STUDIES ON
THE ALLELOPATHIC TREE-CROP-WEED INTERACTION IN AGROFORESTRY SYSTEM OF MIZORAM

By

REBECCA LALMUANPUII

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Mizoram University

Post Box: 190, Aizawl: 796 004, Mizoram (India)

Dr. U.K.Sahoo
Professor (Forestry)

Department of Forestry
School of Earth Sciences & Natural Resource Management
Telephones: +913892330394 (O), +913892326492 (R)
Mobile: +919436150944
E-mail: uksahoo_2003@rediffmail.com
uttamsahoo85@yahoo.com
uttams64@gmail.com

This is to certify that the thesis entitled ***"Studies on the allelopathic tree-crop-weed interaction in agroforestry system of Mizoram"*** *submitted by Shrimati Rebecca Lalmuanpuii for the degree of* ***Doctor of Philosophy in Forestry*** *of the Mizoram University, Aizawl embodies the record of original investigation carried out by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of the Ph. D. degree. This work has not been submitted for any degree of any other University.*

Place: Aizawl
Date: 30th August, 2012

(U.K. SAHOO)
Supervisor

Mizoram University : Aizawl
Department of Forestry

Declaration by the Candidate

I, Rebecca Lalmuanpuii, hereby declare that the subject matter of this Thesis is the record of work done by me under the supervision of Professor U.K.Sahoo, Department of Forestry, Mizoram University, Aizawl and, that the contents of this Thesis did not form basis of the award of any previous degree to me or to anybody else, and that the Thesis has not been submitted by me for any research degree in any other University/Institute. The materials and references are duly acknowledged in this Thesis.

I also declare that the present investigation relates to bonafide research and the title of the Thesis is ***"Studies on the allelopathic tree-crop-weed interaction in agroforestry system of Mizoram"****.*

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Date : 30th August, 2012 ***Rebecca Lalmuanpuii***

Chapter-1

GENERAL INTRODUCTION

The term Allelopathy is derived from two Greek words, "*Allelon*" means *each other* and "*pathos*" means *to suffer* or *suffering* i.e. the injurious effect of one upon another (Narwal and Tauro, 1994). It literally means "*mutual harm*" which refers to the positive or negative influences of one plant without (true) or with (functional) microbial action upon another through chemical means other than nutritional (Bansal and Bhan, 1993). It may be understood as a mutual influence of organisms in the environment through secretions of biochemicals. Plant physiologist, Hans Molisch (1937), University of Vienna, Austria, coined this term which refers to all biochemical interactions (stimulatory and inhibitory) among plants, including micro-organisms (Molisch, 1937). It is considered as important as competition for influencing plant growth both in natural and agricultural ecosystems.

The concept of allelopathy received new attention in 1974, after the publication of the first book in English on the allelopathy by Elroy L Rice, where he defined allelopathy as the effect(s) of one plant on another plants through the release of chemical compounds into the soil environment (Rice, 1984). This definition is largely accepted and includes both positive (growth promoting) and negative (growth inhibiting) effects. Gross (1999) also emphasized that, 'Pathos' also means 'feeling' or 'sensitive' and could therefore be used to describe both positive (sympathetic) and negative (pathetic) interactions. However, many ecologists favour definitions including only negative effects in allelopathy. As for examples, Lambers *et al.* (1998) defined allelopathy as the growth suppression of one plant species by another due to the release of toxic compounds. Broz and Vivanco (2006), refers it to chemical mediated negative interference between plants. Kohli *et al.* (1998) and Singh *et al.* (2001) opined that allelopathy refers to any direct or indirect effect of plants on other plants through the release of chemicals and plays an important role in many agro-ecosystems. Hence, it is worth to mention that, modern research suggests allelopathic effects can be both positive and negative, depending upon the dose and organism affected (Coder, 1999). The stimulatory effect of allelopathic chemical caused increase in root and stem growth (Zeng *et al.,* 2001), it is also commonly defined as any effect; direct or indirect, stimulatory or inhibitory, mediated by a chemical compound released into the environment by a given plant or microorganism (Lotina-Hennsen *et al.,* 2006). Positive effects reports by various authors include: the association of nitrogen fixing symbionts to favour growth of tree species (Chatarpaul and Carlisle, 1983; Fortin *et al.,* 1985) to diminish the adverse effects of excess soil water on tree growth, (Paavilainer and Paivanen, 1995; Penner *et al.*, 1995; Jutras *et al*., 2004).

Allelopathy is an interference mechanism, in which live or dead plant materials release chemical substances, which inhibit or stimulate the associated plant growth (May and Ash, 1990). The interactions between plants are called interference and include positive, negative, and neutral effects on each other (Inderjit *et al.,* 2001; Olofsdotter, 2001; Golisz *et al*., 2007). The plant may exhibit inhibition or rarely stimulatory effects on germination and growth of other plants in the vicinity. It is a mechanism in which chemicals produced by trees and plants may decrease or increase the associated plant growth. As mentioned above, plant neighbours can have both positive and negative interferences on each other, depending upon the species involved and the nature of the factors limiting growth. These effects may be due to allelochemicals present in the tree crops and weeds.

It is believed that, allelopathy involved in many natural and manipulated ecosystems and plays a role in the evolution of plant communities, exotic plant invasion and replant failure (Ridenour and Callaway, 2001; Inderjit and Nilsen, 2003). Most plant species, including crops, are capable of producing and releasing biologically active compounds (allelochemicals) into the environment to suppress the growth of other plants. The chemicals with allelopathy activity are present in many plants and various organs, including leaves and fruits (Sazada *et al.,* 2009) and have potential inhibitory effect on crops (Seigler, 1996). These allelochemicals are usually called secondary plant products or waste products of the main metabolic pathways in plants (Turk *et al.,* 2003; Yokotani *et al.,* 2003; Iqbal *et al.,* 2006). These allelochemicals are transported through the soil and can be transformed, metabolized, or become bound to organic matter during the process, the effects may be severity and the duration of field autotoxicity may vary with environment and geographic location (Victor *et al.,* 2006). This allelopathic potential added into the environment can severely affect crop survival and productivity (Qasim, 1994). Leaching or exudation via roots of plant residues lead to the distribution and subsequent accumulation of such compounds in the biotype, this activity of allelopathic substances may greatly influence the (i) dormancy of seeds and buds as well as the germination of seeds, (ii) resistance of plants to pathogens, (iii) vegetation pattern, (iv) plant successions (Miersch *et al.,*1994).

The definition of 'Allelopathy' accepted by the International Allelopathy Society (IAS) refers to any process involving secondary metabolites produced by plants, algae, bacteria, fungi (microorganisms) and viruses that influence the growth and development of agricultural and biological systems (Anonymous, 1996, Khalid *et al.,* 2002; Khruidhof, 2008). The inclusive definition for allelopathy mentioned above recognizes that compounds (allelochemicals) are involved in the defence against multiple biological threats, including competition by other plants, herbivores and diseases (Macias *et al.,* 2007). These allelochemicals are the secondary metabolites produced by plants and are the by products of primary metabolic processes (Levin, 1976), having both stimulatory and inhibitory effects on the growth and development of their own kind and also on other species grown in their vicinity. But the toxin-producing plants differ widely in their production of secondary metabolites; hence they vary in their ability to produce allelopathic effects (Waller and Feng, 1996). Allelochemicals are defined as 'bio-communicators', suggesting the possibility of active mixtures. There are increasing number of findings in which single compounds are found not active or are not as active as a mixture (Macias *et al.,* 1998), accordingly they emphasize that traditional agriculture practices based on ancient knowledge could be useful as starting points for new allelopathic studies. This approach is based on the belief that the traditional practices result from the close contact between nature and human throughout history.

Due to ever increasing population of the world, the demand for food is increasing and achieving the food security is becoming a challenge to mankind and as a result, yield maximization is becoming an important word of modern agriculture which leads to the use of synthetic chemical fertilizers and insecticides for increasing the production. The use and incorporation of heavy doses of synthetic chemicals like pesticides or fertilizers for controlling pest attack and satisfying nutrient deficiency respectively directed and leads to lowering the land values and causes negative impact directly or indirectly on the produce, environment and overall human health and also resistance to specific synthetic herbicides is increasing dramatically which has become a worldwide problem. It also resulted in great environmental pollution and health hazards particularly from ground water contamination. Thus, allelopathy may help in overcoming these problems through smoothering of crops to control weeds through their inclusion in crop rotations and in crop mixtures or intercropping systems and breeding those for allelopathic potential for weed control (Narwal, 1994).

As a result, it is imperative to concentrate on research to find out some natural extract to control this problem, thereby minimizing or avoiding the frequent use of herbicides in future. In this regard allelopathic effect of different plants is drawing attention of many researchers in the recent past. Shahida *et al.* (2002) have even claimed that the allelopathic compounds can be used as natural herbicides and other pesticides; so that these are less disruptive of the global ecosystem than are synthetic agrochemicals. These naturally occurring allelochemicals could play a valuable role in an integrated weed management system potentially reducing the amount of synthetic herbicides if required for weed control. Allelopathic elements are involved in practically every aspects of plant growth; they can act from stimulants to suppressants. Thus, allelopathic interactions between plants and other organisms may become an alternative to herbicides, insecticides and nematicides for weeds, disease and insect control. Substantial information are available on various aspects of plant growth and development which may be used to increase the yield of crops, vegetables, fruits and woody trees, etc. and to control pests. Major emphasis adopted to find out the best tree-crop interaction in agroforestry systems includes, tree- crop interaction (Harsh and Tejwani, 1993), alley cropping (Singh, 1995, 1996), agroforestry model as an alternative to shifting cultivation (Solanki, 1999), introducing nitrogen fixing tree species (George and Kumar, 1998), trees and shrubs growing in agroforestry system (Nair, 1993), use of multipurpose trees (Tejwani, 1993), litterfall decomposition and nutrient dynamics (Sharma *et al.,* 1997a, b).

Allelopathy occurs through the release by one plant species of chemicals which affect other species in its vicinity, usually to their detriment. Allelochemicals produced by plants may be released from plants and tissues into the soil rhizosphere and environment in sufficient amounts to affect neighbouring and succession species (Qasim, 2001) by means of four ecological processes: i) volatilization, ii) leaching, iii) root exudation, and iv) decomposition of plant residues (Bhatt and Todaria, 1990; Weston, 1996; Golisz *et al*., 2007). However, the effects of allelopathy are selective and vary with different tree species (Melkania, 1983) since this plant will vary in the amount of indigenous secondary metabolites and would release different amount of phytotoxins.

When plants are exposed to allelochemicals, their growth and development are affected. The readily visible effects include inhibited or retard germination rate, seeds darkened and swollen, reduced root or radicle and shoot or coleoptile extension; swelling or necrosis of root tips; curling of the root axis; discolouration, lack of root hairs, increased number of seminal roots; reduced dry weight accumulation; and lowered reproductive capacity (Ayeni *et al.,* 1997). Many abiotic and biotic soil factors have also influences on phytotoxic levels of allelochemicals (Huang *et al.,* 1999; Inderjit *et al.,* 1999). Some allelopathic agents are active only under hot and dry climate as they work in vapour phase such as monoterpenes because the vapour density of the essential oils may penetrate into soil, affecting adversely the under growing plants (Kohli and Singh, 1991; Vaughn and Spencer, 1993; Koitabashi *et al.,* 1997).

As a scientific discipline, allelopathy has already contributed to the solution of practical problems in agriculture and provided explanations for observed plant-plant interactions and is a novel approach to keep the environment safe and to develop sustainable agriculture (Yongying, 2005). Allelopathic compounds play an important role in the determination of plant diversity, dominance, succession, and climax of natural vegetation and in the plant productivity of agro ecosystems. Allelopathy also may be one of several attributes which enable a plant to establish in a new ecosystem (Callaway and Aschehoug, 2000; Callaway and Ridenour, 2004).

The influence of trees on its surrounding plants, i.e. crops, vegetables, bushes, grasses and fruit bearing trees has important implications in agroforestry as these govern and direct the planning of suitable agroforestry systems. The selection of combination of crops with forest trees is another important implication to increase food production and to provide wood as a by product and also to enhance soil preservation, soil protection against erosion, and in some cases weed suppression. Generally, the selection to intercultivate has been done on the basis of the empirical knowledge of the farmers and the allelopathic compatibility of forest and cultivar species, can determine the success of an agroforestry system (Rizvi *et al.,* 2000). Many of tree species and crops are grown together on the same unit of land in order to obtain optimal crop productivity at the same period of time. Such a system also has the potential to help control weeds and pests. When trees that are rich in allelochemicals are introduced can play a major role in regulating vegetation pattern, distribution of plants in communities, nitrification, nitrogen fixation and ecosystem balance. It is thus desirable to conduct series of studies on the effect of tree allelochemicals and weed allelochemicals on germination of seeds, growth and performance of crop plants for their allelopathic either harmful or useful on agricultural crops in agroforestry systems. Narwal (1994) claims that allelopathy can be used i) to increase the yield of food grains, vegetables, fruits and forestry, ii) to decrease harmful effect of modern agricultural practices like multiple cropping, leaching losses of plant nutrients, indiscriminate use of environmental health hazardous pesticides on soil health/productivity, and iii) to maintain the soil productivity and pollution free environment.

However, in our country in general and north eastern India in particular, very little research work has been done on the aspects of allelopathy and it is urged that the results of such research should be available to the farmers in overcoming various problems in a variety of ways.

As mentioned earlier, in modern agriculture, plant production systems rely heavily on inputs of chemicals to provide protection against insects, diseases and weeds. The extensive use of chemicals has caused various detrimental hazardous effects on soil, pests, insects, weeds and environment. As such, alternative approaches include allelopathic chemicals which have already been used to defend crop plants against weeds, insects, nematodes and diseases. Weeds continue to be an important constraint in crop production. Despite the good efforts made in research and extension in the field of weed science, the farmers continue to experience heavy losses in crop yield due to weed interference.

In NE hill region, particularly in Mizoram, shifting cultivation is mainly practised which has resulted into considerable loss of soil and forest, about 80% of the total population living in rural areas are engaged in shifting cultivation. But, because of the ever increasing population, the demand for food increases, and due to this reason, the fallow period between the jhum cycle has decreased to 4-5 years only which was 15-20 years in the last past years. Hence, low input alternatives for land use, e.g. agroforestry has been recommended to reduce the over exploitation of natural resources and to meet the subsistence needs of the tribal communities. Drastic changes in land use in Mizoram, caused by both increasing population and shifting cultivation have been noticed recently, population pressure in upland areas and the hills has led to the expansion of agricultural areas inside evergreen forests and mixed forests dominated by bamboo. Bamboo grows everywhere with varying intensity of growth depending upon when the jhum was last practised, slope cultivation, or jhum cultivation is the principal land use. Mixed cropping of maize, rice, vegetables, chillies, cotton and tobacco is practised.

Mizoram has an impressive record of rich diversity of flora and fauna in the past years, but with the passage of time and also with the increase in population, uncontrolled shifting cultivation/jhumming and continuous felling of trees, the forests have lost their original and natural characters. Remnants of forests that have survived the onslaughts of jhum and uncontrolled fellings are indicative of the original landscape. Visual interpretation of the remotely sensed data indicates that jhum areas dominate the land cover. The secondary forests are characterized by a fairly open and short canopy. Wild bananas and bamboo form the undergrowth, besides the plantation of various trees grown on farm lands, on road side, wasteland and under industrial areas. Teak plantation also occupied vast areas of land which are owned by Government and private farmers.

