPAD value was recorded and is presented in Table 16. There was no striking difference between the treatments.

4.3.4.2. Canopy temperature

There was no considerable difference between the treatments with respect to canopy temperature.

4.3.4.3. Stomatal conductance

The data on stomatal conductance of turmeric was recorded and is presented in Table 16. The highest stomatal conductance was noted in T_2 and T_{12} which were on par. The treatments T_4, T_5 and T_6 were on par with control.

Table 16. Effect of tree leaf leachate on physiological parameters of turmeric

Treatment	SPAD reading	Canopy temperature (^{0}C)	Stomatal conductance (milli mol m^{-2} s^{-1})
T_1 Coconut 1:10	41.03	30.40	153.40
T_2 Cashew 1:10	43.73	30.23	190.06
T_3 Jack 1:10	41.96	30.26	119.20
T_4 Mango 1:10	40.80	30.23	97.36
T_5 Tamarind 1:10	41.00	30.33	78.03
T_6 Teak 1:10	42.16	30.46	49.00
T_7 Coconut 1:15	40.66	30.50	158.30
T_8 Cashew 1:15	40.40	30.26	165.96
T_9 Jack 1:15	41.53	30.13	148.93
T_{10} Mango 1:15	40.03	30.43	123.63
T_{11} Tamarind 1:15	43.06	30.26	142.00
T_{12} Teak 1:15	43.16	30.76	213.33
T_{13} Control	42.63	29.50	66.56
SEm (±)	1.472	0.301	22.595
CD (0.05)	NS	NS	46.457

4.3.5. Yield and Yield components

4.3.5.1. Rhizome yield

The treatments appreciably influenced rhizome yield of turmeric (Table 17). The treatments T_1, T_7, $T_{3,}$ T_8 and T_5 resulted in remarkably higher yield of turmeric whereas T_4 and T_6 had lesser yield (107.46 and 113.16 g $plant^{-1}$ respectively). All other treatments were on par with control.

4.3.5.2. Top yield

The data on top yield of turmeric is presented in Table 17. The treatments T_2, T_8 and T_7 had more top yield and they were on par. All other treatments were on par with control.

4.3.5.3. Dry turmeric

There was no considerable difference in dry turmeric yield between the treatments (Table 17).

Table 17. Effect of treatments on rhizome yield, top yield and dry turmeric

Treatment	Rhizome yield per plant (g)	Top yield per plant (g)	Dry turmeric (recovery %)
T_1 Coconut 1:10	179.30	16.76	17.66
T_2 Cashew 1:10	132.60	20.50	17.26
T_3 Jack 1:10	155.33	14.83	17.03
T_4 Mango 1:10	107.46	18.03	17.40
T_5 Tamarind 1:10	139.30	16.83	18.03
T_6 Teak 1:10	113.16	18.10	18.30
T_7 Coconut 1:15	175.40	20.00	18.03
T_8 Cashew 1:15	139.63	22.03	17.90
T_9 Jack 1:15	127.10	16.66	17.10
T_{10} Mango 1:15	131.40	18.06	18.26
T_{11} Tamarind 1:15	136.70	17.50	18.40
T_{12} Teak 1:15	135.80	18.50	18.53
T_{13} Control	126.00	16.50	18.70
SEm (±)	5.726	1.380	0.551
CD (0.05)	11.774	2.839	NS

4.4. EXPERIMENT IV (POT CULTURE II)

The fourth experiment was undertaken with the objective of assessing the effect of fresh tree leaf loppings on growth and yield attributes of turmeric (*Curcuma longa* Linn.).

4.4.1. Growth characters

4.4.1.1. Plant height at bimonthly interval from 2 MAP

The data on plant height at 2, 4 and 6 MAP are presented in Table 18. Plants under T_1 had markedly lesser plant height at 2MAP while all other treatments were on par with control. Plant height was appreciably greater under T_2 and T_5 whereas it was lesser under T_3 at 4 MAP. At 6 MAP, T_6 had notably taller plants when compared to the control.

Table 18. Effect of tree leaf loppings on plant height, number of tillers and number of leaves of turmeric

Treatment	Plant height (cm)			Number of tillers			Number of leaves		
	2 MAP	4 MAP	6 MAP	2 MAP	4 MAP	6 MAP	2 MAP	4 MAP	6 MAP
T_1 Coconut	29.73	93.70	126.00	0	0.66	2.50	3.83	8.66	13.66
T_2 Cashew	44.46	121.83	133.00	0	0.33	2.16	5.33	8.50	15.66
T_3 Jack	48.30	86.30	141.66	0	0.66	2.33	5.50	8.50	17.00
T_4 Mango	40.33	99.66	133.66	0	0.66	2.00	5.83	8.33	13.50
T_5 Tamarind	39.13	112.70	138.83	0	0.00	1.83	5.33	8.66	15.66
T_6 Teak	51.23	86.66	148.33	0	0.00	3.16	6.00	9.33	13.66
T_7 Control	45.80	97.16	133.83	0	1.33	2.00	5.50	8.33	17.66
SEm (±)	4.305	4.900	5.795	-	0.398	0.745	0.642	0.701	0.995
CD (0.05)	9.235	10.510	12.431	-	NS	NS	NS	NS	2.136

MAP: Month After Planting

4.4.1.2. Number of tillers

The data on number of tillers at 2, 4 and 6 MAP are presented in Table 18. There was no notable difference observed between the treatments. However, the least number of tillers was observed in T_5.

4.4.1.3. Number of leaves

The data on number of leaves at 2, 4 and 6 MAP are presented in Table 18. There was no considerable difference between the treatments at 2 and 4 MAP. The treatments T_1, T_4 and T_6 had lesser number of leaves at 6 MAP while all other treatments were on par with control.

4.4.2. Rhizome characters

4.4.2.1. Rhizome spread

There was no notable difference observed in rhizome spread between the treatments (Table 19). Though not significant, highest rhizome spread was observed in T_6 and the least in T_4.

Table 19. Effect of tree leaf loppings on rhizome characters

Treatment	Rhizome spread (cm)	Rhizome thickness (cm)
T_1 Coconut	24.46	4.06
T_2 Cashew	25.63	4.00
T_3 Jack	24.40	3.96
T_4 Mango	23.50	4.03
T_5 Tamarind	24.50	3.93
T_6 Teak	26.06	4.23
T_7 Control	23.70	3.86
SEm (±)	1.578	0.157
CD (0.05)	NS	NS

4.4.2.2. Rhizome thickness

The data on rhizome thickness recorded at the time of harvest is presented in Table 19. There was no remarkable difference between the treatments.

4.4.3. Root characters

4.4.3.1. Root length

The treatments influenced the root length of turmeric remarkably (Table 20). The treatments T_2 and T_6 were on par with control while in all other treatments root length was less.

Table 20. Effect of tree leaf loppings on root characterstics of turmeric

Treatment	Root length (cm)	Root spread (cm)	Root weight per plant (g)	Root volume per plant (cm^3)
T_1 Coconut	27.90	27.80	3.83	30.33
T_2 Cashew	42.96	25.40	3.30	24.66
T_3 Jack	30.16	23.30	2.96	24.83
T_4 Mango	35.80	24.53	2.16	21.50
T_5 Tamarind	36.96	30.86	2.83	28.33
T_6 Teak	41.40	29.80	2.23	23.66
T_7 Control	40.10	27.66	3.03	24.33
SEm (±)	1.336	1.465	0.258	1.927
CD (0.05)	2.868	3.143	0.554	4.134

4.4.3.2. Root spread

There was notable difference among the treatments with respect to root spread (Table 20). Plants under T_5 had greater root spread (30.86 cm) whereas T_3 had lesser root spread (23.30 cm). All other treatments were on par with control.

4.4.3.3. Root weight per plant

The treatments greatly influenced the root weight (Table 20). The treatments T_2, T_3 and T_5 were on par with control. Substantially more root weight was recorded in T_1, it was on par with T_2 while it was less in T_4 and T_6 which were on par.

4.4.3.4. Root volume per plant

The data on root volume recorded at the time of harvest is presented in Table 20. The treatment T_1 recorded more root volume (30.33 cm^3). All other treatments were on par with control.

4.4.4. Physiological parameters

4.4.4.1. SPAD reading

There was no notable difference in SPAD values between the treatments.

Table 21. Effect of tree leaf loppings on physiological parameters of turmeric

Treatment	SPAD reading	Canopy temperature (^{0}C)	Stomatal conductance (milli mol m^{-2} s^{-1})
T_1 Coconut	42.06	30.66	43.13
T_2 Cashew	42.46	30.53	31.86
T_3 Jack	41.93	30.76	36.56
T_4 Mango	41.76	30.30	72.93
T_5 Tamarind	45.83	30.13	114.90
T_6 Teak	43.73	30.13	49.96
T_7 Control	47.96	29.73	144.20
SEm (±)	2.928	0.278	10.875
CD (0.05)	NS	0.596	23.328

4.4.4.2. Canopy temperature

There was variation in canopy temperature among the treatments (Table 21). Highest canopy temperature was recorded in T_1, T_2 and T_3 which were on par. All other treatments were on par with control.

4.4.4.3. Stomatal conductance

The data on stomatal conductance is presented in Table 21. Lower stomatal conductance was recorded in T_1, T_2 and T_3 and they were on par. Stomatal conductance was considerably higher in T_7 followed by T_5.

4.4.5. Yield and Yield components

4.4.5.1. Rhizome yield

The treatments greatly influenced the rhizome yield of turmeric (Table 22). The treatments T_1 and T_5 were on par with control. Yield was appreciably higher under T_2 (660.23 g $plant^{-1}$), T_3 (557.73 g $plant^{-1}$) and T_6 (565.00 g $plant^{-1}$) whereas it was reasonably less in T_4 (346.73 g $plant^{-1}$).

Table 22. Effect of tree leaf loppings on rhizome yield, top yield and dry turmeric

Treatment	Rhizome yield per plant (g)	Top yield per plant (g)	Dry turmeric (recovery %)
T_1 Coconut	469.43	59.50	14.66
T_2 Cashew	660.23	68.83	14.16
T_3 Jack	557.73	60.00	14.83
T_4 Mango	346.73	60.50	14.50
T_5 Tamarind	449.00	65.00	15.70
T_6 Teak	565.00	62.33	14.66
T_7 Control	463.73	61.83	15.00
SEm (±)	16.203	4.038	1.025
CD (0.05)	34.75	NS	NS

4.4.5.2. Top yield

There was no notable difference observed in top yield between the treatments. Though not significant, T_2 resulted in relatively higher top yield.

4.4.5.3. Dry turmeric

The data on dry turmeric (recovery percentage) is presented in Table 22. There was no considerable difference in recovery percentage between the treatments.

4.4.6. **Nutrient (major) content of the fresh tree leaves**

The content of major nutrients (N, P and K) is abridged in Table 23. Nitrogen content was relatively higher in mango leaf. Phosphorus content was relatively more in teak leaf while potassium was greater in jack leaf.

Table 23. Nitrogen, phosphorus and potassium content of fresh tree leaves

Tree	Nutrient content (%)		
	N	P	K
Coconut	1.12	0.095	1.88
Cashew	1.12	0.113	2.46
Jack	1.12	0.092	2.80
Mango	1.68	0.113	1.20
Tamarind	1.12	0.103	1.38
Teak	1.12	0.167	2.28

Discussion

5. DISCUSSION

An investigation was conducted to assess the allelopathic effect of certain trees commonly planted in the homesteads of Kerala on sprouting, growth and yield of turmeric. The results obtained in the four experiments are discussed in this chapter.

5.1. EXPERIMENT I (BIOASSAY I)

Sprouting of seed rhizomes of turmeric was exceptionally affected by leaf leachates of all trees except coconut (1:10 and 1:15) and cashew (1:15). Jack, tamarind and teak at both concentrations (1:10 and 1:15) severely inhibited sprouting whereas cashew and mango at higher concentration (1:10) alone caused inhibition. The inhibitory effects of cashew and mango were alleviated with dilution. Tamarind leaf leachate was most inhibitory and dilution failed to alleviate the inhibition. With regard to the time taken for sprouting coconut, cashew and mango leaf leachate at lower concentration (1:15) caused earlier germination of seed rhizomes. The period for sprouting under all other tree leachates was on par with control.

With respect to growth of seedlings, cashew leaf leachates at lower concentration promoted shoot growth while cashew and mango at higher concentration were on par with control. All other tree leaf leachates remarkably inhibited the shoot growth. At higher concentration, teak leaf leachate caused maximum inhibition followed by jack, coconut and tamarind. Dilution did not alleviate the inhibitory effects. The inhibition was caused by jack and teak was as high as 53 and 67 per cent respectively. The root growth of turmeric was notably inhibited by all the tree leaf leachates except coconut and cashew at lower concentration (Fig.2). Mango at higher concentration and tamarind at both concentrations caused most severe suppression of root growth (62 %). The number of roots produced was appreciably affected by leaf leachates of all trees

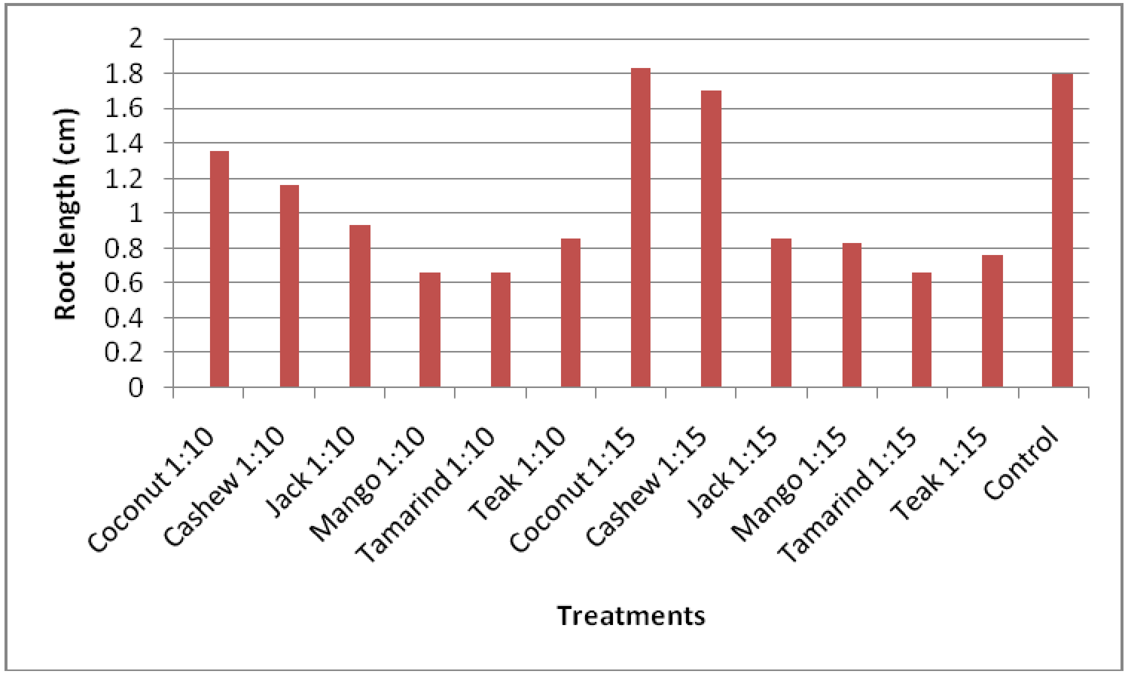

Fig. 2. Effect of tree leaf leachates on root growth of turmeric seedlings

except cashew. The least number of roots was observed under teak, irrespective of the concentration. The next most inhibitory were mango and tamarind at higher concentration and the effect could not be alleviated with dilution.