In Mizoram, farmers grow a variety of native tree species such as neem, teak, schima, subabul, jack fruit, tree bean, mango and various fruits and horticultural crops in their homesteads and orchards. The people of Mizoram have been practising different tree crop combinations since time immemorial in traditional agro-forestry practices (Sahoo *et al.*, 2005). The farmers also have been experiencing low agricultural production under teak plantation so most of the farmers avoid growing crops under teak plantation these days. Similar concern about deleterious effects for crop production is also observed for other tree species. However, our knowledge of the conditions under which certain crops residue cause allelopathic effect on subsequent crop is extremely lacking. Similarly, there has been no information on tree-crop-weed allelopathic interactions. Keeping in view of the above, the proposed study seeks to understand:

i) the effect of aqueous leaf leachates of the selected trees and weeds species on the test crops in respect of germination percentage, extension of root and shoot length, and the biomass of fresh and dry weights of root and shoot under different treatments in laboratory bioassay condition compared with control.

ii) the effect of different treatments of soil under pot culture in respect of germination percentage, plant growth and development, yield of the test crops and biomass of fresh and dry weights of root and shoot compared with control.

iii) the effect of Teak and Neem on the germination percentage, plant growth and development, yield of the test crops and biomass of fresh and dry weights of root and shoot compared with control under field condition.

For evaluating the allelopathic interaction of trees, crops and weeds, the following species were considered.

(a) Tree species :

i) *Melia azadirach* L.

ii) *Tectona grandis* L.

(b) Crop species:

i) *Zea mays* L. (Local variety-Sticky maize)

ii) *Oryza sativa* L. (IR-64)

(c) Weed species:

i) *Mikania micrantha* L.

ii) *Ageratum houstonianum* L.

In multi-storey home gardens of Mizoram, as mentioned earlier, numerous crops and trees species are grown together among which, paddy, maize and vegetables are essential components. These tree species are used as fuel, fodder or small timber by local people. The multipurpose trees and different weeds component comprise a virtually untapped reservoir of allelochemicals and these trees species found in farms or in between cultivated fields have been less investigated for allelopathic influences in Mizoram. Systemic evaluation of crop and woody plant combinations for allelopathic interactions may provide useful information to design new systems. The selection of species combination will influence the productivity and eventual success of the agroforestry system. In order to assess the allelopathic effects of common weeds and leaf leachates of some multipurpose trees planted in the multi-storey home garden in Mizoram, this investigation was undertaken to assess the allelopathic effect of aqueous leaf leachates of certain multipurpose tree species of Teak (*Tectona grandis* L.) and Neem (*Melia azadirach* L.) planted in home gardens and weeds *Ageratum houstonianum* L. and *Mikania micrantha* L. present in the vicinity of farm, in the experimental field, in pot condition and in laboratory condition on percentage of germination, growth behaviour and performance and yield of paddy and maize under agroforestry system in Mizoram.

Chapter-2

REVIEW OF LITERATURE

Evidence for allelopathy has accumulated in the literature over many years and many kinds of allelochemicals have been isolated and characterized from various plants (Gross and Paritheir, 1994; Seigler, 1996) which provided an extensive review of allelopathy emphasizing its importance in agriculture and forestry. Unfortunately, research in allelopathy did not receive the attention it deserved. Only a few historical reports are found prior to the beginning of twentieth century. However, involvement of plant-produced chemicals in plant-plant interaction was first suggested by the Swiss scientist M.A-R de Candolle in 1842 (Alam *et al*., 2001).

Growing crops and trees together is not a new concept and is practised by farmers in both developing and developed countries. Historically, this practice existed in tropical and sub-tropical countries since long, although the term Agroforestry was coined only at the time of establishing the International Council for Research in Agroforestry (ICRAF) during 1977. From time immemorial to a limited extent, a combination of food crops and forest trees had been adopted in land management by the farmers throughout the world. Multispecies agro ecosystems (associations of two or more species growing together on the same piece of land in a certain temporal and spatial arrangement) are widespread throughout the tropics. In comparison with monocrops, such systems promise increased productivity, increased stability and increased sustainability to the farmers and hence complement agricultural production. Trees are planted on farm boundaries, or inter-cropped with field crops without much loss of the main crops. They are raised primarily to benefit farms by its soil enriching effect and also providing subsistence products like fodder and fuelwood (Hedge, 2011). Intercropping with trees under rainfed ecosystem ensures better yield and minimizes risk of crop loss due to weather changes (Basavaraju and Gururaju, 2000). The integration trees on farms also provide wind breaks, source of organic matter, shade and soil binder to prevent soil erosion while generating additional income. This integration of trees into the agricultural land base through tree-crop intercropping systems has shown great potential in other temperate regions, where they can contribute to the adoption of sustainable agricultural practices (Thevathasan *et al*., 2004). Establishing shelterbelts by planting tall growing trees on field bunds is very popular in India (Hedge, 2011) and practised of growing trees with crops is also prevalent in Mizoram. A detailed account of the traditional agroforestry practices in the north east region has been reviewed by Solanki (1999). A brief description of the agribiodiversity and traditional practices prevailed in Mizoram has also given by Sahoo *et al*. (2005). Growing trees on agricultural fields, combined with crops is now becoming popular among the farmers and has been observed that trees grown under agroforestry attained higher growth as compared to the trees grown in forest condition (Singh *et al*., 1988).

While promoting tree planting on private lands, the reference of farmers should be considered. Tree species to be selected, should be based on the quality of land, availability of moisture, suitability of climate, growth rate, gestation period, profitability and for fulfilling certain objectives. Agroforestry is uniquely suited to improving food and fuel security, while they continue to provide essential ecosystem services. It is seen as an important means of "climate smart" development. Maximising the productivity of trees and crops in agricultural landscapes becomes important as they serve as the much needed 'carbon sinks'. A significant improvement in soil physical chemical characteristics and the ability of the soil to sequester carbon increases tremendously after five years of planting trees on degraded lands (Maikhuri and Negi, 2011). King (1979) pointed out the need for investigations of allelopathy in various tree species used in agro-forestry where there is a good chance of allelochemicals released by the intercrop trees affecting food and fodder crops. Therefore, it seems essential that the allelopathic compatibility of crops with trees should be checked before introducing in agroforestry system (Khan and Alam, 1996). Allelopathy is an important mechanism in which plant parts disperse toxic substances in the environment as their competitive strategies (Minorsky, 2002; Mirshekari, 2003). These allelochemicals were released in different ways such as leaching from plant tissues by rain and dew and excretion from plant roots (Rashedmohalsel *et al*., 2006). It is an important environmental friendly approach to weeds control, to increase yield and herbicide application reduction (Rizvi and Rizvi, 1992; Rezayi *et al*., 2008)

In India, agro-forestry is commonly practised by the hill dwellers of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. These systems can generate several positive and negative properties depending upon the trees selected for planting with food crops. A combination of appropriately selected woody components and herbaceous crops essentially contributes to both productivity and sustainability of the farming system on marginal and sub-marginal lands by increased production of organic matter, maintaining soil fertility, reduction of water and wind erosion and creating a micro-climate favourable for associated crops and livestock. Further, integration of farmers into tree management processes has a salubrious effect in making the farmers' conscious of the importance of the tree cover for the sustainability of the farm production.

In agroforestry, allelopathy has been correlated to problems with crop production on certain soil types (Bhatt and Todaria, 1990), and with certain types of crop rotations (Patrick, 1971). It is well known that some trees and weeds have a toxic effect on surrounding crops which may hinder the germination, growth and vigourness of the effected crops. A number of weed and crop species have been reported to possess allelopathic activity on the growth of other plant species (Rice, 1984). Allelopathic substances were first detected by Davis (1928) in black walnut tree (*Juglans nigra*) whose foliar leachates containing Juglone was found to damage germination and seedling growth of crops beneath the tree. Bora *et al.* (1999) found the allelopathic effect of leaf extracts of *Acacia auriculiformis* on seed germination of some agricultural crops. It was also reported that allelopathic effect is species specific and concentration dependent (Einhelling, 1996). Other workers indicated that most allelochemicals are released at early stage of crop growth (Economou *et al.,* 2002). It was also noticed that leaves of *Conyza albida* had more allelopathic effect than stems, additionally and it was reported that leaves of congress weed (Tefera, 2002) and alfalfa (Chon and Kim, 2002) had more allelopathic effect than stem and roots. Moreover, it was reported that some plants can release allelopathic compounds later in the crop growth (Ben-Hammouda *et al*., 2001).

Ebana *et al.* (2001) reported that aqueous extracts of two rice varieties differed in their allelopathicity against growth of lettuce. The hot and humid climate coupled with intermittent rainfall during growing season, however, can encourage weed growth resulting in severe crop-weed competition (Saraswat, 1999). Cultural practices are important management factors that affect the yield of a crop. Weeding is one of the most important cultural practices for the crop plants to take nutrients, moisture, light, space and sometimes controlling many diseases, organisms and insect pest (Alam *et al*., 2010).

It has been reported that invasive plants use allelochemicals as novel chemical weapons to increase the plants ability to interfere with its neighbour. This hypothesis was described initially by Callaway and Aschehoug (2000), as one mechanism influencing exotic plant invasion. Although these interactions are difficult to quantify and their impacts in the field are not well established, many invasive plants appear to utilize allelopathy or root exudation as a means to further compete and increase invasive interference (Douglas *et al*., 2011).

Allelopathy as a mechanism of plant interference in agro ecosystems offers an opportunity to manage weeds in a crop sequence, but could also adversely affect crop yields and influence choice of rotation (Moncef *et al.,* 2001). Evidence showed that higher plant releases diversity of chemicals into the environment, which includes phenolics, alkaloids, long-chain fatty acids, terpenoids and flavinoids (Chou, 1995) which are often observed to occur early in the life cycle, causing inhibition of seed germination and /or seedling growth. Interpretations of mechanisms of action are complicated by the fact that individual compounds can have multiple phytotoxic effects (Einhelling, 2002).

In multi-storey cropping systems, since many trees, weeds and crops grown together, tree-crop-weed interactions are implicit. Researchers have often ignored allelopathy as a possible mechanism in their tree-crop-weed interaction studies. The phenomenon of allelopathy where one plant exerts detrimental effect on another through the production of germination and growth inhibiting substances has been widely reported (Rizvi *et al.,* 2000). Great losses occurred when nutsedge competed with crops (Messiha *et al.,* 1993; Bryson *et al.,* 2003; William and Hirase, 2004, 2005). Due to interference by another plant species, one plant species fails to germinate, grows more slowly, shows symptom of damage or does not survive at all which can be a result from competition and allelopathy (Angiras *et al.,* 1988; Nelson, 1996). Decline in crop yields in cropping and agroforestry system in recent years has been attributed to allelopathic effects. Crop rotations are practised to eliminate the effect of monoculture, but the succeeding crop may be influenced by the phytotoxins released by the preceding crop (Reigosa *et al.,* 2006). Certain weeds found in multi-storey cropping greatly affect the yield of crops. Among which, *Mikania micrantha* a common weed of banana, traditional taro (*Colocasia esculenta* (L.) Schott) and cassava (*Manihot esculenta* Crantz) cultivation (Macanawai *et al.,* 2010b, 2011a) affect the crops. In India, *Mikania micrantha* is one of the four weeds that have a severe impact on the production of tea mainly due to its affects on both young and mature crops (Barbora, 2001; Rajkhowa *et al.,* 2005; Puzari *et al.,* 2010).

In agroforestry systems, the allelochemicals added from the perennial tree component through leaching, root exudation and litter decay over several years, might accumulate and exceed threshold levels, thereby leading to soil sickness which may be caused by: a) destruction of nutrients, micro nutrients, deficiencies and excess of fertilization, b) destruction of soil structure and physical properties of soil, c) evolution of phyto pathogenic microflora, d) disproportionate development of several groups of microflora, e) increased production of pest and weeds, f) changes in soil pH, g) accumulation of phytotoxins in soil (Narwal *et al.,* 2004). Different studies reveal that some allelopathic agents are volatile (emanated from different plant parts) (Bradow and Connick, 1998) or exuded from roots into the root zone and interfere in root growth and various functions (Qasim and Hill, 1989). A recent study on the cases of *Ageratum conyzoids* L., *Ambrosia trifida* L. and *Lantana camara* L. provides examples of allelopathic weeds and use of their allelochemicals that have been incorporated into ecological pest management and control in China (Kong, 2010).

Tree planting on degraded and wasted lands can dramatically increase the native forest species diversity. Under appropriate conditions these plantations seem to catalyze natural forest succession by modifying understorey micro-climatic conditions and soil fertility thereby, creating a more favourable environment for the establishment of biological diversity (Verma *et al*., 2005). Farmers generally keep the rice crop unweeded due to scarcity of labours. Heavy rains do not permit timely weeding which is very essential to get higher production (King, 1974). The knowledge on behaviour of emergence of kharif weeds in paddy crop is almost lacking which is very essential for developing effective and cheapest control measure. The extent of reduction in kharif crop due to weed is also reported by Jain and Tiwari (1993) and Agrawal *et al*. (1995). Rice is reported to be the most sensitive crop to weed competition (Choudhary *et al.,* 1995).

Some water soluble allelochemicals are leached from foliage parts by rain, mist, dew, or fog drip (Qasim, 1994). In order to have any effect on the target plant the allelochemicals have to be released from the donor plant which happen in different ways:

i) Runoff and leachate from leaves and stem of plants. As for example, the allelochemicals in the leaves of black walnut, *Juglans nigra*, which are washed off with rain can inhibit the growth of the vegetation of black walnut tree (Bode, 1958).

ii) Volatile phytotoxic compounds from the green parts of a plant, e.g. *Salvia leucophylla* and *Artemisia calofornica* (Halligan, 1973).

iii) Phytotoxic compounds from decomposing plant material, such as rye (*Secale cereale*) when used as a mulching material. Apart from shading and keeping the soil moist, rye mulch also inhibits both germination and growth of weeds through release of phytotoxins (Barnes and Putnam, 1986).

iv) Phytotoxic compounds released from the plant roots. Rice is an example, where living rice plants are able to suppress weed growth selectively (Navarez and Olofsdotter, 1996; Olofsdotter *et al.,* 1997).

Chung *et al.* (2003) described the effect of allelopathic potential of rice (*Oryza sativa* L.) residues against *Echinochloa crus* galli P. Beauv. var. *Oryzi cola* Ohwi (barnyard grass), an associated weed of paddy. Microscopic studies revealed that allelopathic rice cultivars seem to inhibit secondary growth in barnyard grass roots besides reducing root elongation (Olofsdotter *et al.,* 2002). Uremis *et al.* (2005) have reported significant suppression of *Physalis angulata* L. a problem weed in maize, cotton and soybean by aqueous extracts of *Brassica species*.

A literature on the effect of vegetation on crop seedling survival and growth shows that competition varies greatly depending on tree-crop species (Wagner *et al*., 1996, Mitchel *et al*., 1999; Reynolds *et al*., 2002). The beneficial and harmful effect on crops by trees and weeds may be due to allelopathic effect in its surrounding areas, once the environment has been disturbed to a certain degree, the ecosystem deterioration occurs. In its palaeotropic exotic range, *Mikania* has become a horrific invader and a notorious weed, severely damaging forestry and plantation crops (Zhang *et al*., 2004). Most published work has shown that foliage leachates are most potent source of toxic metabolites (Suresh and Vinaya Rai, 1987; May and Ash, 1990). Some information on the allelopathic effect of tree crops on the germination and growth of food crops has been documented (Bhatt and Todaria, 1990). However, report of Bhatt *et al*. (1993) revealed that legume food crops are most susceptible to toxic response of tree crops. The overwhelming evidence suggests that plant phenolics play a major role in allelopathy (Inderjit, 1996; An *et al.,* 2000). Gaynar and Jadhav (1992) also reported strong phytotoxic response of foliage from *Terminalia tomentosa* on paddy crops. Phytotoxic responses of foliage of various agroforestry tree crops on germination and radical extension of food crops have also been reported by Bhatt *et al*. (1993). Bhatt and Todaria (1990) reported that soil mulched with dried leaves of *Adina cordifolia* and *Prunus cerasoides* significantly inhibited germination and DMP of *Hordeum vulgare* and *Glycine max* due to phytotoxic influences of these species. Bhatt *et al.* (1996) reported that farming of *Juglans regia, Ficus neerifolia* and *Grewia oppositifolia* significantly reduced ground cover due to their allelopathic influences. The dried leaf powder of mango (*Mangifera indica*) was reported to significantly inhibit sprouting of purple nutsedge tubers (James and Bala, 2003) and its aqueous extract inhibiting germination and growth of some crops (Yang *et al*., 2006). Inderjit and Dakshini (1991) reported the presence of several phenolic compounds in soil in which cocongrass was growing and in plant leachates that did not occur in control soil. Moreover, most cocongrass leachates affected seed germination and seedling growth of crop plants. Allelopathic effect of tree leaf extracts on the germination of wheat and maize (Thakur and Bhardwaj, 1992) is also reported. Bhatt *et al.* (1993, 2000) and Kaletha *et al.* (1996) had also reported that legume food crops were most susceptible to toxicity of weeds.

All these studies indicate the release of phytotoxic chemicals. The observed different phytotoxicity of weeds may be attributed to the presence of variable amount of phytotoxic substances in different parts that leak out under natural conditions. According to Lavabre (1991), allelopathic effects are controversial and still poorly understood. Allelochemicals (inhibitors) are produced by plants as end products, by-products and metabolites and are contained in the stem, leaves, roots, flowers, inflorescence, fruits and seeds of the plants. Of these plant parts, leaves seem to be the most consistent producers of these allelochemicals (Horsley, 1977).

Bhatt and Todaria (1990) and Bhatt *et al.* (1993) also reported that although the toxic metabolites are distributed in all plant tissues, the bark and leaves are the most potent source. It was also demonstrated that leaf litter is the major source of phenolic compounds as a by product during putrefaction and green leaf leachates contained tannin (Hattenschwiler and Vitousek, 2000). The chemicals with allelopathy activity are present in many plants and various organs including leaves and fruits (Inderjit, 1996, Sazada *et al.,* 2009) and have potential inhibitory effect on crops (Seigler, 1996). The elongation of forage grasses radical was more responsive than seed germination upon treatment with *Leucaena* (Antonio *et al.,* 1999). Fruits kernels of *Terminalia chebula* contain palmistic, stearic, oleic, linoleic, arachidic and behenic acid. Moreover, chebulin is released by the flowers of *Terminalia chebula* which might inhibit the germination, growth and yield of other plants (Rastogi and Mehrotra, 1993a). Oleanolic acid, maslinic and arjunolic acids are found in fruits of *Terminalia tomentosa* which possibly inhibited the growth attributes of herbaceous plant (Rastogi and Mehrotra, 1993b.). Inhibition or delay of seed germination and radicle growth by allelochemicals from many species for example; sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), sunflower (*Helianthus annus*) and rye (*Secale cereale*) were reported and reviewed (Wu *et al.,* 1999; Inderjit and Callaway, 2003; Inderjit and Duke, 2003; Weston and Duke, 2003). There is evidence that allelochemicals liberated from certain weeds into the soil reduce crop growth (Hoque *et al.,* 2003). Rice (1984), stated that plants are known to exhibit allelopathy by releasing water soluble phytotoxins from leaves, stem, roots, fruits and seeds and such metabolites play an inhibitory role in delay or complete inhibition of seed germination, stunted growth and injury to root systems of plants. The magnitude of the chemicals effects on other plants, depends on their concentration and the quantity these substances released into the environment (Rice, 1984). It has been reported that *Eucalyptus* and *Acacia spp.* have phytotoxic effects on tree crops and legumes (Velu *et al.,* 1999; Selles *et al.,* 2000). Wheat cultivars are capable of inhibiting root growth of ryegrass and it is possible to breed for cultivar with enhanced allelopathic activity for weed suppression (Wu *et al.*, 2000).

Several phytochemicals have been identified by various researchers in various parts of test trees; some of these may be inhibitory. *Tamarindus indica* contains terpineol, cinnamaldehyde, ethylcinnamate, golacturonic acid, geranial essential oil, limonene, linoleic acid, myristic acid, oleic acid, palmitic acid, pantothenic acid, phenol, pipecolinic acid, tannin and tartaric acid; the phytochemicals betulin and betulinic acid are also present in teak plant (Duke, 1992). For successful utilization of allelopathic properties the identification of allelochemicals is necessary. It may happen that more than one allelochemicals are involved in allelopathic mechanism. In case of rice the identification of allelochemical are in progress (Rimando *et al*., 2001; Mattice *et al.,* 2001). At IRRI, a research programme was started in 1996 to understand the genetic control of allelopathy (Courtois and Olofsdotter, 1998).

Allelochemicals produced by plants may be released into the surrounding environment to affect neighbouring and succession species (Akram *et al.,* 1990). These compounds are inhibitory to growth of weed plants (Chon and Kim, 2004). If some of these compounds are released into the soil environment, from leaching, litter decomposition, root exudation, or direct volatilization, they could effect (either positively or negatively) germination and growth of other species. The allelopathic effect of some plants was studied including germination inhibition (Williamson *et al.,* 1992, Patil, 1994, Djurdjevic, 2004), plumule and radical length (Tobe *et al.,* 2000, Turk and Tawaha, 2003) seedling growth retardation (Bhatt and Todaria, 1990, Kalburtji and Mosjidis, 1993a, b) poor seedling survival (Smith, 1990). Oudhia (1999) found that extracts of some weeds as *Calotropis gigantea* have caused allelopathic effects inhibited germination and growth of *Lathyrus sativus*. Weeds cause reductions in rice and maize yields and quality and remain one of the biggest problems in rice production. Allelopathy is one of the options to weed control (Rimando and Duke 2003; Maclas *et al*., 2007; Kong, 2008; Teslo and Ferrero, 2010). Allelopathy is the direct influence of an organic chemical released from one living plant on the growth and development of other plants (Inderjit and Duke 2003; Belz, 2007; Maclas *et al.,* 2007). Allelochemicals can provide a competitive advantage for host-plants through suppression of soil micro-organism and inhibition of the growth of competing plant species because of their anti-bacterial, anti fungal and growth inhibitory activities (McCully 1999; Hawes *et al*., 2000; Bais *et al*., 2004). Flaxleaf Fleabane (*Conyza bonariensis* L.) weed has a deep tap root that can greatly reduce stored water supplies in fallow and can compete with crops reducing yield (Wu *et al.,* 2010). The risk of crop yield loss due to competition from weeds by all seedling methods is higher than for transplanted rice because of absence of size differential between crops and weeds and concurrent emergence of competitive weeds along with rice seedlings (Rao *et al.,* 2007).

Kaul *et al.* (1991) and Bansal *et al*. (1992) studied the inhibitory effect of *Eucalyptus, Bambussa* spp., *Tectona grandis*, *Acacia nilotica*, *Dalbergia sissoo, Bauhinia variegata, Ficus bengalensis, Morus alba, Populus deltoides, Salix babylonica* and *Leucaena leucocephala* on the germination and seedling growth of certain food crops. Bora *et al*. (1999) found the phytotoxic effect of leaf extracts of *Acacia auriculiformis* on seed germination of some agricultural crops. It was observed that the leaf extracts of *Acacia auriculiformis* delayed as well as hindered the germination significantly in the plants like mustard (*Brassica juncea* L.); chickpea (*Cicer arietinum*), black gram (*Phaseolus mungo*), radish (*Raphanus sativus*) and falen (*Vigna unguiculata*) compared to the control. Antonio *et al.* (1999) reported the effects of aqueous extracts of *Leucaena* on germination and radical elongation of three forage grasses in which radical elongation was more sensitive indicator extracts effects rather than seed germination. Rafique Hague *et al.* (2003) found that the water soluble leachate from fresh leaves of *Albizia saman* has the allelopathic potential that reduces the germination as well as suppresses the growth and development of agricultural crops.

Allelopathic associated problems often result to accumulation of phytotoxin and harmful microbes in soil, which give rise to phytotoxicity and soil sickness (Sahar *et al.,* 2005). A large number of trees and weeds have properties of allelopathy which possess growth inhibiting effect on crops. Hence, chemicals with allelopathic activity are present in many plant parts and various organs, including leaves and fruits and have potential inhibitory effects on crops (Seigler, 1996). As noted by Jadhar and Gayanar (1992), the percentage of germination, plumule and radical length of rice and cowpea, were decreased with increasing concentration of *Acacia auriculiformis* leaf leachates. The inhibitory effect of the species on seed germination and seedlings of maize may be related to the presence of allelochemicals including tannins, wax, flavinoides and phenolic acids. Furthermore, the toxicity might be due to synergistic effect rather than single one (Fag and Stewart, 1994). Phenolic acids have been shown to be toxin to germination and plant growth processes (Einhelling, 1995). Rajangam and Arungam (1999) found that, the use of Z-aqueous extracts of *Excoecaria agallocha* leaves inhibited seed germination and plumule and radical elongation of rice. Joes and Gillespi (1998) reported that juglone released from black walnut exhibited inhibitory effects on all measured variables including photosynthesis, transpiration, stomatal conductance, leaf and root respiration in corn and soyabean. The species *Rhazya stricta* is reported to contain alkaloids which are recognized as allelopathic agents (Putnam and Duke, 1978). The allelopathic effects include germination inhibition (Williamson *et al*., 1992; Patil, 1994), seedling growth retardation (Bhatt and Todaria, 1990; Kalburji and Mosjidis, 1993a, b) and poor seedling survival (Conard, 1985; Smith, 1990).

The potential use of allelopathy in weed control has been explored by several researchers worldwide on the germination and growth of weeds such as redstem, duck salad, barnyard grass (*Echinochloa crus* galli), dirty dora (*Cyperus deformis*), toothcup (*Ammannia coccinea* Rottb.) and desert horsepurslane *Trianthema portulacastrum* (Fuji, 1992; Hassan *et al*., 1994; Dilday *et al*., 1994, Olofsdotter *et al*., 1995; Olofsdotter and Navarez, 1996; Marambe, 1998). It is, therefore, considered to be a suitable choice for both identifying allelochemicals and studying allelopathy genetics (Olofsdotter, 2001). Phenolic acids have been identified in allelopathic germplasm (Rimando *et al.,* 2001). Turk and Tawaha (2003) studied the allelopathic effect of black mustard (*Brassica nigra* L.) on germination and seedling growth of wild oat (*Avena fatua* L.). Allelopathic effect of extracts of different plant parts like leaf, stem, flower and root of black mustard was found to affect the germination and radicle length by extract solutions and the inhibitory effect on germination increased with the increasing concentration of extract solution of the fresh plant parts which was also observed that the protease enzyme activity was suppressed causing reduced water uptake, which led to the poor seed germination of wild oat. Turk and Tawaha (2003) also found that residue incorporation affected the germination, plant height and dry matter accumulation per plant and the effect was greater for both root and shoot incorporation than only root incorporation.

Studies have been done on the exploitation of allelopathy via the use of allelopathic mulches and the application of cover crops (Olofsdotter *et al*., 1995). Nodule characteristics, root length and root/shoot ratios of *Melilotus parviflora* were significantly affected when growing with weed. Joshi (1991) reported that *Cassia uniflora* is a good biological control for *Parthenium hysterophorus* and has replaced the weed in some Indian states. At early years, studies have been conducted to demonstrate the nature of allelopathic effects of weeds on crops (Tukey, 1996). Barnyard grass interference also reduced rice yield and plant dry weight (Stauber *et al*., 1991). *Parthenium hysterophorous* L. exerts negative effects on agriculture, animal husbandry, ecology and the environment (Kohli and Rani, 1994) which is mainly due to the presence of parthenin, a sesquiterpene lactone of pseudoguanolide nature in various parts of the plants (Kohli *et al.,* 1993; De la Fuente *et al.,* 2000; Batish *et al.,* 2002, 2007; Singh *et al.,* 2002), Parthenin is known to have specific inhibitory effects on germination and growth of crops (Tefera, 2002; Singh and Singh, 2003; Batish *et al.,* 2005a, b; Wakjira *et al.,* 2005; Wakjira, 2009). The two synergistically acting groups of allelochemicals significantly decrease the seed germination and subsequent growth in many crops (Batish *et al.,* 2005a, b; Singh *et al.,* 2003). Whenever two or more plants are grown together, they compete with each other for various life support requirements (Caton *et al.,* 1999). Residues, exudates and leachates of many plant have been reported to effect the growth of the other plants, a wide range of injurious effect on crop growth has been reported as being due to phytotoxic decomposing products, release from leaves, stem, roots, fruits and seeds. Alam and Islam (2002) reported that plant produce chemicals which interfere with other plants and affect seed germination and seedling growth. Among various weeds, *Eupatorium odoratum* L, *Mikania micrantha* L., *Physalis minima* and *Drymeria cordata* were found most toxic (Bhatt *et al*., 2001).

Research on cucumber and rice germplasm has found large differences in allelopathic potential among accessions. Certain accessions strongly inhibited weed germination and growth (Olofsdotter and Navarez, 1996). In some cases, up to 70 % population of rice weeds, such as duck-salad (*Heteranthera limosa* (sw) Wild.), purple ammania (*Ammania coccinea* Rottb.), and broadleaf signal grass (*Brachiaria platyphylla* (Griseb.) Nash), were controlled by those accessions with strong allelopathic potential (Dilday *et al.,* 1992).

Recent research has revealed that there are some plants producing chemicals which are more effective in promoting growth of the other plants like gibberellins and IAA (Indole Acetic Acid) (Hasegawa, 1993), the proper use of allelopathy may also help to reduce the overuse of pesticides, herbicides, fungicides, nematicides, insecticides and fertilizers. Weeds in cropping systems are most often considered to be detrimental. In general, allelopathy has also been used to increase the yield of crops, vegetables, fruits and woody trees, etc. and to control insect pest diseases and weeds (Narwal, 1994). Daniel (1999) reported that allelopathy includes both promoting and inhibitory activities and is a concentration dependent phenomenon. The leaves and roots of subabul are very rich in nutrients like N, P, K, Ca and Mg (NAS, 1979) which can add substantial amount of nutrients to the soil through leaf litter.

Weeds pose a serious problem in crop production, when growing among crop plants, they adversely affect yield and quality of the harvest and increase production costs, resulting in high economic losses (Alam, 1991). Weeds compete with the main crops for nutrients and other resources and hamper the healthy growth ultimately reducing the yield both qualitatively and quantitatively. Rajan (1973) investigated the possible inhibitory effects of fruits and receptacles of *Parthenum hysterophorus* weed on germination and seedling growth of wheat and found out that seed germination was slowed, but total germination was not affected. Joshi (1991) reported that *Cassia uniflora* is a good biological control plant for *Parthenum hysterophorus* which is thought to significantly influence both the diversity and productivity of grassland plant communities (Navie *et al.,* 2004; Adkins and Navie, 2006; Nguyen *et al*., 2010; Nigatu *et al*., 2010). Weeds can cause significant yield loss of rice under tropical climatic conditions (Azmi and Karim, 2008). The production of allelochemicals in crop plants and their release into the soil could influence the germination and growth of plant species (Rice, 1984). These effects are selective, depending upon the concentrations and residue type, either inhibitory or stimulatory to the growth of companion or subsequent crops or weeds (Bhowmik and Doll, 1984; Naseem *et al*., 2003; Cheema *et al*., 2004; Jalili *et al*., 2007). Thus the intensity of competition between crops and weeds for space, light, moisture and nutrient will differ under various field conditions, which in turn will affect the allelopathic potentiality. Therefore, this area needs special attention for allelopathic researchers.

The above mentioned review of literature reveals that although significant amount of work has been carried out on various field crops and weeds, allelopathic works on trees are relatively less. On the contrary, a large number of trees and weeds are on trial with various crops in different agroforestry systems of our country.