From this experiment it can be inferred that the leaf leachates of trees have varying allelopathic effect on sprouting and initial growth of turmeric. The degree of inhibition of root growth was much more pronounced when compared to sprouting and shoot growth. Dilution alleviated the inhibition in several instances. All tree leaf leachates were acidic, and tamarind leaf leachate had the lowest pH. However, the observed inhibitory effects, especially that caused by tamarind, cannot be attributed to the acidity as the pH of the leachates were adjusted to the range between 6-7 by adding either alkali (KOH) or acid (HCl) before applying. Osmolality values were also in the normal range and not considerably greater than tap water and hence, the observed effects are not due to exosmosis. Therefore, it is logical to conclude that the observed effects are due to phytochemicals present in the leaf leachates. Mango, teak and tamarind leaf leachates were more or less consistent in their greater inhibitory effects on sprouting and growth. This was probably due to the relatively higher phenol and tannin content in the leaf leachates as evidenced from the estimations made under this study (Fig.3 and Fig.4).

Duke (1992) reported the presence of alanine, alpha-pinene, beta-pinene, gallic acid, gallotannic acid, isoleucine, isomangiferolic acid, kaempferol, lauric acid, limonene flower, linoleic acid, linolenic acid, mangiferic acid, mangiferine, mangiferol, mangiferolic acid, mangiferonic acid, myristic acid, p-coumaric acid, palmitic acid, quercetin, tannin and threonine are present in *Mangifera indica*. Alpha terpineol, cinnamaldehyde, ethyl cinnamate, galacturonic acid, geranial essential oil, geraniol essential oil, limonene, linoleic acid, myristic acid, oleic acid, palmitic acid, pantothenic acid, phenol, pipecolinic acid, tannin and tartaric-acid is found in *Tamarindus indica*. *Tectona grandis* contains betulin and betulinic-acid. These phytochemicals may be present in varying amounts in the

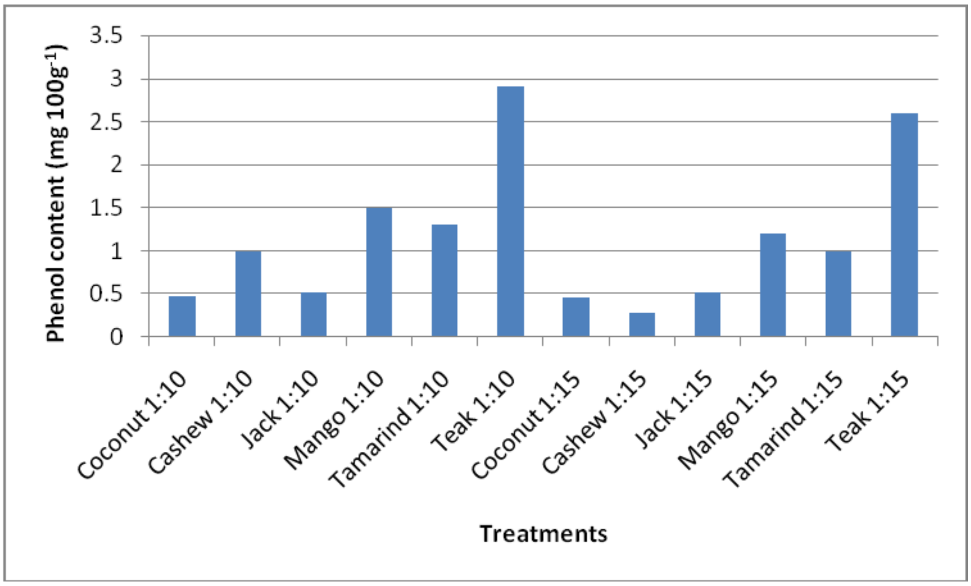

Fig.3. Phenol content of tree leaf leachates

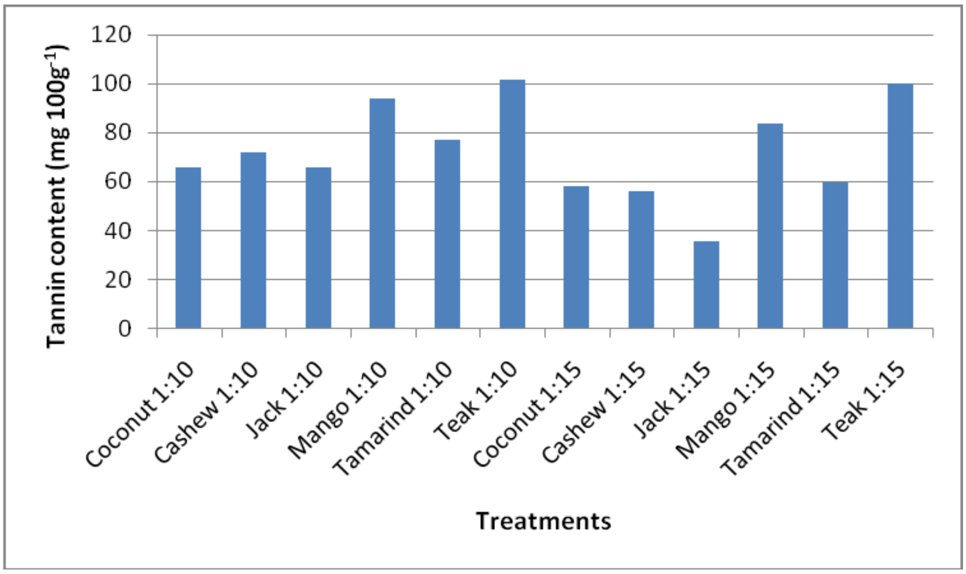

Fig.4. Tannin content of tree leaf leachates

tree leaf leachates. At this juncture, it is not possible to state which of these chemicals might have caused the inhibitory effect.

Similar reports of the inhibitory effects of these trees on other crops are available. The inhibitory effect of teak leaf leachate on tomato, aubergine and chilli seed germination was reported by Krishna *et al*. (2003). Jacob *et al*. (2007a) also reported the inhibitory effects of leaf leachate of *Tectona grandis* on seed germination of cowpea. Mango showed strong inhibitory effect on germination of brinjal. Krishna *et al*. (2005) reported that mango inhibited germination of kasthuri bendi (*Abelmoschus moschatus*) and sanka pushpa (*Clitoria ternatea*). Konar and Kushari (1989) also reported that the treatment of rhizomes of *Costus speciosus* with leaf leachates of mango and other trees shortened the sprouting time. Jacob and Nair (1998) and Jacob (2007a) have reported the inhibition of plumule growth in rice and cowpea by tamarind leachates.

5.2. EXPERIMENT II (BIOASSAY II)

Leaf extracts of all the trees except cashew and jack remarkably reduced the sprouting of rhizomes. Higher concentration of mango caused most severe inhibition (73%) followed by teak (1:10). However, days to sprouting was not influenced greatly by the leaf extracts. Yet though not remarkable, relatively earlier sprouting was observed when subjected to leaf extracts of coconut.

Shoot growth of turmeric seedlings was inhibited by the leaf extracts of all trees except coconut (1:10), cashew (1:15) and jack (1:15). The leaf extract of teak (1:10) suppressed shoot growth most severely followed by mango (1:10) and tamarind (1:10) and the extent of inhibition was 50, 47 and 44 percent respectively. Root growth was inhibited by the leaf extracts of all trees (Fig.5). Coconut at higher concentration caused the greatest inhibition (77%). The inhibition by cashew, tamarind and teak was also considerable. Notably higher number of roots was recorded with mango leaf extracts at both concentrations and

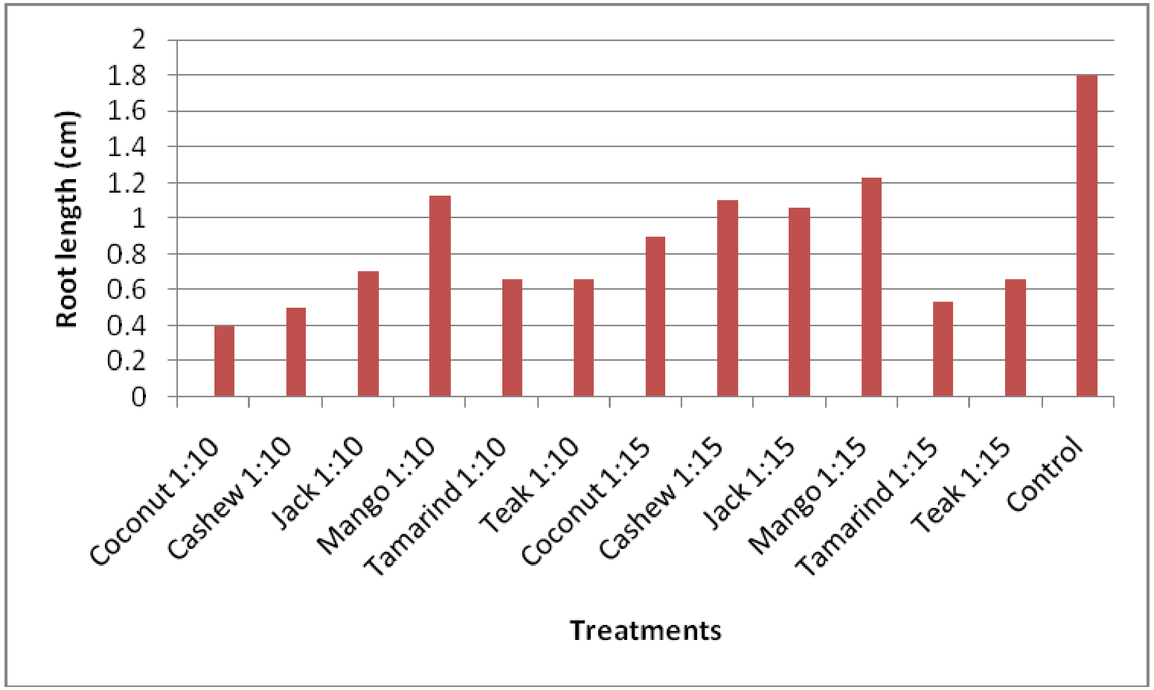

Fig. 5.Effect of tree leaf extracts on root growth of turmeric seedlings

cashew and jack at lower concentration. Subjecting the rhizomes to higher concentration of leaf extracts of coconut and tamarind inhibited root production the most.

From this study it can be concluded that the allelopathic effects on sprouting and initial growth of rhizomes varied with trees species. As in the case of leaf leachates, the magnitude of inhibition of root growth was much more when compared to sprouting. Dilution was effective in certain cases in alleviating allelopathic inhibition. In general, the degree of inhibition by leaf extracts was relatively higher than that by leaf leachates. Here also, the inhibitory effects of tamarind extracts cannot be attributed to acidity as the pH of the extracts were adjusted to a neutral range before application. Osmolality values were also not in a range to cause exosmosis, hence the observed inhibitory effects can be confirmed due to allelochemicals only. Leaf extracts were prepared by blending the tree leaves with water. Hence, as the leaves are subjected to crushing, the nature and number of the phytochemicals present in the extract will be entirely different from that in leachate. At both 1:10 and 1:15 concentration, the highest phenol content was observed in mango leaf extracts (6.0 and 4.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively). The teak leaf extract had highest tannin content (106.2 and 105.6 mg $100g^{-1}$ at 1:10 and 1:15 concentrations respectively) followed by mango. Higher phenol and tannin content might be responsible for the inhibitory effects of mango and teak (Fig.6 and Fig.7). Coconut leaf extract also had appreciable quantity of phenols and tannin. The phenol content, in particular, was more in leaf extract than in leachate. This may be a reason for the inhibitory effects of coconut leaf extracts, especially on root growth.

A large number of phytochemicals may be present in the leaf extracts, some of which may be responsible for inhibition and certain for stimulation. Jacob *et al.* (2007b) reported that fresh leaf extract of cashew contains terpenoids, triterpenes and saponins, jack contains flavonoids and terpenoids, mango contains

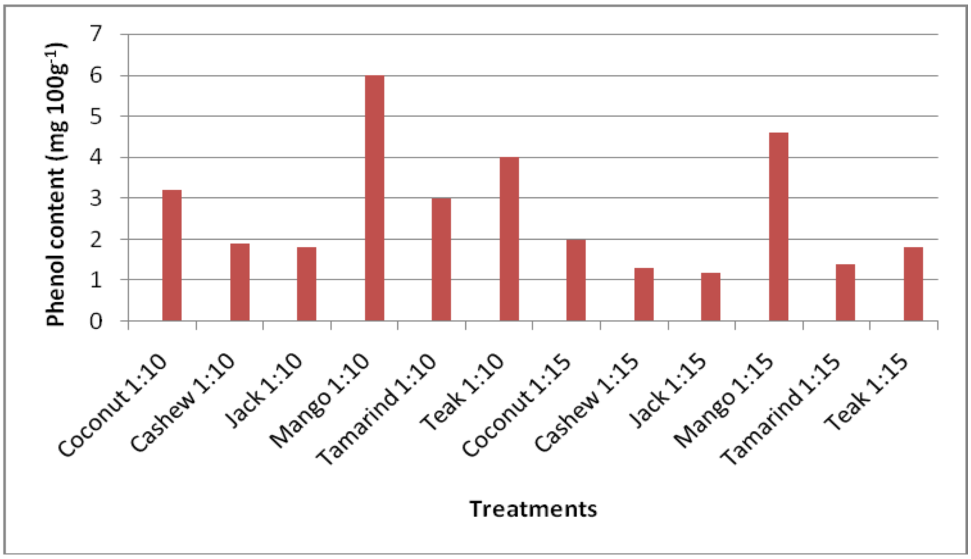

Fig.6. Phenol content of leaf extracts

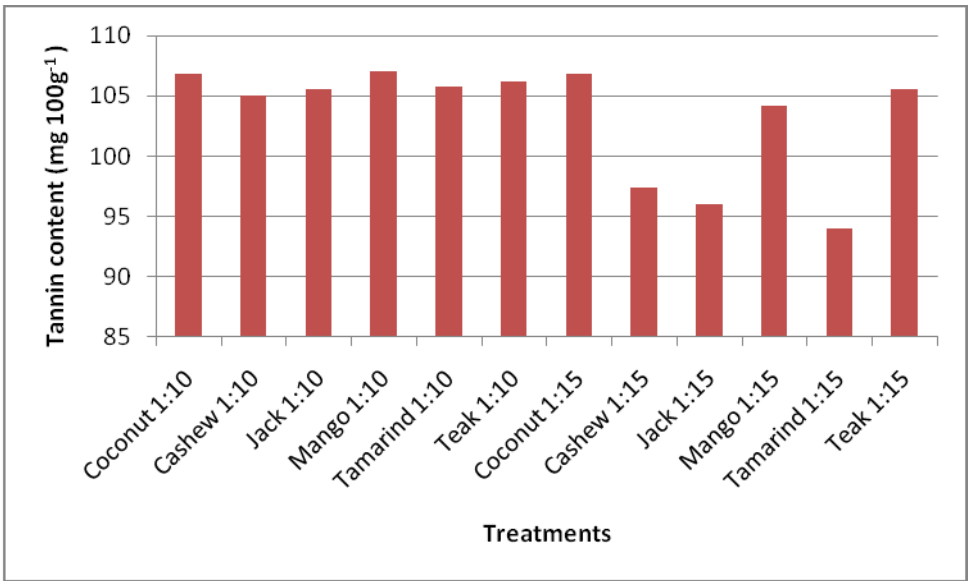

Fig.7. Tannin content of leaf extracts

terpenoids and triterpenes, tamarind contains flavonoids and terpenoids and teak contains triterpenes.

While certain processes in the plant may be stimulated, some may be inhibited by these chemicals. This could be a reason for the simultaneous stimulatory and inhibitory effects brought about by the same tree leaf extract as observed in this study. Similar reports of both stimulatory as well as inhibitory effect by aqueous fresh leaf extracts of mango on germination, shoot and root growth in receptor plants are available (Sahoo *et al*., 2010).