In order to understand tree-crop-weed compatibility, it is desirable that the important trees that are commonly grown in agroforestry set up are well studied for their allelopathic potential and similarly, it is equally important to know under such situation, how the important field crops would behave when grown under different tree combination. Since agroforestry systems are more complex than any agro ecosystem involving trees, crops, weeds and a multitude of horizontal and vertical structure, the present attempt on tree-crop-weed interaction is expected to contribute a better understanding of our knowledge on their performance and management of the systems.

Chapter-3

STUDY SITE DESCRIPTION, MATERIALS AND METHODS

3.1 Study Area Description:

3.1.1 General description of Mizoram:

Lying in the north-eastern corner of India, Mizoram has a geographical area of 21,087 sq. km. and it lies in between 92^{0}.15' to 93^{0}. 29' E longitude and 21^{0}.58' to 24^{0}.35' N latitude. The shape is oblong whereas the length is 320 km. and the breadth is 160 kms. The surface is undulating, mostly mountainous and hilly with precipitous slopes having a forest cover of 15,853 sq. km. which is 75.18 % of the total land area (Statistical Abstract, Mizoram, 2010-2011). It is flanked by Myanmar in the east, Bangladesh and Tripura in the south and west and Cachar district of Assam and Manipur in the north. It has total of 630 miles (1088 km) boundary with Myanmar and Bangladesh and has the most variegated hilly terrain in the eastern part of India. The broken hills mainly run from north to south which are steep and are separated by rivers which flow either to the north or the south creating deep gorges between the hill ranges. The average height of the hills is about 900 metres. The annual rainfall ranges from 2000 mm to 2500 mm. In Mizoram, only 77 % of the land is reported to have less than 20% slope while 72 % of the land is having more than 50 % slope, the former is ideal for sustainable crop production (Anon, 1992).

3.1.2 Site description:

The field experiments were carried out at Tanhril near Mizoram University Campus located on the south-western part of Aizawl city, the Capital of Mizoram. The site is moderately slope and gradually decreases downwards. The average slope of the study site is about 26 % and located at an altitude of 850 metres MSL with an average rainfall of 2300mm. Pot experiment and laboratory (bioassay) experiment were carried out in the Department of Forestry, Mizoram University Campus, Tanhril, Aizawl which is 15 kms away from Aizawl city and lies between 23^0.42' to 23^0.46' N latitude and 92^0.38' to 92^0.42'E longitude (Figure: Map of Mizoram showing the study site).

The field experiment was carried out in an area of under 10 years old Teak (*Tectona grandis* L.) grown at a spacing of 2 x 2m and Neem (*Melia azadirach* L.) grown at a spacing of 2 x 2m which already had decomposed leaf litter under the plantation needed for the experiment. The areas (10 x 5m) for carrying out the experiment each under these tree areas were cleaned up for sowing seeds of the selected test crop seeds of maize (*Zea mays* L.) and paddy (*Oryza sativa* L.). Controlled plot was also made adjacent to the experimental sites. The selected crops were sown on the experimental sites from which observations and records were made at one month interval till the crops reach maturity and harvesting stage. Likewise, observations and records were made from pot and laboratory experiments. Another experiment for making out the effect of the selected weeds and trees *viz: Ageratum houstonianum* L., *Mikania micrantha* L., and *Melia azadirach* L., *Tectona grandis L.* on the crops were also carried out under pot and laboratory condition.

3.1.3 Climate:

Mizoram passes through the tropic of cancer, thereby providing a favourable climate for plant growth throughout the year. It is humid tropical characterized by short and dry winter from part of November to end of February and long summer without rainfall, except few showers from first part of March to end of April and monsoon rains from May to September with an average rainfall of 2000mm-2628mm while heavy rainfall occurs from June to August accounting nearly 78% to 80% of the total annual rainfall. The rainfall is not evenly distributed and the intensity in some period of time is very high that it causes landslips in some places. During monsoon period high rainfall occurs and the humidity is high. The precipitation during monsoon period is also very high, low in summer and medium in winter. Winter is also moderately cold. The mean summer and winter temperatures vary from 24^0C to 30^0C and 10^0C to 20^0C respectively (Figures 1a, b, c). The summer months are warm and wet. Although the temperature in the morning is cool, the temperature at noon is quite comfortable. Similarly, the highest temperature recorded is 29.2^0C which is also not so common during summer season. On the basis of temperature and rainfall, the year can be divided into three seasons, namely; spring or mild summer (March to April), rainy or wet summer (May to October) and winter (November to February). As a whole, Mizoram climate is pleasant and comfortable without chilling during winter and moderately warm during summer which is entirely under the direct influence of the monsoon.

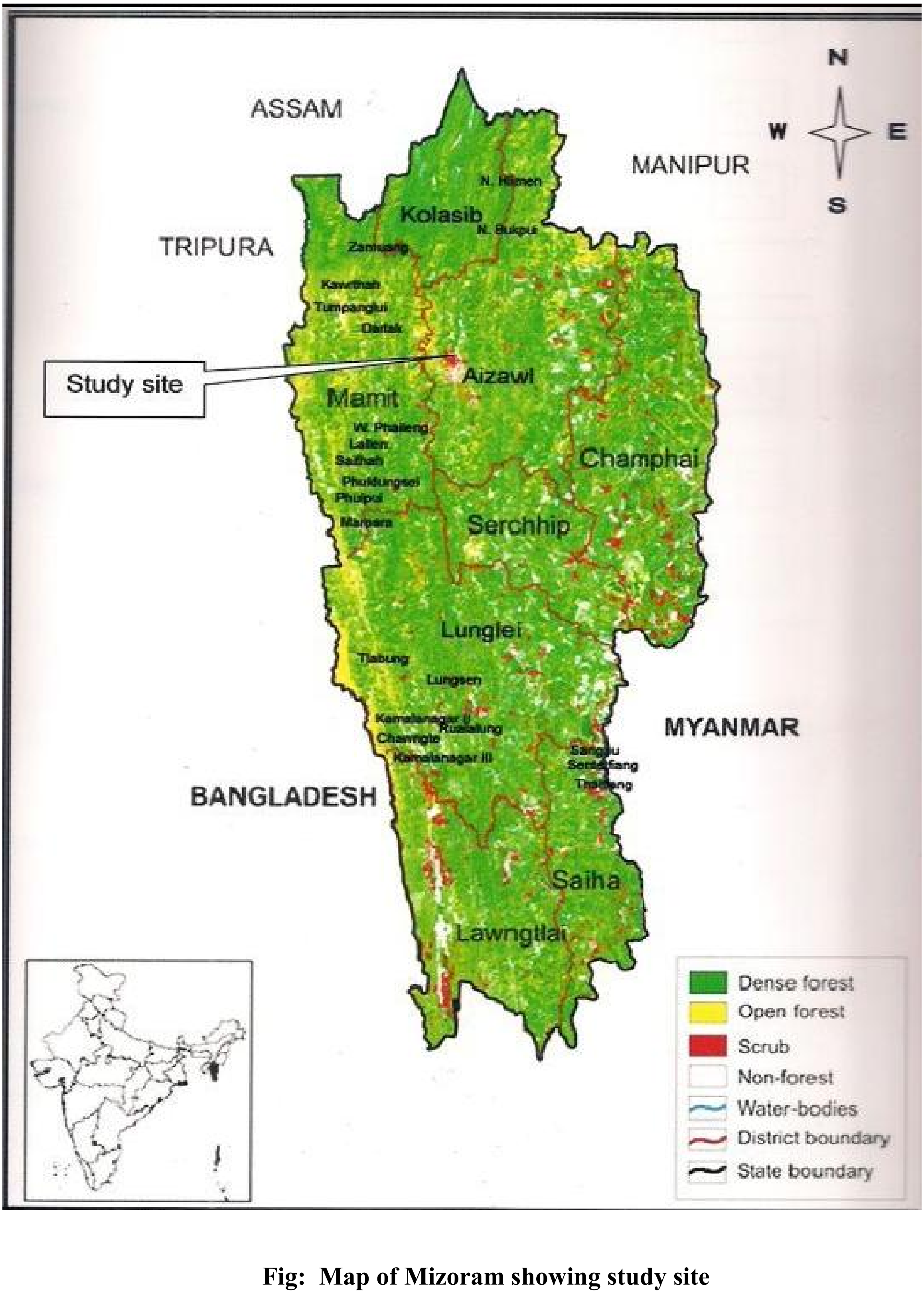

Fig: Map of Mizoram showing study site

(Source: MIRSAC, Aizawl, Mizoram).

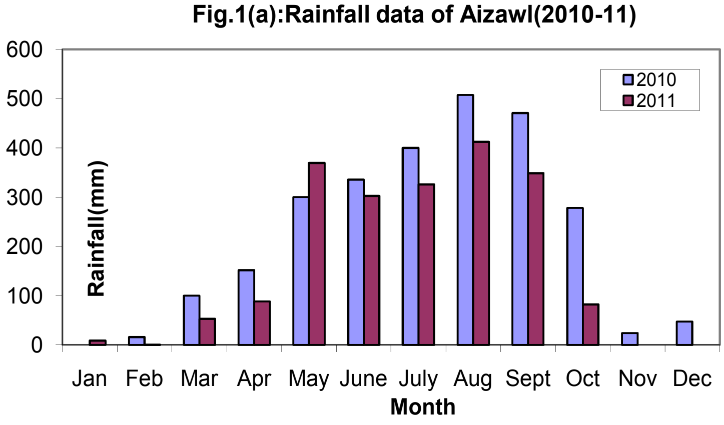
Fig.1(a):Rainfall data of Aizawl(2010-11)
600
500
400
300
200
100
0
Rainfall(mm)
2010
2011
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Month

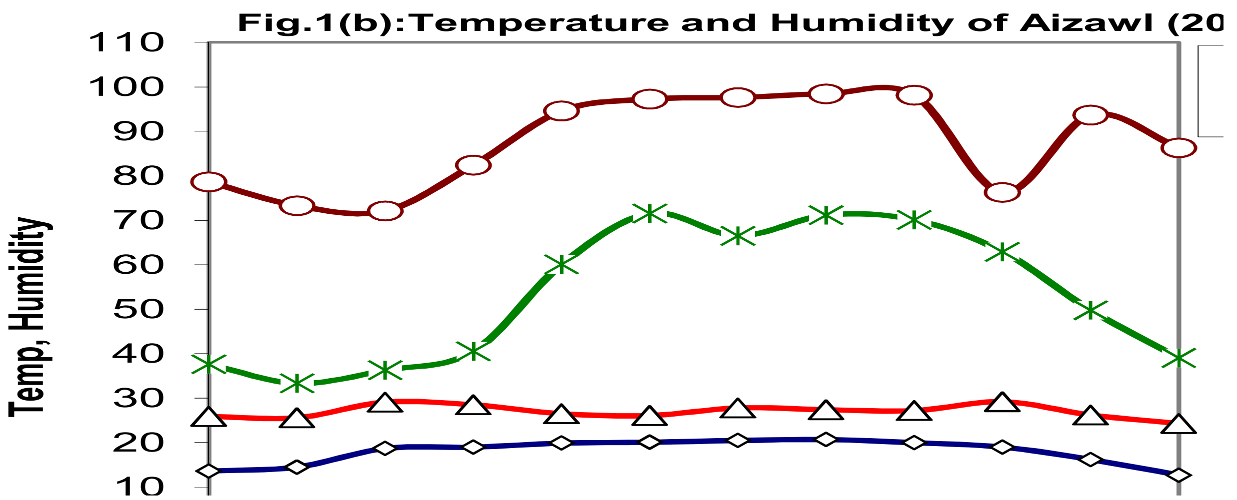
Fig.1(b):Temperature and Humidity of Aizawl (20
110
100
90
80
70
60
50
40
30
20
10
Temp, Humidity

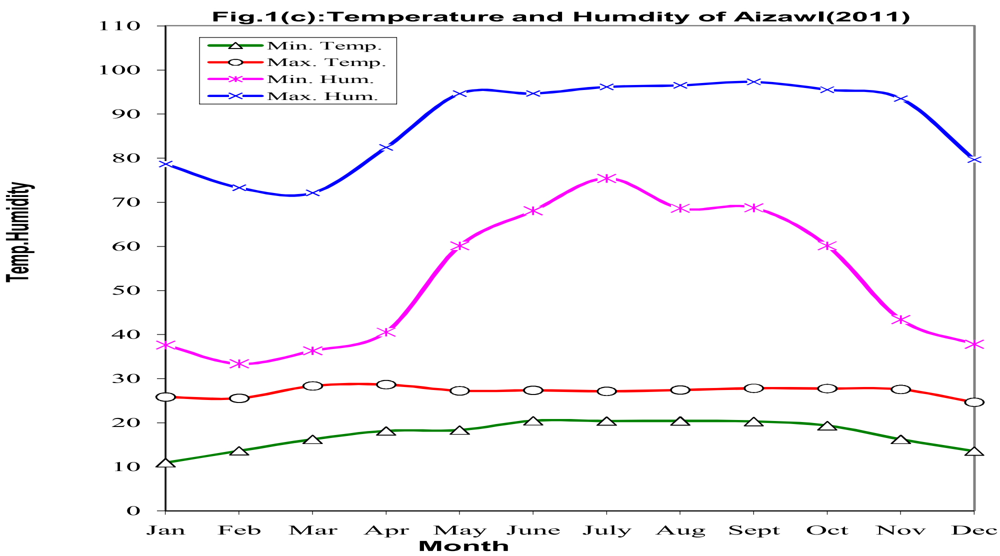
Fig.1(c):Temperature and Humdity of Aizawl(2011)
110
100
90
80
70
60
50
40
30
20
10
0
Temp.Humidity
Min. Temp.
Max. Temp.
Min. Hum.
Max. Hum.
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec
Month

3.1.4 Soil:

The study site, in general has acidic soil (pH ranges from 5.03 – 5.50). The particle fractionation of the soil and textural classes revealed it to be sandy loam soil. In general, soil of hilly terrains of Mizoram is highly leached, rich in iron, poor in bases, medium in potash and low available in phosphate due to heavy rainfall. The soil is young without very hard rocks and the quality of the sand is poor. The organic carbon content in the soil is also found inadequate. Almost all field crops thrive well in Mizoram soils.

3.2 Description of species under experiments:

3.2.1 Test crops:

i) *Zea mays* L. (Maize)

Scientific Classification:

Family	:	Poaceae
Botanical name	:	*Zea mays* L.
Common names	:	Corn, dent corn, maize
Local name	:	*Vaimim*

Maize (*Zea mays* L.) is the 2^{nd} most important cereal crop in the state of Mizoram and is grown in varied agro ecosystems as sole crop or in combination with other crops and trees. About 9005.00 ha. and 6904.50 ha. of land {Statistical abstract 2010-2011 and 2011-2012, published by Directorate of Agriculture (CH) Mizoram: Aizawl} is reported to have been brought under maize cultivation in the state of Mizoram during the year 2010-2011 and 2011-2012 respectively. Maize is the third most important cereal grown after wheat and rice is known as the 'king of grain crops' (Anon, 2006).

The level of production is somewhat moderate in Mizoram and it needs to be substantially increased to meet the growing demand for human food, animal and poultry feed. The species flourishes well and can be successfully grown in rainy (*kharif*), winter (*rabi*) and summer (*zaid*) crop seasons. Because of its divergent types, it can be grown over a wide range of climatic conditions and can be grown under a wide variety of soil but adapted to well drained mildly alkaline at a soil pH range of 7.5 to 8.5 and requires light (sandy), medium (loamy) and heavy (clay) soil. It grows best in 600-1500mm rainfall and is known to susceptible to water logging as well as soil moisture stress throughout its life cycle.