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5.3. EXPERIMENT III (POT CULTURE I)

Plant height was less at 2 MAP in plants treated with the leaf leachate of mango (1:10), but further dilution removed the inhibition. Plants under coconut (both concentrations) and teak at the lower concentration were taller at 4 MAP. Coconut leaf leachate, at both concentrations, resulted in greater plant height at 6 MAP also. There was no appreciable difference between the treatments at 2, 4 and 6 MAP with respect to number of tillers. Leaf production was considerably affected at 4 and 6 MAP when sprayed with teak leaf leachate at higher concentration. At 6 MAP, tamarind leaf leachate at a lower concentration also resulted in lesser leaves.

With respect to rhizome characters, rhizome spread was not conspicuously affected by the tree leaf leachates. However, though not significant, cashew at a lower concentration and coconut leaf leachate at both concentrations resulted in greater rhizome spread. The treatments did not cause any remarkable difference in rhizome thickness of turmeric.

Root length was not profoundly influenced by tree leaf leachates. Though not significant, application of coconut leaf leachate resulted in the longer roots. Plants subjected to the leachate of teak (1:10) had exceptionally lesser root spread, while mango and teak leaf leachates at a lower concentration resulted in considerably greater root spread.

Root weight was extremely less in plants treated with leaf leachate of teak (at both concentrations) and tamarind at higher concentration (1:10). Root volume was appreciably less when subjected to higher concentration of tamarind leaf leachate (1:10). However, root volume was notably more in plants treated with lower concentration of coconut and mango leaf leachate.

There was no difference between the treatments with respect to SPAD values and canopy temperature. The highest stomatal conductance was noted in cashew (1:10) and teak (1:15) which were on par.

Rhizome yield was remarkably less when subjected to higher concentrations of mango and teak leaf leachate. However, leachates of coconut (1:10 and 1:15), jack (1:10), cashew (1:15) and tamarind (1:10) resulted in profoundly higher rhizome yield (Fig.8). Applying leaf leachates of cashew (1:10 and 1:15) and coconut (1:15) resulted in significantly more top yield and they were on par. Dry turmeric (recovery percentage) was on par in all treatments.

The reduced yield in plants subjected to leaf leachate of teak and mango may be due to the higher phenol and tannin content as evidenced through the estimations made as part of this study. Inhibitory effects of phenolics include changes in membrane permeability, inhibition of nutrient uptake, inhibition of cell division and elongation, adverse effect on plant photosynthesis and respiration, effects on various enzyme functions, synthesis of plant endogenous hormones and protein synthesis (Li *et al*., 2010). The inhibition of root spread and root weight may be another reason for the yield reduction by teak. Macias *et al*. (2010) isolated a new compound, abeograndinoic acid from teak, which has an unusual carbon skeleton. A further 21 known terpenoids including four sesquiterpenoids, eight diterpenes and nine triterpenes were also isolated. Though not notable,

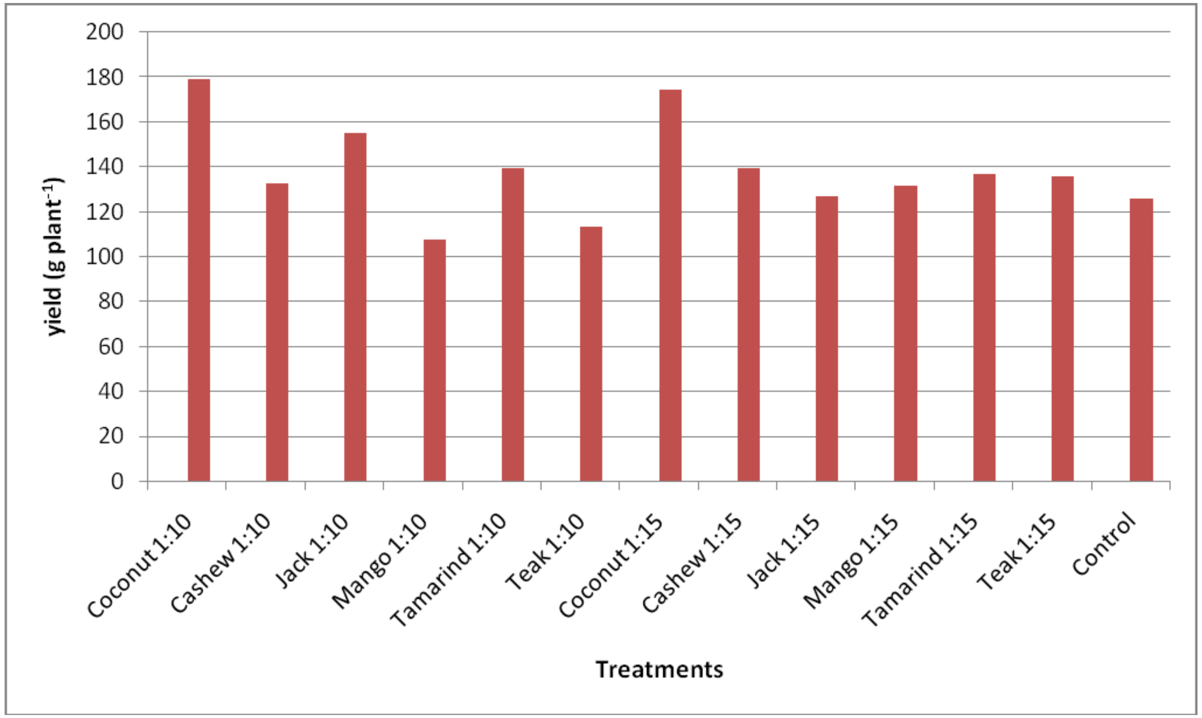

Fig.8. Effect of tree leaf leachates on yield of turmeric

rhizome spread and thickness was relatively less in plants treated with mango leaf leachates.

The acidity of the leachates was not an inhibitory factor, as the yield in plants treated with tamarind leaf leachate was significantly higher than the control. Cashew leaf leachate at lower concentration resulted in better leaf production at 4 and 6 MAP and significantly higher rhizome yield. Certain phytochemicals reported in cashew plant include alpha-linolenic acid, anacardic acid, anacardol, beta sitosterol, capric acid, caprylic acid, cardanol, cardol, gadoleic acid, gallic acid, lauric acid, limonene, linoleic acid, naringenin, palmitic acid, squalene, tannin, and threonine (Duke, 1992). Any of these chemicals might have caused the stimulatory effect.

A notable fact is that coconut leaf leachate promoted plant growth appreciably as evidenced from the remarkably greater plant height, relatively more number of leaves, root length, root spread, root volume, top yield and consequently higher yield, especially at lower concentration. The stimulatory allelopathic effects of coconut leaf leachate (5 and 10 %) on beneficial microbes of coconut rhizosphere have been reported (Gopal *et al*., 2006). Jacob *et al*. (2011) reported that when compared to several other trees, shoot growth was significantly higher and maximum in pepper plants trailed on coconut. The stimulatory effect of coconut leaf leachate is an aspect that needs to be investigated further and the possibility of exploiting this at field level should be explored.

5.4. EXPERIMENT IV (POT CULTURE II)

Plant height was remarkably more when mulched with cashew and tamarind leaves, whereas it was lesser under jack at 4 MAP. At 6 MAP, plants mulched with teak leaves were considerably taller when compared to the control. There was no difference between the treatments with regard to tillers. At 6 MAP, the number of leaves was strikingly less in plants mulched with leaves of coconut, mango and teak.

There was no appreciable difference in rhizome spread between the treatments. Though not remarkable, greatest rhizome spread was observed when mulched with teak leaves and the least with mango. Rhizome thickness was not influenced by the treatments.

Root length was considerably less in plants mulched with leaves of coconut, jack, mango and tamarind. Plants mulched with tamarind leaves had profoundly greater root spread whereas jack leaves resulted in lesser root spread. Root weight was remarkably more when mulched with coconut leaves while it was less under mango and teak. Mulching with coconut leaves resulted in significantly higher root volume.

Highest canopy temperature was recorded in plants mulched with coconut, cashew and jack leaves which were on par. All other treatments were on par with control. Conspicuously lower stomatal conductance was recorded in coconut, cashew and jack and they were on par.

Rhizome yield was exceptionally higher when mulched with cashew (660 g plant^{-1}), jack (557 g plant^{-1}) and teak (565 g plant^{-1}) leaves. However, mulching with mango leaves resulted in strikingly lesser yield (346.73 g plant^{-1}) (Fig.9). There was no significant difference in top yield and dry turmeric (recovery percentage).

Nitrogen content was slightly higher in mango leaf, phosphorus in teak and potassium in jack. However, the differences in nutrient content were only marginal and not significant to cause any difference in yield. Moreover, the quantum of leaves applied as much per grow bag was also very less (112 g plant^{-1}). Soil moisture content and soil temperature was not measured in this study. The

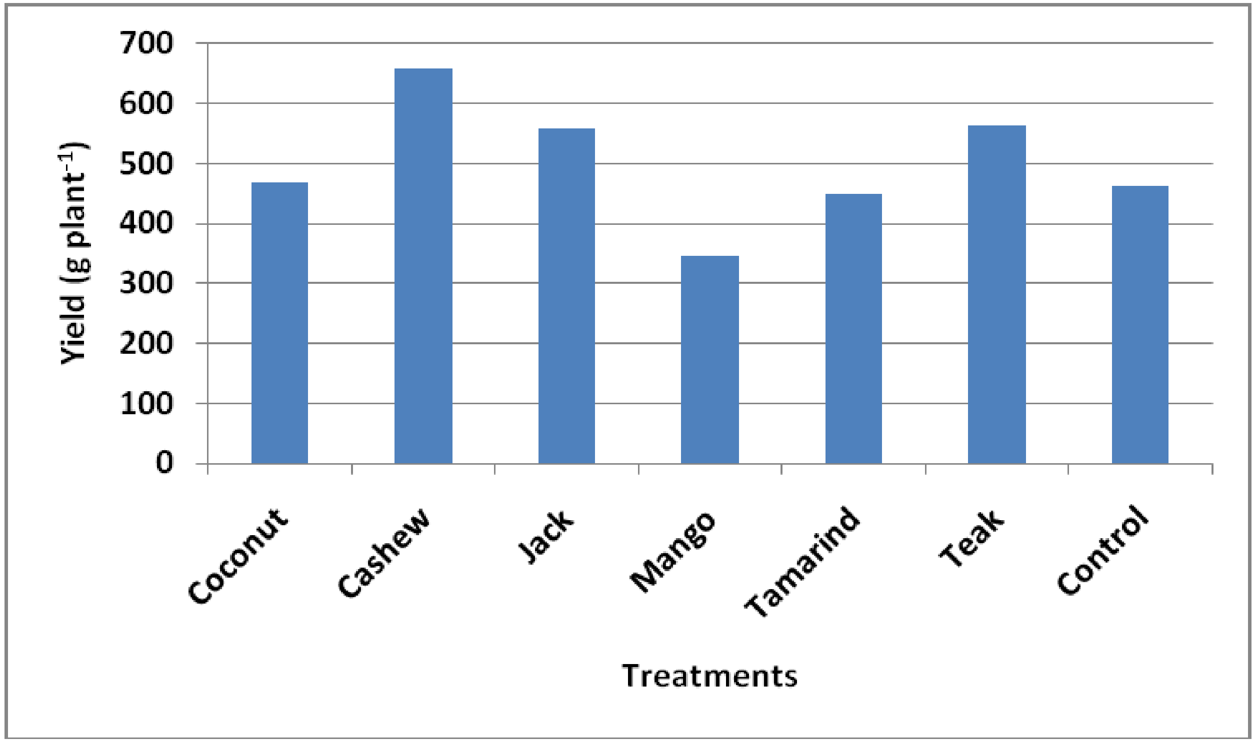

Fig.9. Effect of tree leaf loppings on yield of turmeric

leaves of cashew, jack and teak are relatively larger and also thicker and hence, are likely to reduce soil temperature and conserve soil moisture better than the other tree leaves. The higher yield obtained by mulching with cashew, jack and teak leaves may be due to the favourable influence on soil moisture and soil temperature. Babu *et al*. (2015) recorded that mulching in turmeric with green leaves is crucial to enhance germination of seed rhizomes. It also helps to add organic content to the soil and conserve moisture during the later part of the cropping season.

Mulching with mango leaves resulted in reduced yield of turmeric. This is probably due to the remarkably lesser leaf production, root length and root weight in turmeric when mulched with mango leaves. Also, though not notable, root volume was also less. This is supported by the findings of Sahoo *et al*. (2010) who reported that water soluble leachate from the mature fresh leaves of mango has the allelopathic potential to reduce the germination as well to suppress the growth and development of the test crops. They recorded that the root lengths were more sensitive to allelochemicals than the shoot length ultimately affecting the biomass. In the present study it was found that fresh leaf extracts of mango contain more phenol. These also might have been released into the soil during the process of decomposition. Mango leaves are reported to contain 43-46.7 per cent euxanthin acid ($C_{19}H_{16}O_{10}$) and also some euxanthon ($C_{13}H_8O_4$), hippuric acid and benzoic acids and four per cent mangin (Bhatt and Todaria, 1990). A high-performance liquid chromatography analysis showed that caffeic acid, ferulic acid, coumaric acid, benzoic acid, vanillic, chlorogenic, gallic, hydroxybenzoic and cinnamic acid were present in mango leaf extract (El-Rokiek *et al*., 2010). These chemicals too might have had a role in the observed effect of mango leaves.

From the experiments undertaken, it can be inferred that, in general, the trees have varied allelopathic effects on the growth and development of turmeric. The leaf extracts were more inhibitory than leaf leachates. Among the growth parameters, inhibition of root growth was more pronounced. Dilution does have a prominent role in alleviating inhibitory allelopathic effects. The essentiality of mulching with fresh tree leaves in turmeric is confirmed from the second pot culture experiment where yield was substantially higher than the yield obtained in the first pot culture experiment where mulching was not done.

Based on the experiments, it can be specifically concluded that leachates and extracts of teak, tamarind and mango are inhibitory and hence, caution should be exercised and measures to alleviate the inhibitory effects through copious irrigation may be adopted while planting turmeric under the canopy of these trees. Alternatively, the stimulatory influence of leaf leachate of coconut should be exploited at field level. The leaf loppings of mango inhibited growth and yield and hence, cannot be recommended for mulching in turmeric. Leaf loppings of cashew, jack and teak enhanced yield and hence, can be recommended to farmers for applying as mulch in turmeric @ 15 t ha^{-1} (112.5 g per grow bag of 25 cm height and 30 cm diameter, capable of holding 15 kg potting mixture comprising of soil:sand:cow dung in 1:1:1 ratio) immediately after planting and again after 50 days.

An interesting observation is that fresh turmeric rhizome yield of upto 650 g was obtained from a single grow bag when mulched with leaves of the trees. At the current market price of Rs.100/- per kg of fresh turmeric rhizome, this generates a return of Rs.65/- per grow bag. The cost of a grow bag is Rs.15/- and cost of potting mixture, fertilizer etc. will be nearly Rs.15/-, thus totaling Rs.30/-. The grow bag and potting mixture (after enriching) can be used for at least three years. This highlights the immense opportunity for growing turmeric in grow bags in terrace gardens in the homesteads of Kerala and urban households.

Summary

6. SUMMARY

An experiment entitled "Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Lin.)" was undertaken at the College of Agriculture, Padannakkad, Kerala during the period from April 2014 to January 2015. The main objective was to investigate the allelopathic effect of certain multipurpose trees commonly planted in the homestead gardens of Kerala on sprouting, growth and yield of turmeric. The study involved two bioassays and two pot culture experiments.