The species is grown as a sole cropping under jhum or with mixed cropping successfully intercropped with paddy, brinjal, chilli, bittergourd, pumpkin, cucumber, melon, and other short duration varieties of pulse crops like greengram, blackgram, cowpea, etc. and oilseed crops (groundnut, soybean, sesamum). The species is also found cultivated under different tree species *viz.,* leucaena, jack fruit, tree bean, etc. at a definite spacing and does not lower the yield than that of pure maize, while intercrop would be a bonus.

ii) *Oryza sativa* L. (Paddy)

Scientific Classification:

Family	:	Poaceae
Botanical name	:	*Oryza sativa* L.
Common name	:	Rice
Local name	:	*Buh*

Paddy is the most important cereal of the state of Mizoram, reported to have been grown in about 46092.00 ha. and 38976.00 ha. of agricultural land in the year 2010-2011 and 2011-2012 respectively {Statistical abstract 2010-2011 and 2011-2012, published by Directorate of Agriculture (CH) Mizoram: Aizawl}. It is grown under rainfed condition on hills and Wet Rice Cultivation (WRC) on valleys. It is the most important crop for human nutrition and calorie intake, providing more than $1/5^{th}$ of the calories consumed and is the staple food of Mizoram. It thrives in all types of soil ranging from pH 5-8 and can be grown under different environmental conditions.

Crop rotations increase the yields and facilitate sustained productivity through increased nitrogen supply, improvement of soil health, water and nutrient availability, improvement in soil microbial activity, improvement in weed control, decreased disease-pest pressure and availability of growth promoting substances originating from crop residues. Experiments on rice-based cropping systems involving pre-*kharif* green manure crop (greengram, cowpea, sunhemp or dhaincha) followed by *kharif* rice and non-rice *rabi* crop (groundnut, sunflower, soyabean or blackgram) have shown that rice crop gets directly benefited from the preceding green-manure crop.

3.2.2 Tree species:

i) *Melia azadirach* L. (Neem)

Scientific Classification:

Family	:	Meliaceae
Botanical name	:	*Melia azadirach* L.
Common names	`:	Bead tree, Chinaberry tree, White Cedar, Bakain, Persian lilac, etc.
Local name	:	*Neem thing*

Neem is elegant, tall and evergreen tree with a broad canopy, extensively used as roadside and avenue tree in Mizoram. It has an almost straight trunk and spreading branches, covered with dark grey, cracked bark moderately thick, furrowed longitudinally and obliquely, dark grey, reddish brown inside and the tree is mostly used as fencing material in Mizoram. It is planted at a spacing of 2 x 2m under which maize and paddy can be grown in Mizoram.

The plant prefers open sun and can do well in partial shade too. It is hardy to most frosts and can withstand many environmental adversities including drought and infertile stony, shallow and acidic soils. Neem improves health and vigour of the plant, soil fertility, soil texture and porosity, soil aeration, nutrient retaining properties of soil. It also helps in availability of nutrients in the soluble form coinciding with the growth and development stages of the plant, increases soil micro flora, improves drought tolerance by build up of stable humus, soil structure, and correct soil pH. It also acts as soil conditioner (EXONA conditioner- natural soil conditioner). Neem gives better yields, it is ideal for crops like cereals, pulses, oilseeds, vegetables, fodder crops and plantation crops.

Neem increases greenness of the leaves and promotes photosynthetic activity of crop plants. Neem cake is an excellent organic by product of neem seed oil and is several times rich in plant nutrients than manure. Neem cake is used as a natural fertilizer, rich in nitrogen (2-3%), phosphoros (1.0%) and potash (1.4%). It is most useful for paddy, cotton and sugarcane. Neem cake when used in combination with superphosphate, the yield of paddy increases by 19% as compared to other manures. Shyam Sunder (2006), reported yield data from large scale farm trials on paddy and sugarcane with neem cake coated urea, the increase in paddy yield was 22.8% over urea alone and in sugarcane it was 15.5%. (Shyam Sunder, 2006).

Neem trees have many unique compounds that have been identified (Sankaram, 1987). The more common and the most analyzed compounds include nimbin (anti-inflamatory), nimbidin (anti-bacterial, anti-ulcer, analgesic, anti-arrhythmic, anti-fungal), nimbidol (anti-tubercular, anti-protozoan, anti-pyretic), gedunin (anti-malaria, anti-fungal), sodium nimbinate, queceretin, salanin and azadirachtin (repellent, anti-feedant, anti-hormonal) (Sankaram,1987).

ii) *Tectona grandis* L. (Teak)

Scientific Classification:

Family	:	Verbanaceae
Botanical name	:	*Tectona grandis* L.
Common name	:	Teak
Local name	:	*Tlawr*

Teak is one of the chief importance and principal timber trees of India and Mizoram. It is undoubtedly a global leader of high quality tropical timbers (Bhat *et al*., 2005) extensively used for ship-building, house building, construction, furniture and cabinet-work, general carpentry, and numerous other purposes. The timber has gained high reputation and popularity, as it is generally accepted as a comparison standard for timbers. Teak wood is the first choice of an experienced user for its proven merit (Bhat, 1991). Teak timber is largely exported from Burma (Myanmar) to Europe.

Teak is found in a variety of habitats and climatic conditions from arid areas with only 500mm of rain per year to very moist forests with up to 5000mm of rain per year. Typically, though, the annual rainfall in areas where teak grows averages 1250-1650mm with a 3-5 months dry season. Teak is a large, deciduous tree up to 40m (131ft) tall. The species is a pronounced light demander and will not tolerate suppression at any period of its life, and requires complete overhead light. It produces a large deep root system and has greater power of resisting the effects of fire than the majority of its associates. It can be grown at an altitude of 0-1200m, and at an annual mean temperature of 14-36^{o}C. It is grown at a large scale plantation by the teak grower at a spacing of 2 x 2m in Mizoram, to fetch a good return under which maize and paddy are often grown.

Above all, the teak requires good subsoil drainage, and will not endure stiff soil which is liable to water-logging. Their most suitable soil is deep, well drained, fertile alluvial-colluvial soil with a pH of 6.5-8 and a relatively high calcium and phosphoros content. Phytochemicals betulin, betulinic acids and silica, etc. are present in teak (Duke, 1992) which could be the reason that a plant does not thrive well grown under teak plantation.

3.2.3 Weeds species:

i) *Ageratum houstonianum* L.

Scientific Classification

Family	:	Asteraceae
Botanical name	:	*Ageratum houstonianum* Mill.
Common name	:	Floss flower, blue mink, garden ageratum, etc.
Local name	:	*Vailenhlo*

A weed of garden, roadsides, disturbed sites, waste areas, pastures, crops, wetlands and water ways in the tropical, sub-tropical and warmer temperate regions of most of the countries and is one of the most prevalent weeds in Mizoram.

The plant is erect, 0.3-1m high, coarsely hairy or nearly glabrous stems and leaves. The leaves are mostly oppositely arranged, borne on stalks (i.e. petioles) 0.5-3 cm long. It flowers most of the year, mainly during summer and is short lived (i.e. annual or biennial). Blue billy goat weed is regarded as an environmental weed. It escapes frequently and invades bushland and other natural environments resulting in substantial changes in native plant communities. It often forms dense stand that excludes other species and there is evidence to suggest that it has allelopathic properties that inhibit the growth and germination of other plants.

Ageratum houstonianum L. has evolved an ingenious method of protecting itself from insects; it produces a prococene compound which interferes with the normal function of the corpus allatum, the organ responsible for secreting juvenile hormone. This chemical triggers the next moulting cycle to prematurely develop adult structures, and can render most insects sterile if ingested in large quantities. *Ageratum houstonianum* L. is toxic to grazing animals, causing liver lesions and is tumorigenic. It contains pyrrolizidine alkaloids. *Ageratum houstonianum* L. weed has a long history of use as an ornamental plant and has been spread around the world for this reason. It is also used in some cultures as a medicinal plant.

ii) *Mikania micrantha* L.

Scientific Classification

Family	:	Asteraceae
Botanical name	:	*Mikania micrantha* L.
Common name	:	Mile-a-minute, Chinese creeper, bitter vine, etc.
Local name	:	*Japan hlo*

Also known as the common names of climbing hempweed, one of the most noxious weeds in Mizoram found commonly everywhere. It is a fast growing vine. It thrives in warm and humid environments, and has been observed to grow almost half a metre per week under optimal conditions and it can smother and overwhelm other small plants and even large trees. It has been documented as a pest in banana, cocoa, coconut, oil palm, rubber and rice plantations. Mile-a-minute is one of the top one hundred global invasive weeds.

Mikania has vigorous vegetative and sexual reproductive capacity, but cannot tolerate dense shade. Seeds are dispersed over long distances by wind and the plants can grow vegetatively from the nodes and from very small segments of the stem. Seed dispersal occurs during October-April. Wind, water, and animals are the common agents for the dispersal of seeds. The weed covers the canopy of trees, thereby reducing light penetration causing damage to tree crops and agroforestry/multipurpose trees and other crop plants competing for soil nutrients and sunlight.

Mikania micrantha L. is becoming an increasing problem in many countries (Dovey *et al*., 2004; Ellison *et al*., 2008). Its rapid growth and ability to climb and smother plants severely impact on crop production and net income of farmers who report that the weed can retard growth of crops through direct competition for space, nutrient or light by smothering plants, thus reducing yield and income. In India, *Mikania micrantha* L. was identified as the number one problem faced by farmers in Kerala, with the presence of *Mikania micrantha* L. increasing production is lost by about 10% (Muraleedharan and Anitha, 2001). It has a high potential for causing significant economic and ecological damage in agricultural and natural areas (Manrique *et al.,* 2011). It has been listed as one of the hundred most invasive alien species in the world (Lowe *et al*., 2001) and is one of the top ten worst weeds in the world (Holm *et al*., 1977), it has invaded widely and caused vast economic loss in Hong Kong, Guang Dong and Hainan (Feng *et al*., 2002; Zhang *et al.,* 2004). *Mikania* poses a threat to coconut, rubber, teak and *Pinus* plantations. Besides the effect on crop yield, *Mikania* makes harvesting cumbersome due to its twining and creeping habit.

3.3.2 Methodology:

In order to achieve the objectives set forth in the thesis, experiments have been conducted under three set up.

a) Under bioassay – laboratory conditions,

b) Under pot culture – under controlled conditions, and

c) Under field condition – under tree plantations.

3.3.1 Bioassay experiment:

i) Collection of plant (leave) samples for bioassay :

The leaf samples from two tree species *viz.* a) Teak (*Tectona grandis* L.), b) Neem (*Melia azadirach* L.), and two weed species *viz.* a) *Ageratum houstonianum* L. b) *Mikania micrantha* L. were collected directly from the mature plants from their lower, middle and upper portions to represent the entire canopy in such a manner that there was no biasness in sampling. All the contaminants like soil, dust particles, etc. were removed from the collected leaf samples by dry wiping with soft brush and wash with tap water for only a few seconds followed by quick rinsing with distilled water, which may have influenced the chemical composition of the leachates. The leaves were then stored in a polythene bag and put it in a refrigerator at 4^{o}C for preventing it from fermentation and then shade dried after which again ground with the help of mortar and pestle.

ii) Preparation of leachates:

Aqueous leachates of all the four selected species (two trees, two weeds) were prepared by soaking the powdered leaves of the respective species in distilled water in 1:10 (w/v) ratio i.e. in low osmolality, so that the inhibitory/ stimulatory effects can be attributed to allelochemicals. The soaking of powdered leaves was allowed to remain for 24 hours so that it leaches out most of the allelochemicals. The leachates was filtered through Whatman No.1 filter paper. The leachates was then diluted to 10%, 30%, 60% and 90% concentration with distilled water and undiluted 100% concentration which were depicted as T1, T2, T3, T4 and T5 respectively. The leachates thus prepared were then stored at 7-8^{o}C for future use.

iii) Evaluation of bioassay:

The bioassay was conducted at the Laboratory of Forestry Department, Mizoram University, Aizawl. Uniform healthy seeds of maize (Sticky maize) and paddy (IR-64) (20 seeds each of the two test crops) were put in a uniform diameter Petri-dishes (9cm diameter), sterilized at 120^{o}C to eliminate bacterial and fungal contamination. The seeds were saturated with adequate quantity of leachates. Whatman No.1 filter paper was used for germination media. During the observation period, respective leachates were added on alternate days to maintain adequate moisture in all the treatments. A control was maintained for each species with distilled water. Percentage of germination for each test crops and other initial growth parameters were observed and recorded till the 12th day.

iv) Parameters recorded:

Various parameters recorded under bioassay were *viz.;* a) Percentage of germination, b) root and shoot length, c) biomass of fresh and dry weights of root and shoot.

Treatments of different concentrations used for the experiment under bioassay condition were as below:

Control - Seeds of maize and paddy grown under distilled water only.

T1 - Seeds of maize and paddy grown under aqueous leaf leachate of 10 % concentration.

T2 - Seeds of maize and paddy grown under aqueous leaf leachate of 30 % concentration.

T3 - Seeds of maize and paddy grown under aqueous leaf leachate of 60 % concentration.

T4 - Seeds of maize and paddy grown under aqueous leaf leachate of 90 % concentration.

T5 - Seeds of maize and paddy grown under aqueous leaf leachate of 100 % concentration.

3.3.2 Pot culture experiment:

i) Collection of soil samples for pot culture:

Soils from different areas under the selected field for conducting experiment were collected mostly from the upper 15cm of the rhizosphere of teak and neem plantations very carefully by using soil auger, mixed well and brought for pot experiment. Soil from the adjacent open areas was also collected that served as control and soil from the growing area of *Mikania* and *Ageratum* which served the respective treatments.

ii) Preparation of soil samples:

The soil samples collected were spread and then dried under sun for 2 days in order to remove harmful microorganisms. Plant debris and stones were also removed; soil aggregates were broken up by grinding lightly leaving primary soil and gravel particles.

iii) Collection of leaf litter and preparation of leaf powder:

Normally shed leaves beneath the plants were collected and cleaned in order to prevent the litter from microorganisms and fermentations and partially ground with the help of mortar and pestle and put it in a vessel for making leaf litter. Leaf powder was also prepared which were added into the mixer of soil.

32 polypots (size 25 x 15cm) were filled with 3kgs of soil each from beneath the neem and teak plantation, out of which 16 polypots each were mixed with 200gm of leaf litter, 20gm of leaf powder. Another 16 polypots were filled with 3kgs of soil (for each polypot) taken from the growing area of *Mikania* and *Ageratum* which were also mixed with 200gms of leaf litter and 20gms of leaf powder of *Mikania* and *Ageratum*. Eight polypots were also prepared which contained only ordinary soil free of leaf litter and leaf powder that served as control. Altogether there were 56 polypots used in the experiment. The polypots were then placed under partially shaded (50%) green house for further use.

iv) Evaluation of pot culture:

For all the treatments and control, 8 number of maize (Sticky maize) and paddy (IR-64) seeds were sown in polypots which were irrigated with the respective leachates at 3 days interval to maintain sufficient and uniform moisture and also to prevent over desiccation of soil in the pots. Pots containing ordinary soil mixture, irrigated only with tap water were considered as control.

A seed was considered germinated, when the hypocotyl/epicotyl/coleoptyl or primary root protrudes through the seed. After emergence, the seedlings were thinned to five in each polypot. Seed germination, performance and yield of the crops were recorded at monthly interval.

v) Parameters recorded:

The various parameters recorded under pot culture experiment were, a) percentage of seed germination, b) plant height, c) number of leaves, d) diameter of stem, e) number of cobs, f) weight of cob, g) number of grains per cob, h) biomass of fresh and dry weights of root and shoot.

vi) Treatments:

The different treatments under pot culture experiment were as below:

Control - Pot containing ordinary soil, irrigated only with tap water.

ST- Soil from beneath the teak plantation.

DT- Soil beneath the teak plantation mixed with 200gms of teak leaf litter and 20gms of teak leaf powder.

SN- Soil from beneath the neem plantation.