The first experiment (Bioassay I), laid out in completely randomized design, comprised of 13 treatments replicated thrice *viz.,* T_1 [leaf leachates of coconut (1:10)], T_2 [Cashew (1:10)], T_3 [Jack (1:10)], T_4 [Mango (1:10)], T_5 [Tamarind (1:10)], T_6 [Teak (1:10)], T_7 [Coconut (1:15)], T_8 [Cashew (1:15)], T_9 [Jack (1:15)], T_{10} [Mango (1:15)], T_{11} [Tamarind (1:15)], T_{12} [Teak (1:15)], and T_{13} (Ordinary tap water). The second experiment (Bioassay II) was also conducted in the same manner as the first experiment but using leaf extracts instead of leaf leachates as treatments. The third experiment (Pot culture I) was laid out in completely randomized design using the same thirteen treatments as in the first experiment and replicated thrice. The fourth experiment (Pot culture II), laid out in completely randomized design, comprised of seven treatments replicated thrice *viz*., T_1 (Mulching with fresh leaf loppings of coconut), T_2 (Cashew), T_3 (Jack), T_4 (Mango), T_5 (Tamarind), T_6 (Teak), T_7 (News paper). These mulches were applied @ 15 t ha^{-1} (112.5 g per grow bag of 25 cm height and 30 cm diameter, capable of holding 15 kg potting mixture comprising of soil:sand:cow dung in 1:1:1 ratio) immediately after planting and again after 50 days, as recommended in the Package of Practices Recommendations for crops by the Kerala Agricultural University. Turmeric variety 'Sobha' was raised for the experiment.

In Bioassay I, sprouting of seed rhizomes of turmeric was exceptionally affected by leaf leachates of all trees except coconut (1:10 and 1:15) and cashew (1:15). Jack, tamarind and teak at both concentrations (1:10 and 1:15) severely

inhibited sprouting whereas cashew and mango at higher concentration (1:10) alone caused inhibition. The inhibitory effects of cashew and mango were alleviated with dilution. Tamarind leaf leachate was most inhibitory and dilution failed to alleviate the inhibition. With regard to the time taken for sprouting coconut, cashew and mango leaf leachates at lower concentration (1:15) resulted in earlier germination of seed rhizomes.

With respect to growth of seedlings, cashew leaf leachate at lower concentration promoted shoot growth while cashew and mango at higher concentration were on par with control. All other tree leaf leachates remarkably inhibited the shoot growth. At higher concentration, teak leaf leachate caused maximum inhibition followed by jack, coconut and tamarind. Dilution did not alleviate the inhibitory effects. The inhibition was caused by jack and teak was as high as 53 and 67 per cent respectively. The root growth of turmeric was notably inhibited by all the tree leaf leachates except coconut and cashew at lower concentration. Mango at higher concentration and tamarind at both concentrations caused most severe suppression of root growth (62%). The number of roots produced was appreciably affected by leaf leachates of all trees except cashew. The least number of roots was observed under teak, irrespective of the concentration. The next most inhibitory were mango and tamarind at higher concentration and the effect could not be alleviated with dilution.

All leaf leachates were acidic and tamarind leaf leachate had the lowest pH of 4.5 and 4.6 for 1:10 and 1:15 concentrations respectively. Osmolality of the tree leaf leachates were in the normal range and not significantly greater than tap water and hence, not likley to cause any exosmosis. At both 1:10 and 1:15 concentrations, the highest phenol content was observed with teak leaf leachate (2.9 and 2.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango. The teak leaf leachate had highest tannin content (101.4 and 100 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango.

In Bioassay II, leaf extracts of all the trees except cashew and jack remarkably reduced the sprouting of rhizomes. Higher concentration of mango caused most severe inhibition (73%) followed by teak (1:10). However, days to sprouting was not influenced greatly by the leaf extracts. Yet though not remarkable, relatively earlier sprouting was observed when subjected to leaf extracts of coconut.

Shoot growth of turmeric seedlings was inhibited by the leaf extracts of all trees except coconut (1:10), cashew (1:15) and jack (1:15). The leaf extract of teak (1:10) suppressed shoot growth most severely followed by mango (1:10) and tamarind (1:10) and the extent of inhibition was 50, 47 and 44 percent respectively. Root growth was inhibited by the leaf extracts of all trees. Coconut at higher concentration caused the greatest inhibition (77%). The inhibition by cashew, tamarind and teak was also considerable. Notably higher number of roots was recorded with mango leaf extracts at both concentrations and cashew and jack at lower concentration. Subjecting the rhizomes to higher concentration of leaf extracts of coconut and tamarind inhibited root production the most.

All the tree leaf extracts were acidic and tamarind leaf extract had lowest pH of 4.5, at both concentrations. Osmolality of the leaf extracts were in the normal range and not significantly greater than tap water. At both concentrations, the highest phenol content was observed with mango leaf extracts (6.0 and 4.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively). The teak leaf extract had highest tannin content (106.2 and 105.6 mg 100 g^{-1} at 1:10 and 1:15 concentrations respectively) followed by mango.

In Pot culture I, plant height was less at 2 MAP in plants treated with the leaf leachate of mango (1:10), but further dilution removed the inhibition. Plants under coconut (both concentrations) and teak at the lower concentration were taller at 4 MAP. Coconut leaf leachate at both concentrations, resulted in greater plant height at 6 MAP also. There was no appreciable difference between the treatments at 2, 4 and 6 MAP with respect to number of tillers. Leaf production was considerably affected at 4 and 6 MAP when sprayed with teak leaf leachate at higher concentration. At 6 MAP, tamarind leaf leachate at a lower concentration also resulted in lesser leaves.

With respect to rhizome characters, rhizome spread was not conspicuously affected by the tree leaf leachates. However, though not significant, cashew at a lower concentration and coconut leaf leachate, at both concentrations, resulted in greater rhizome spread. The treatments did not cause any remarkable difference in rhizome thickness of turmeric.

Root length was not profoundly influenced by tree leaf leachates. Though not significant, application of coconut leaf leachate resulted in the longer roots. Plants subjected to the leachate of teak (1:10) had exceptionally lesser root spread, while mango and teak leaf leachates at a lower concentration resulted in considerably greater root spread. Root weight was extremely less in plants treated with leaf leachate of teak (at both concentrations) and tamarind at higher concentration (1:10). Root volume was appreciably less when subjected to higher concentration of tamarind leaf leachate (1:10). However, root volume was notably more in plants treated with lower concentration of coconut and mango leaf leachate.

There was no difference between the treatments with respect to SPAD values and canopy temperature. The highest stomatal conductance was noted in cashew (1:10) and teak (1:15) which were on par.

Rhizome yield was remarkably less when subjected to higher concentrations of mango and teak leaf leachate. However, leachates of coconut (1:10 and 1:15), jack (1:10), cashew (1:15) and tamarind (1:10) resulted in profoundly higher rhizome yield. Applying leaf leachates of cashew (1:10 and

1:15) and coconut (1:15) resulted in significantly more top yield. Dry turmeric (recovery percentage) was on par in all treatments.

In Pot culture II, plant height was remarkably more when mulched with cashew and tamarind leaves, whereas it was lesser under jack at 4 MAP. At 6 MAP, plants mulched with teak leaves were considerably taller when compared to the control. There was no difference between the treatments with regard to tillers. At 6 MAP, the number of leaves was strikingly less in plants mulched with leaves of coconut, mango and teak.

There was no appreciable difference in rhizome spread between the treatments. Though not remarkable, greatest rhizome spread was observed when mulched with teak leaves and the least with mango. Rhizome thickness was not influenced by the treatments.

Root length was considerably less in plants mulched with leaves of coconut, jack, mango and tamarind. Plants mulched with tamarind leaves had profoundly greater root spread whereas jack leaves resulted in lesser root spread. Root weight was remarkably more when mulched with coconut leaves while it was less under mango and teak. Mulching with coconut leaves resulted in significantly higher root volume.

Highest canopy temperature was recorded in plants mulched with coconut, cashew and jack leaves which were on par. All other treatments were on par with control. Conspicuously lower stomatal conductance was recorded in coconut, cashew and jack and they were on par.