DN- Soil beneath the neem plantation mixed with 200gms of neem leaf litter and 20gms of neem leaf powder.

DM- Soil beneath the *Mikania* growing area mixed with 200gms of *Mikania* leaf litter and 20gms of *Mikania* leaf powder.

DA- Soil beneath the *Ageratum* growing area mixed with 200gms of *Ageratum* leaf litter and 20gms of *Ageratum* leaf powder.

3.3.3 Field experiment:

i) Field preparation:

An area measuring 10 × 5m width under plantation with same age of both tree species were demarcated for field experiment. The same area of land adjacent to plantation site free of tree plantation was selected which serves as control plot. After identification of plot, the field was cleaned by removing unwanted plants, weeds, stones and other plant debris, twigs, branches, leaves, etc. for cultivation of the selected species. Similar treatments were given to all the plots. The experimental sites had similar topography, site conditioning and average slope percentage of 26-35%.

ii) Evaluation of field experiment:

For all the treatments and control, 8 numbers of maize (Sticky maize) and paddy (IR-64) seeds were sown at a spacing of 30 × 30cm on all the fields under rainfed condition, after germination, thinning was done in some places leaving 5-6 numbers of plants in each hole. During the growing period, 6 to 7 times weeding was done at 20 days interval, monthly performances of the crops on all the plots had been recorded regularly throughout the study period.

iii) Parameters recorded:

The various parameters observed during the study periods were *viz.* a) Percentage of germination, b) plant height, c) number of leaves, d) diameter of stem, e) number of cobs/ number of grains per sheaves, f) weight of cobs/grains, g) number of grains per cob, h) biomass of fresh and dry weights of root and shoot.

The different treatments under field experiment were as below:

Control - Plot free of any standing trees and plants,

T1 - under Teak,

T2 - under Neem.

3.4 Statistical Analysis:

All the data collected from various experimental fields were subjected to statistical treatments for meaningful comparison and interpretation of results. The results were always compared from the control treatments. The inhibition or promotion of various growth parameters such as germination, root and shoot length, diameter, number of leaves, yield of crops, biomass of fresh and dry weight of root and shoot were compared from the Critical Difference resulted out of the Analysis of Variance (ANOVA).

The % of promotion/inhibition was calculated following the formula used by Chung *et al.,* (2003),

% promotion/inhibition = [(Control-extract)/control] x 100

in which negative sign indicates stimulation and positive sign shows inhibition.

Chapter-4

EFFECT OF LEAF LEACHATES OF TREES AND WEEDS ON THE TEST CROPS UNDER BIOASSAY

4.1 Effects of aqueous leaf leachate of *Tectona grandis* L. on seed germination and initial growth parameters of seedlings of the test crop.

i) Seed germination:

The seed germination of *Oryza sativa* L. was significantly ($P<0.05$) inhibited by 10%, 20% and 35% under T3, T4 and T5 of leaf leachate concentration of *Tectona grandis* L. while there were no discernible variations at T1 and T2 (0.00%) leachates concentration (Table 1, Figure 2a).

However in the case of *Zea mays* L., the seed germination was significantly ($P<0.05$) inhibited irrespective of leaf leachate concentration and the inhibition was proportional to the leachate concentrations (Table 3, Figure 3a).

ii) Root and shoot length:

The data showed that the elongation of root and shoot of *Oryza sativa* L. was significantly ($P<0.001$) suppressed with an increase in aqueous leaf leachate concentration. The aqueous leaf leachates at T1 concentration did not have impact on the root growth (6.44%) when compared with control. The root extension was suppressed by 53.16%, 45.89%, 85.02% and 91.01% at T2, T3, T4 and T5 leachate concentration respectively, while the shoot elongation was suppressed by 22.94%, 33.27%, 64.80% and 73.32% at T2, T3, T4 and T5 leachates concentration respectively (Tables 1 and 2).

Similar was the case for *Zea mays* L. The percentages of inhibition of root growth of maize were 33.33%, 50.51%, 60.15%, 67.04% and 94.54% and the percentages of inhibition of shoot growth were 7.87%, 19.91%, 40.52%, 70.99% and 85.16% at T1, T2, T3, T4 and T5 leachate concentration respectively when compared with the control (Figures 3 b, c). On an average, the extension of root and shoot were significantly inhibited ($P<0.001$) as the percentage of concentration increased (Tables 3 and 4).

iii) Fresh weight of root and shoot:

The fresh weight of root of *Oryza sativa* L. under all the leachate concentration was significantly ($P<0.001$) reduced when compared with the control. Similar was in the case with fresh weight of shoot which was non-significant at $P<0.05$ level. The highest reduction in fresh weight of root and shoot was observed under T5 leaf leachate concentration as compared to control (69.23% and 71.79%) (Tables 1 and 2, Figures 2d, e).

In case of the fresh weight of root and shoot of *Zea mays* L., weight of root under all the treatments was significantly inhibited at $P<0.001$. The percentage of inhibition gradually increased as the per cent of concentration increased. The lowest percentage of inhibition was observed at T1 concentration of the leachates (23.53%) while the highest inhibition was observed at T5 concentration of the leachates (86.27%). Reduction in weight of shoot was also observed as the per cent of concentration increased. Under T1 leaf leachates concentration, only 0.33% inhibition was observed which revealed that the leaf leachate concentration (T1-10% concentration) had almost no or least effect as compared to higher concentrations. This is further evidenced at T5 (100%) leaf leachates concentration where maximum reduction (81.37%) was observed (Tables 3 and 4, Figures 3d, e).

v) Dry weight of root and shoot:

Dry matter production of *Oryza sativa* L. was significantly ($P<0.001$) inhibited as the percentage of aqueous leaf leachate increased. The dry root weight of *Oryza sativa* L. was significantly reduced under all the treatments which were highest under T5 (100% reduction) as compared to control. Similar trend was observed in dry weight of shoot at $P<0.05$ level. A reduction in percentage of 14.28%, 42.86% and 85.71% was recorded under T1, T2, T3, T4 and T5 and differences were significant at $P<0.05$ and $P<0.001$ level (Tables 1 and 2, Figures 2f, g).

The dry weights of root and shoot of *Zea mays* L. under leaf leachates concentration of *Tectona grandis* L. were significant at $P<0.001$ (Tables 3 and 4, Figure 3f, g). Under different treatments of the leaf extract, it was observed that the per cent of reduction in weight of root gradually increased with an increase in leachate concentration and the corresponding reduction were 20%, 46.67%, 53.33%, 66.67% and 80% for T1, T2, T3, T4, and T5 respectively. In the case of dry weight of shoot, no adverse impact was seen under T2 (30%) leaf leachates concentration, however, 3.2%, 32.26%, 61.29% and 74.19% reduction was observed at T1, T2, T3, T4 and T5 leaf leachates concentration and were significant at $P<0.001$ respectively.

Discussion:

The results show that the inhibitory effect of aqueous leaf leachate of *Tectona grandis* L. on *Oryza sativa* L. and *Zea mays* L. on the seed germination, root and shoot length, fresh and dry weight of root and shoot were a concentration dependent phenomenon. The reduced seedling germination, root and shoot length and biomass of fresh and dry root and shoot is attributed to the accumulation of toxic or poisonous chemicals of the donor in the aqueous leaf leachate which could be harmful for the crops. It was well known that, plant parts contain allelochemicals in the soil and media known to inhibit or sometimes promote germination, growth, development, distribution and propagation of plants species (Tawaha and Turk, 2003). Although allelochemicals emanate from all the plant parts, but leaves are most potent sources (Horsley, 1977). The present observation is in line with others that the extent of leachates effect depends on the rate of production, leaching amount and their combination time, which they released in the soil (Muller, 1996; Assaeed and Al Doss, 1997), also the amount of chemical released in the soil or in solution (Malik, 2004). The leachate solution not only affected percent germination and caused complete failure of germination (Assaeed and Al Doss, 1997). Allelochemicals decreased elongation, expansion and division of cells which are growth prerequisite (Dos Santosh *et al.,* 2004). Also, allelochemicals inhibit absorption of ions (Patil, 1994) and therefore, resulted in arrested growth (Dekker and Maggit, 1983).

The results on germination and overall seedling growth nevertheless were depended on the concentration of the leachates. This was clearly evidenced as the concentration increased, the per cent of inhibition also increased on growth parameters (Table 1-4), the results also support the findings of Alam (1990); Joshi and Prakash (1992); Nadal (1993) and Bora *et al.* (1999). In almost all the cases, the concentration especially from 60% onwards, significant reduction of germination and growth of seedlings was observed. The adverse effect of *Tectona grandis* L. on the germination and growth of the test crop might be attributed to the phytotoxic chemicals released from the leaves. It is proved that the allelopathic effect from *Tectona grandis* L. leaves has been tested on solanaceae species such as the tomato (*Lycopersicum esculentum*), egg plant (*Solanum melongena*) and pepper (*Capsicum annum*) (Krishna *et al.,* 2003). The extracts significantly inhibited germination and growth of these plant species. *Tectona grandis* has also shown high allelopathic activity on wheat (*Triticum aestivum*) (Krishna *et al.,* 2003). Although laboratory bioassays are of great importance to point out the single allelopathic effect, more studies are recommended while proposing the trees as an associated species for large scale agroforestry plantations. It is well known that foliage leachates are potent sources of toxic metabolites and that the toxic effects are species specific. Bhatt and Todaria (1990) recorded that leaf mulching and aqueous extract of *Adina cordifolia* and *Prunus cerasoides* significantly reduced the dry matter production of *Hordeum vulgare* and *Glycine max* ($P<0.05$). The results obtained from Table 1- 4 clearly revealed that the leaf extract of *Tectona grandis* L. exhibited an inhibitory effects and the intensity of decrease was proportional to the leachate concentrations. As the concentration of leachate increased the intensity of the inhibition also increased.

Bumibhamon *et al.* (1980) have reported that the presence of a phytocide in *Tectona grandis* aqueous extract of its fruits mesocarp inhibited germination of rice and pine seeds. Duke (1992) also reported that phytochemicals like betulin, betulinic acid and silica are present in teak. Thus, inhibition of aqueous leaf leachates of *Tectona grandis* L. on seed germination, growth and biomass production of fresh and dry weight of paddy and maize were a concentration of leachates dependent under bioassay condition.

Table 1: Effect of aqueous leaf leachate of *Tectona grandis* L on seed germination, root and shoot extension, biomass of fresh and dry weights of root and shoot of *Oryza sativa* L. under bioassay condition.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	100±0.00	16.696±0.149	13.51±0.062	0.013±0.000	0.039±0.000	0.004±0.00002	0.007±0.00002
T1 (10%)	100±0.00	15.62±0.320	10.451±0.225	0.011±0.000007	0.023±0.005	0.003±0.000007	0.006±0.010
T2 (30%)	100±0.00	7.82±0.041	10.41±0.148	0.01±0.00001	0.029±0.051	0.001±0.00001	0.006±0.00001
T3 (60%)	90±0.00	9.033±0.057	9.015±0.099	0.006±0.00004	0.021±0.00001	0.002±0.000005	0.004±0.00001
T4 (90%)	80±0.00	2.5±0.030	4.755±0.164	0.005±0.00003	0.019±0.00004	0.001±0.00007	0.004±0.00001
T5 (100%)	65±0.00	1.5±0.102	3.604±0.099	0.004±0.00001	0.011±0.002	0±0.0	0.001±0.00007
CD at P ≤ 0.05	0.00	2.731	2.55	0.003	0.375	0.002	0.074

± SE. m, n= 4

Table 2: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Tectona grandis* L. on growth attributes of *Oryza sativa* L. under bioassay condition.

Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
	F- Value	F- Value	F- Value	F- Value	F- Value	F- Value
T1 (10%)	9.2759 ns	171.5364***	160.0000***	1.5635 ns	29.5849***	0.7230 ns
T2 (30%)	3291.074***	373.023***	0.00	0.937 ns	89.286***	23.967**
T3 (60%)	2301.794***	1463.867***	355.057***	3018.105***	86.943***	144.029***
T4 (90%)	8700.171***	2477.577***	200.000***	575.577***	174.491***	144.029***
T5 (100%)	7069.616***	7154.333***	1287.364***	48.509***	322.667***	657.509***

** significant at P<0.05, *** significant at P<0.001, ns - non significant.

Table 3: Effect of aqueous leaf leachate of *Tectona grandis* L. on seed germination, root and shoot extension, biomass of fresh and dried weights of root and shoot of *Zea mays* L. under bioassay condition.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	75±0.00	22.057±0.155	21.725±0.088	0.102±0.00003	0.306±0.00003	0.015±0.00001	0.031±0.00002
T1 (10%)	30±0.00	14.704±0.021	20.014±0.123	0.078±0.00004	0.305±0.00006	0.012±0.00002	0.030±0.00004
T2 (30%)	30±0.00	10.915±0.123	17.4±0.078	0.072±0.00004	0.249±0.00002	0.008±0.00001	0.031±0.00004
T3 (60%)	30±0.00	8.79±0.055	12.915±0.04	0.047±0.00004	0.161±0.00003	0.007±0.00001	0.021±0.00005
T4 (90%)	25±0.00	7.270±0.001	6.302±0.008	0.034±0.00002	0.082±0.00003	0.005±0.00003	0.012±0.00003
T5(100%)	10±0.00	1.205±0.039	3.223±0.038	0.014±0.00002	0.057±0.001	0.003±0.000007	0.008±0.00001
CD at P ≤ 0.05	0.00	1.530	1.308	0.006	0.012	0.003	0.006

± SE. m, n= 4

Table 4: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Tectona grandis* L. on growth attributes of *Zea mays* L. under bioassay condition.

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Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
	F- Value	F- Value	F- Value	F- Value	F- Value	F- Value
T1 (10%)	2202.530***	126.750***	2280.819***	6.277**	101.822***	4.383 ns
T2 (30%)	3162.38***	1342.44***	3513.54***	20971.30***	715.74***	4.38 ns
T3 (60%)	6487.41***	8247.55***	9011.87***	87793.30***	1955.35***	271.33***
T4 (90%)	9073.5***	30202.0***	25280.4***	216618.5***	732.8***	2189.1***
T5 (100%)	16930.71***	36808.01***	51983.11***	29109.67***	4786.96***	6399.21***

** significant at P<0.05, *** significant at P<0.001, ns - non significant.

Fig. 2a: Germination of *Oryza sativa* L. under aqueous leaf leachates of *Tectona grandis* L.

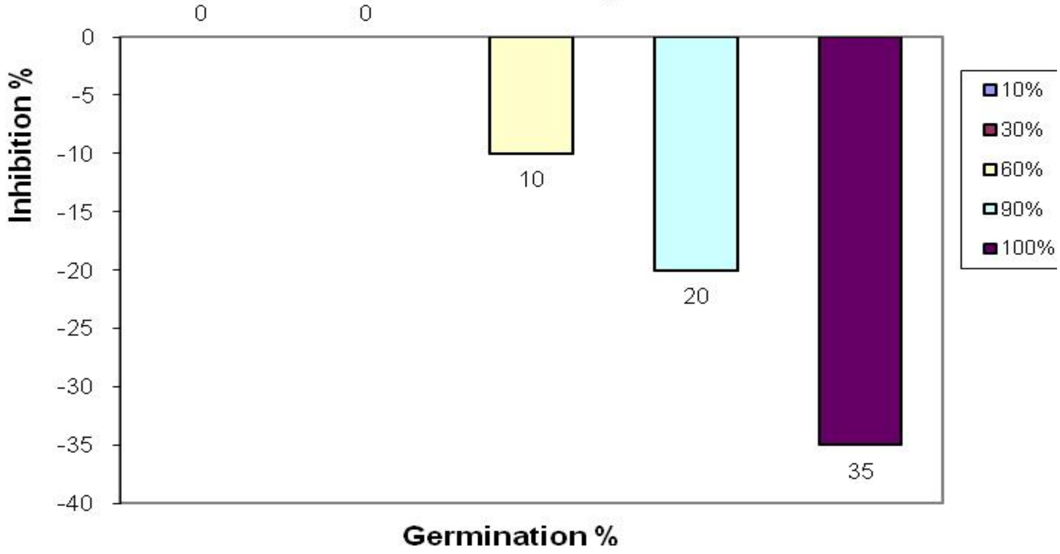


Fig. 2b: Root length of *Oryza sativa* L. under aqueous leaf leachates of *Tectona grandis* L.