Rhizome yield was exceptionally higher when mulched with cashew (660 g plant^{-1}), jack (557 g plant^{-1}) and teak (565 g plant^{-1}) leaves. However, mulching with mango leaves resulted in strikingly lesser yield (346.73 g plant^{-1}). There was no difference in top yield and dry turmeric (recovery percentage).

From the experiments undertaken, it can be inferred that, in general, the trees have varied allelopathic effects on turmeric. The leaf extracts were more inhibitory than leaf leachates. Among the growth parameters, inhibition of root growth was more pronounced. Dilution does have a prominent role in alleviating inhibitory allelopathic effects. The essentiality of mulching with fresh trees leaves in turmeric is confirmed from the second pot culture experiment where yield was substantially higher than the yield obtained in the first pot culture experiment where mulching was not done.

Based on the experiments, it can be specifically concluded that leachates and extracts of teak, tamarind and mango are inhibitory and hence, caution should be exercised and measures to alleviate the inhibitory effects through copious irrigation may be adopted while planting turmeric under the canopy of these trees. Alternatively, the stimulatory influence of leaf leachate of coconut should be exploited at field level. The leaf loppings of mango inhibited growth and yield and hence, cannot be recommended for mulching in turmeric. Leaf loppings of cashew, jack and teak enhanced yield and hence, can be recommended to farmers for applying as mulch in turmeric @ 15 t ha^{-1} (112.5 g per grow bag of 25 cm height and 30 cm diameter, capable of holding 15 kg potting mixture comprising of soil:sand:cow dung in 1:1:1 ratio) immediately after planting and again after 50 days.

Future line of work

- The findings of the present study, especially the laboratory bioassays, are of preliminary nature. Detailed studies need to be undertaken by raising turmeric under the canopy of the trees so as to ascertain whether the inhibitory effects noticed in the lab bioassay and pot culture are expressed in the field too. Such studies should include in-depth observations on physiological parameters.

- If inhibitory effects are noticed in field experiments, measures to alleviate the adverse effects should be evolved. Trials should be undertaken to explore ways to alleviate the inhibitory effect of leaves of mango on turmeric.
- From the available literature, it is evident that numerous phytochemicals are present in tree leaf leachates and leaf loppings. But it is essential to identify which chemical is responsible for bringing about the inhibition, for which exhaustive biochemical studies are required. Identifying such a phytochemical and using it at higher concentration could offer an opportunity for utilizing it as a natural herbicide.
- Field experiments should be undertaken to explore the possibility of exploiting the stimulatory property of coconut leaf leachate in turmeric and other crops.

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Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Linn.)

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ABSTRACT

The experiment entitled "Allelopathic effect of trees grown in homesteads of Kerala on turmeric (*Curcuma longa* Lin.)" was undertaken at College of Agriculture, Padannakkad during the period from April 2014 to January 2015. The study involved two laboratory bioassays and two pot culture experiments. The main objective of the study was to investigate the allelopathic effect of certain multipurpose trees commonly planted in the homestead gardens of Kerala on sprouting, growth and yield of turmeric.

The first experiment (Bioassay I), laid out in completely randomized design, comprised of thirteen treatments replicated thrice *viz*., T_1 [leaf leachates of coconut (1:10)], T_2 [Cashew (1:10)], T_3 [Jack (1:10)], T_4 [Mango (1:10)], T_5 [Tamarind (1:10)], T_6 [Teak (1:10)], T_7 [Coconut (1:15)], T_8 [Cashew (1:15)], T_9 [Jack (1:15)], T_{10} [Mango (1:15)], T_{11} [Tamarind (1:15)], T_{12} [Teak (1:15)], and T_{13} (Ordinary tap water). The second experiment (Bioasay II) was also conducted in the same manner as the first bioassay but using tree leaf extracts instead of leaf leachates as the treatments. The third experiment (Pot culture I) was laid out in completely randomized design using the same thirteen treatments as in the first experiment and replicated thrice. The fourth experiment (Pot culture II), laid out in completely randomized design, comprised of seven treatments replicated thrice *viz.,* T_1 (Mulching with fresh leaf loppings of coconut), T_2 (Cashew), T_3 (Jack), T_4 (Mango), T_5 (Tamarind), T_6 (Teak), T_7 (News paper). These mulches were at the rates recommended in the Package of Practices Recommendations for crops by the Kerala Agricultural University. Turmeric variety 'Sobha' was raised for the experiment.

In the first bioassay, it was observed that the leaf leachates of tamarind, teak, jack (at 1:10 and 1:15 concentration) and cashew and mango (at 1:10) severely inhibited sprouting. All the tree leaf leachates except cashew and mango

(1:15) severely inhibited the shoot growth. All the leaf leachates except coconut and cashew at lower concentration remarkably inhibited the root growth.

In the second bioassay, leaf extracts of all the trees except cashew and jack considerably reduced the sprouting of rhizomes. Higher concentration of mango caused most severe inhibition (73%) followed by teak (1:10). Shoot growth of turmeric seedlings was inhibited by the leaf extracts of all trees except coconut (1:10), cashew (1:15) and jack (1:15). The leaf extract of teak (1:10) suppressed shoot growth most severely followed by mango (1:10). Root growth was inhibited by the leaf extracts of all trees.

In the first pot culture experiment, coconut leaf leachate at both concentrations resulted in greater plant height at 4 and 6 MAP. Leaf production was notably affected at 4 and 6 MAP when sprayed with teak leaf leachate at higher concentration. The teak leachate (1:10) reduced root spread remarkably. Root weight was appreciably less in plants treated with leaf leachate of teak (at both concentrations) and tamarind at higher concentration. Root volume was conspicuously less when subjected to higher concentration of tamarind leaf leachate. The coconut leaf leachates at both concentrations, jack and tamarind (1:10) and cashew (1:15) resulted in considerably higher yield. The leaf leachates of mango (1:10) and teak (1:10) reduced the yield.

In the second pot culture, at 6 MAP the number of leaves was significantly less in plants mulched with leaves of coconut, mango and teak. Rhizome yield was remarkably higher when mulched with cashew (660 g $plant^{-1}$), jack (557 g $plant^{-1}$) and teak (565 g $plant^{-1}$) leaves. However, mulching with mango leaves resulted in appreciably lesser yield (346.73 g $plant^{-1}$).

To get an insight about the causes for the observed inhibition/stimulation, the pH, osmolality, phenol content and tannin content of the leaf leachates and extracts were analysed. The higher tannin and phenol content might be responsible for the observed inhibitory effects, especially of mango and teak.

Based on the experiments, it can be specifically concluded that leachates and extracts of teak, tamarind and mango are inhibitory and hence, caution should be exercised and measures to alleviate the inhibitory effects through copious irrigation may be adopted while planting turmeric under the canopy of these trees. Alternatively, the stimulatory influence of leaf leachate of coconut should be exploited at field level. The leaf loppings of mango inhibited growth and yield and hence, cannot be recommended for mulching in turmeric. Leaf loppings of cashew, jack and teak enhanced yield and hence, can be recommended to farmers for applying as mulch in turmeric @ 15 t ha^{-1} (112.5 g per grow bag of 25 cm height and 30 cm diameter, capable of holding 15 kg potting mixture comprising of soil:sand:cow dung in 1:1:1 ratio) immediately after planting and again after 50 days.

Appendix

Appendix I

Monthly weather data during the cropping period

Monthly weather data during the crop period						
Period	Temperature (^oC)		Humidity (%)		Total Rain fall (mm)	Evaporation (mm)
	Max.	Min.	Max.	Min.		
April	34.51	24.56	82.5	66.10	50.43	5.24
May	33.04	24.17	86.26	69.53	250.24	4.05
June	31.18	23.57	90.43	77.26	576.18	2.73
July	29.22	22.94	92.18	84.60	1456.38	1.73
August	29.22	22.92	93.56	79.46	754.55	1.89
September	31.00	23.34	90.38	71.39	144.74	3.39
October	31.51	23.13	89.05	69.82	168.58	2.87
November	32.30	21.31	88.54	63.09	83.65	3.03
December	32.39	21.65	89.78	59.39	0.00	2.80
January	31.66	19.34	89.68	57.90	0.00	3.34