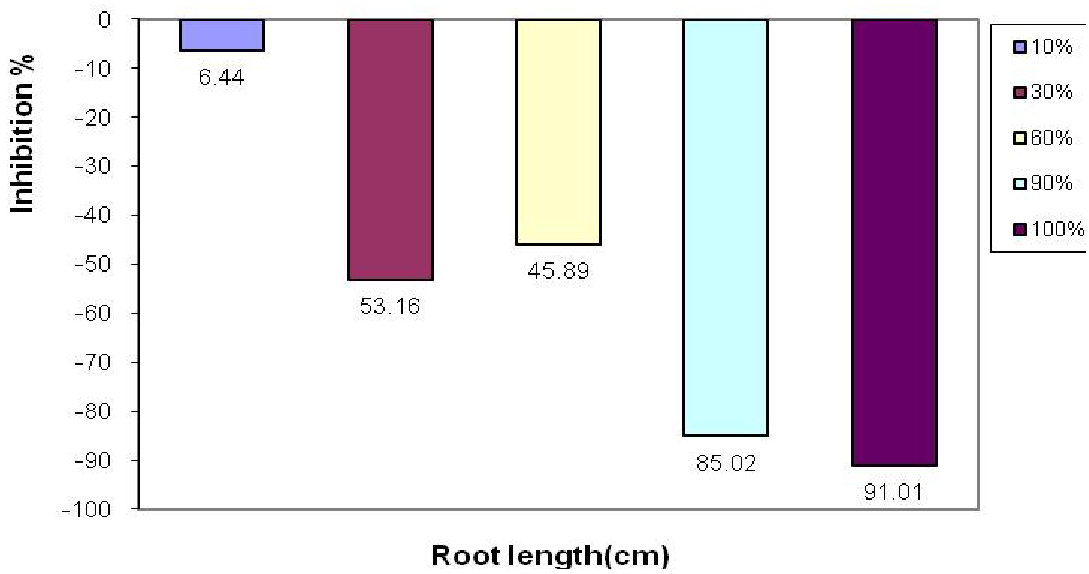


Fig. 2c: Shoot length of *Oryza sativa* L. under aqueous leaf leacates of *Tectona grandis* L.

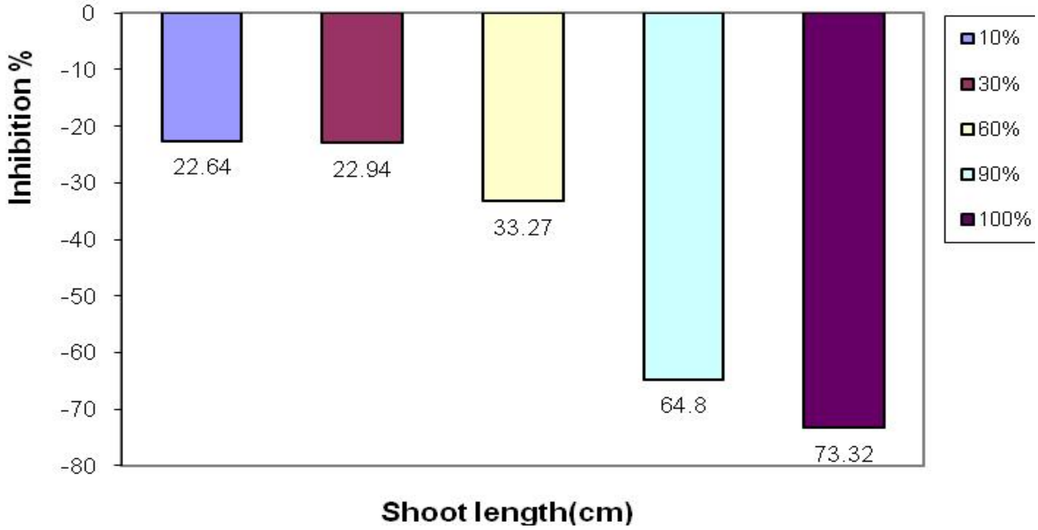


Fig.2d: Fresh root weight of *Oryza sativa* L. under aqueous leaf leachate of *Tectona grandis* L.

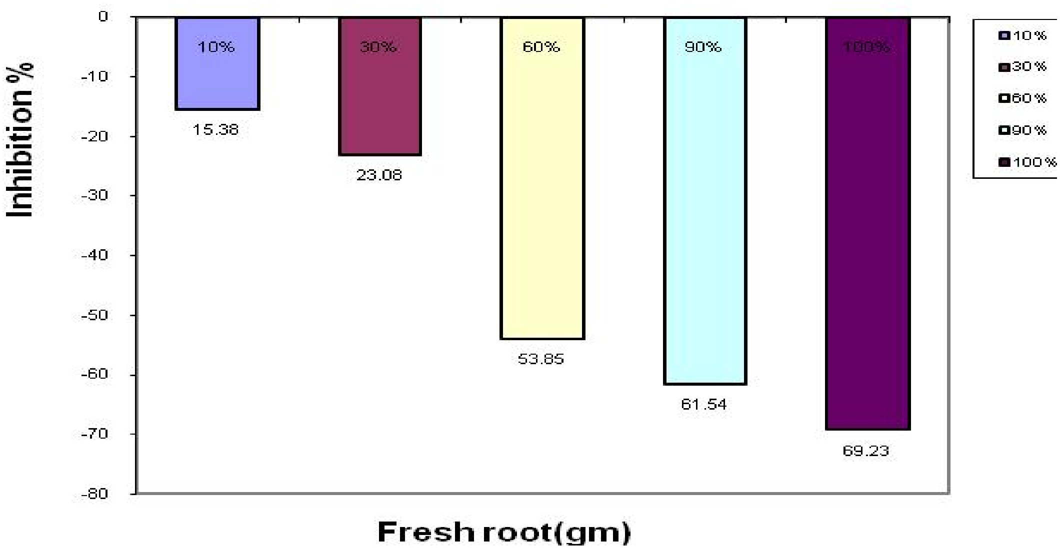


Fig. 2e: Fresh shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Tectona grandis* L.

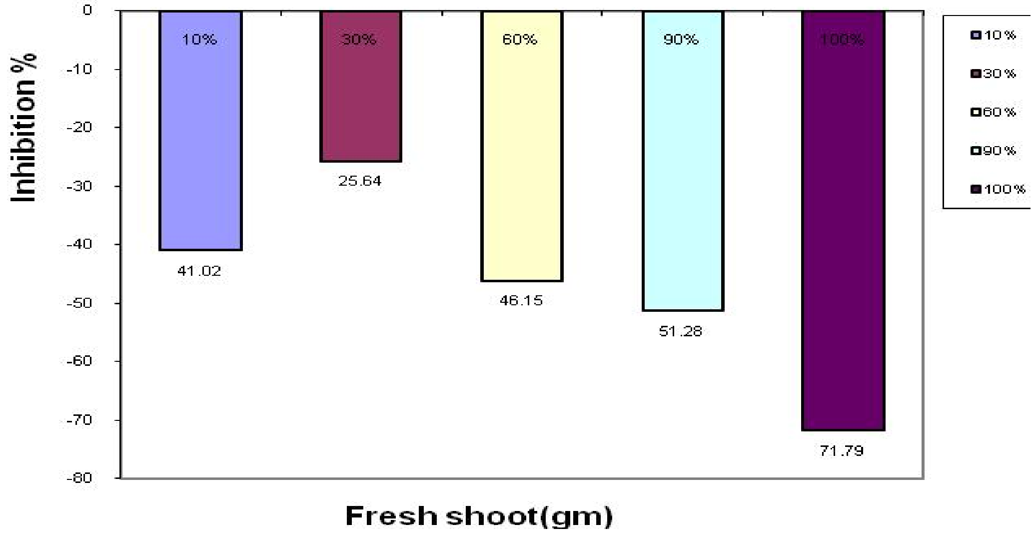


Fig. 2f: Dry root weight of *Oryza sativa* L. under aqueous leaf leachate of *Tectona grandis* L.

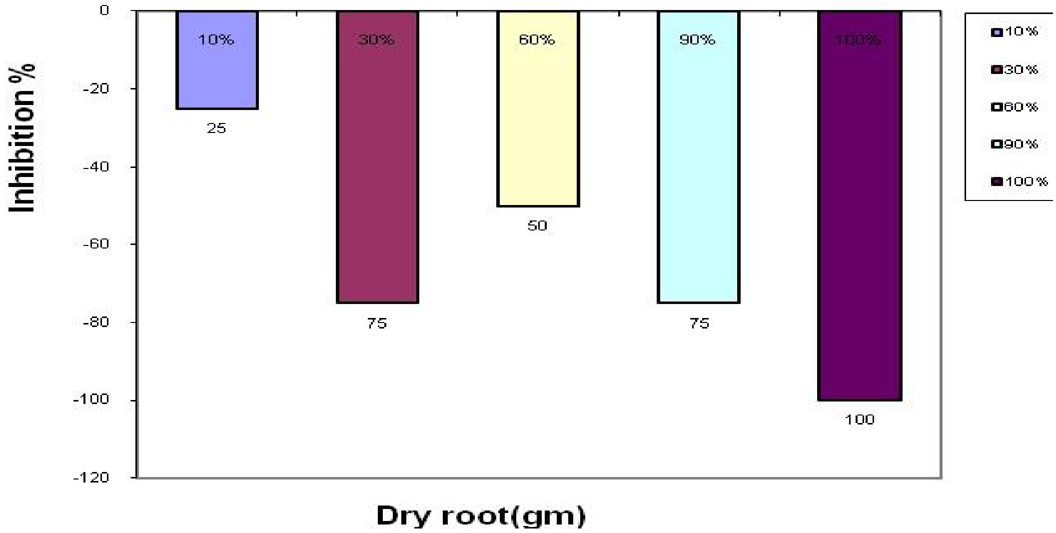


Fig.2g: Dry shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Tectona grandis* L.

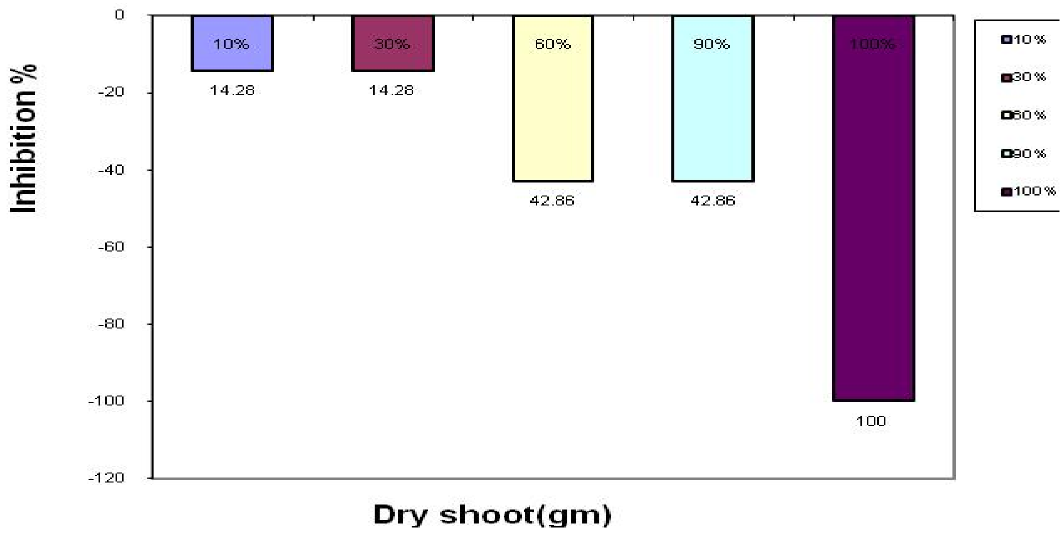


Fig.3a: Germination of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

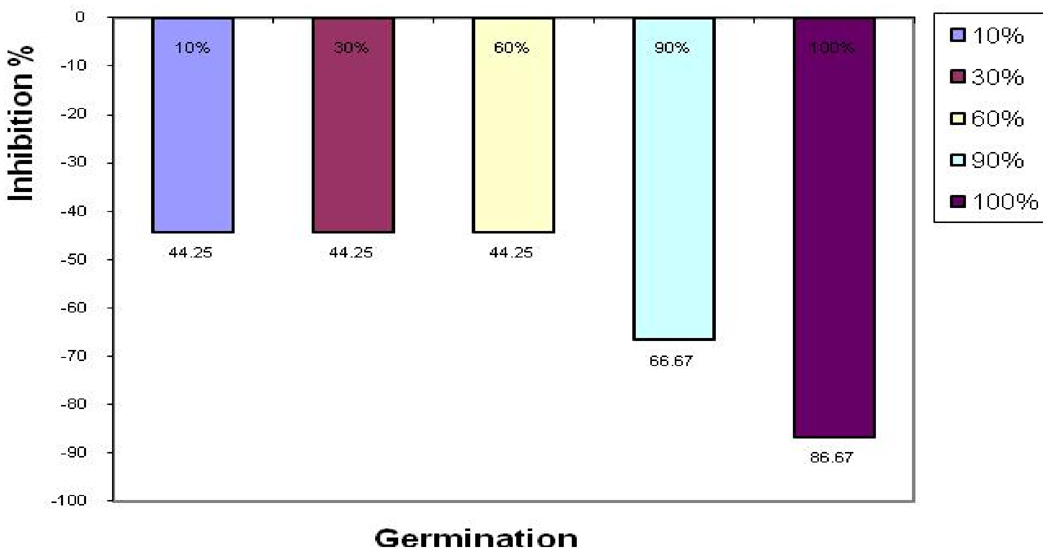


Fig.3b: Root length of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

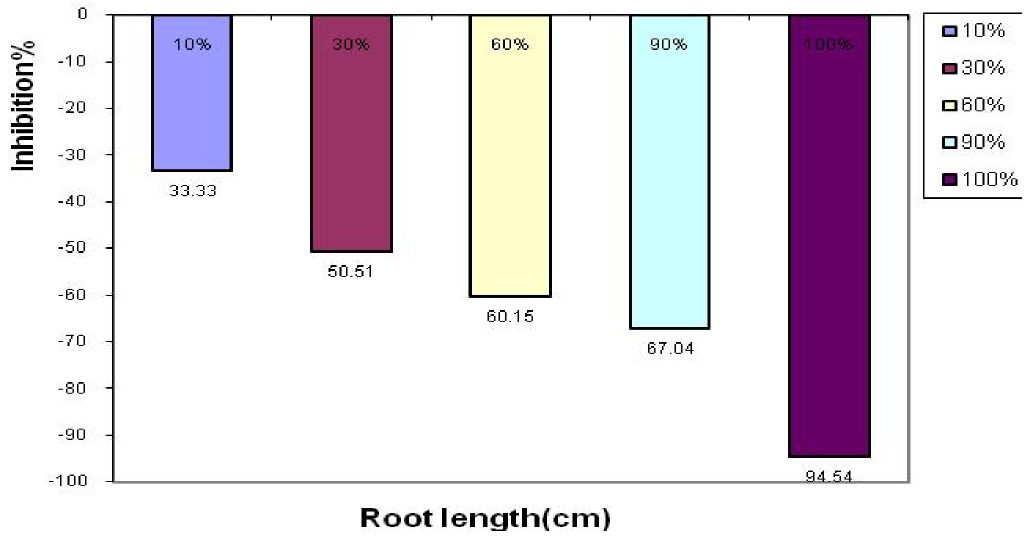


Fig.3c: Shoot length of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

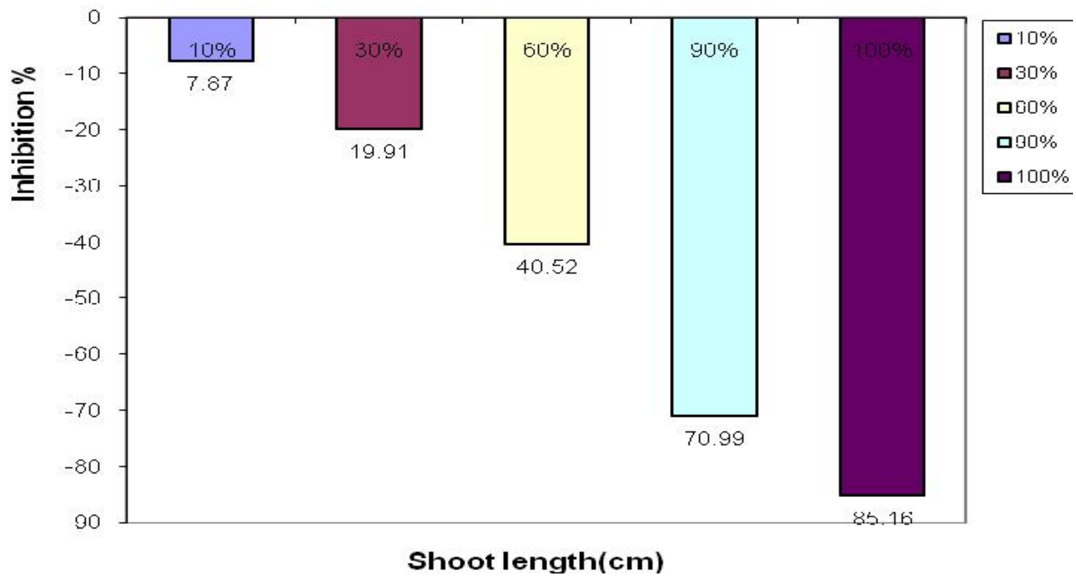


Fig.3d: Fresh root weight of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

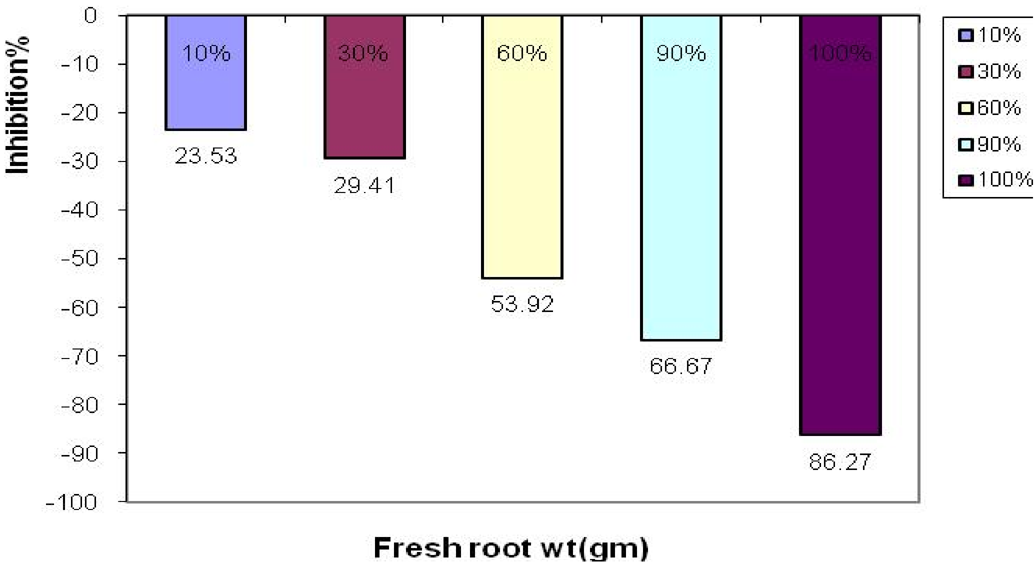


Fig.3e: Fresh shoot weight of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

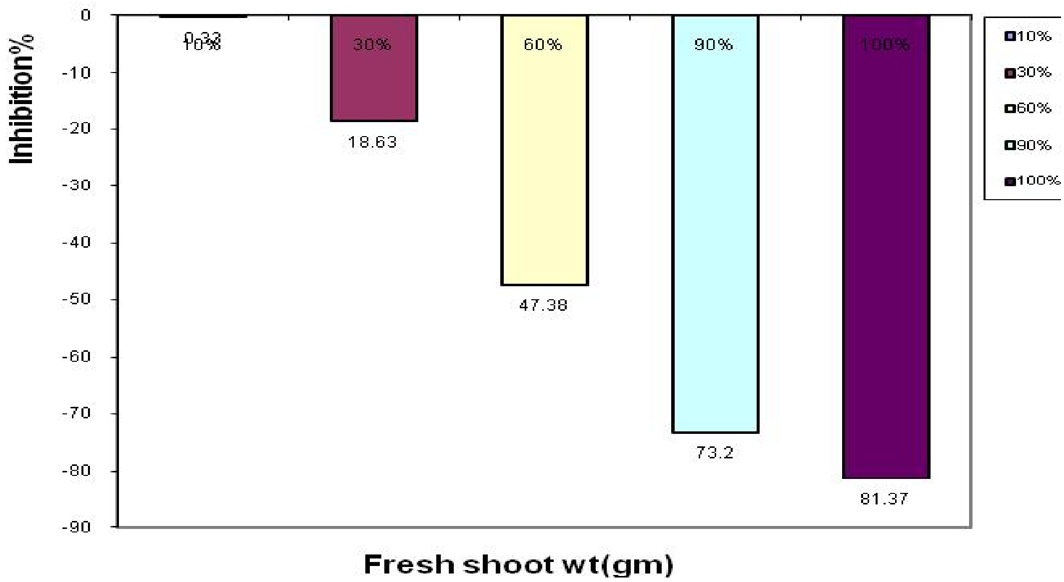


Fig.3f: Dry root weight of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.

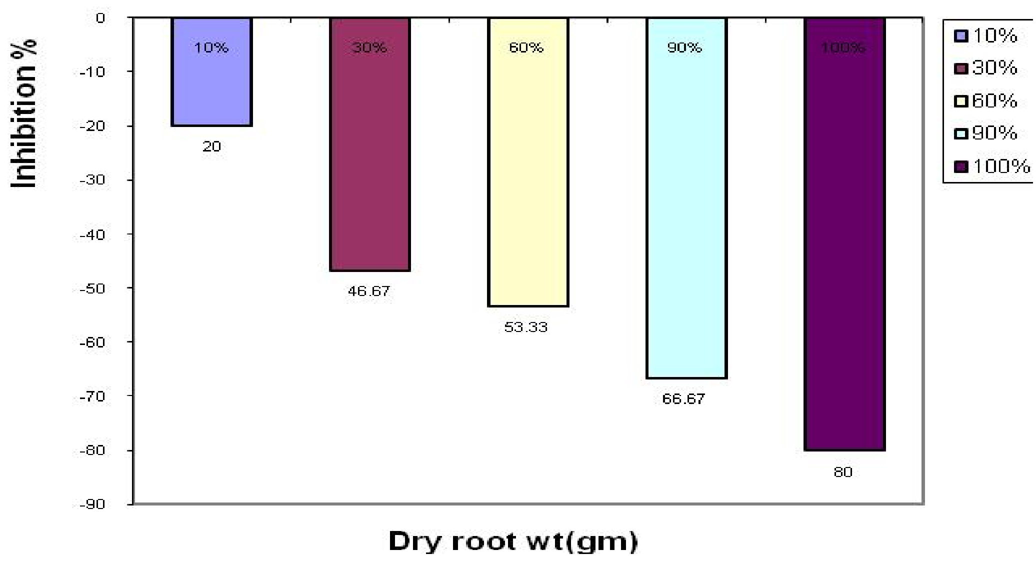
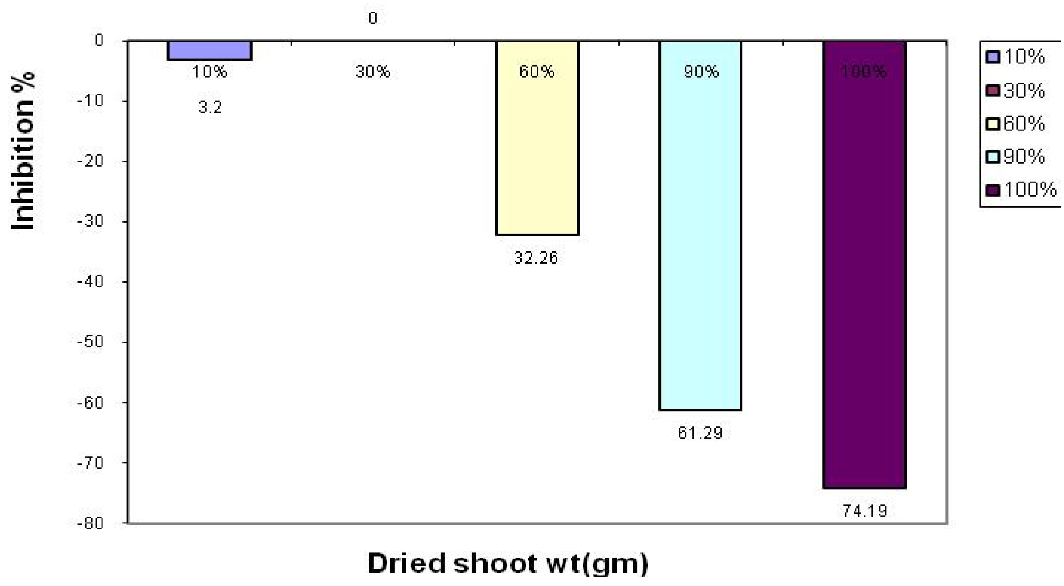


Fig.3g: Dry shoot weight of *Zea mays* L. under aqueous leaf leachate of *Tectona grandis* L.



4.2 Effect of aqueous leaf leachate of *Melia azadirach* L. on seed germination and initial growth parameters of the test crops.

i) Seed germination:

The seed germination of *Oryza sativa* L. was significantly ($P<0.05$) inhibited by the aqueous leaf leachate of neem at different concentrations. T1 (10% leaf leachates concentration) had least (10% inhibition) effect on the germination while T5 (100% leaf leachates concentration) had the highest (50% inhibition) effect in case of *Oryza sativa* L. (Tables 5 and 6, Figure 4a). The leaf leachates of neem at T2 (30%), T3 (60%) and T4 (90%) concentrations, however, reduced the seed germination by 30% (inhibition) compared to the control.

The other test crop *Zea mays* L. also experienced similar inhibition at different leachate concentrations. T1 and T2 (10% and 30%) experienced 33.33% inhibition, while T3 and T4 (60% and 90%) leaf leachates concentrations, experienced 60% inhibition and at T5 (100%) leaf leachates concentration, seed germination was suppressed by 73.33% compared to the control (Tables 7 and 8, Figure 5a).

ii) Root and shoot length:

The effect of leaf leachates concentration of different treatments has been summarized in Tables 5 and 6. The root length of *Oryza sativa* L. was found to be suppressed significantly ($P<0.001$) in all the treatments exhibiting a trend of concentration dependent. The highest and lowest inhibitory effect on root length was recorded under T1 concentration (53.32%) and T5 concentration (88.61%) respectively (Figure 4b). The inhibition of shoot length was significantly ($P<0.001$) reduced by exposure to aqueous leaf leachates of all the treatments when compared with control. The higher concentration here also suppressed the shoot development. The highest and lowest shoot elongation was recorded as 75.54% and 26.14% under T5 and T1 concentration of leaf leachates respectively (Tables 5 and 6, Figure 4c).

The percentage of inhibition of root and shoot length in *Zea mays* L. are shown in Tables 7 and 8. The results showed clear differences as affected by different concentrations of the leaf leachates. The suppression of root extension was significantly ($P<0.001$) higher with the higher leaf leachates concentration. The lowest concentration T1 (10%) of the leachates had least effect (64.82%) and gradually the extension of root decreased as the percent of concentration increased. At T5 (100%) leachates concentration the inhibition percentage was 95.93%. The results also indicated that the extension of shoot under different concentration was significantly inhibited. Among the treatments, the highest inhibitory effect (82.55%) was observed at T4 which was more pronounced than T5 (63.16%). In general, the higher the concentration of leaf leachates, the greater was the inhibition in growth of root and shoot (Tables 7 and 8, Figures 5b, c).

iii) Fresh weight of root and shoot:

The reduction in weight of fresh root and shoot of *Oryza sativa* L. depended on the percentage of leaf leachate concentration of neem. The result clearly indicated that the weight of root was significantly inhibited ($P<0.001$) gradually as the leaf leachate concentration increased. However, among the treatments, at T3 leachate concentration the reduction in both fresh and dry root and shoot was significantly ($P<0.001$) low (38.46%) in comparison to other concentrations. The highest inhibition was observed at T5 concentration (92.31% inhibition). In case of shoot, 7.69%, 10.26% and 15.38% of inhibition were observed at T1, T2 and T3 leaf leachate concentration respectively. The rate of inhibition dramatically increased at T4 and T5 concentration (61.54% and 66.67% respectively) (Tables 5 and 6, Figures 4d,c) and all treatments were significantly inhibited at P<0.001 level.

Table 6 depicts the effect of leaf leachates of *Melia azadirach* L. on the fresh weight of root and shoot of *Zea mays* L. In case of root weight, maximum inhibition was observed under T5 concentration of leaf leachates (92.16% inhibition) and minimum under T1 concentration (78.43% inhibition) which was dramatically high when compared with control. Nevertheless, the fresh weight of root was greatly inhibited significantly (P<0.001) with the increasing concentration of the leaf leachates (Figures 5d, e). Tables 7 and 8 also clearly indicated that the different concentration of leaf leachates on fresh weight of shoot was significantly inhibited at P<0.001 level. The highest inhibition (90.85%) was recorded under T4 leaf leachates concentration than T5 leaf leachates concentration which resulted in inhibiting the fresh weight by 84.97% compared to the control. The lowest (64.70%) inhibition, however, was recorded at T1 i.e. at 10% leaf leachates concentration.

vi) Dry weight of root and shoot:

The effects of various leaf leachate concentration of neem on the dry weight of root and shoot of *Oryza sativa* L. is summarized in Tables 5 and 6. At T1 (10% leaf leachates) concentration, no adverse impact was observed, but there was a gradual increase in inhibition with the increasing concentration (Figure 4f). In the case of dry weight of shoot, T2 (30% leaf leachates) concentration did not show any inhibitory effect compared with control. However, at T1 concentration of leaf leachates, it showed 14.28% inhibition, and from T3 concentration onwards, the inhibition percentage drastically increased to 85.71% (Figure 4g).

Similarly, the biomass of dry weight of root and shoot of *Zea mays* L. was reduced significantly ($P<0.001$) as the concentration of leachates increased (Tables 7 and 8, Figures 5f, g). Due to competition among the maize seedlings during the initial growth period, the root and shoot elongation might have been suppressed besides the negative effect of the leachates concentration. In most of the cases, the biomass production of root and shoot were significantly inhibited at $P<0.001$ level.

Discussion:

From the above observations, overall seed germination, root and shoot length and biomass of fresh and dry weight of root and shoot of the seedlings were significantly ($P<0.001$) inhibited by the leaf leachates concentration. In case of germination percentage of *Oryza sativa* L. and *Zea mays* L. treated with the leaf leachates of *Melia azadirach* L., the germination percentage had been decreased to 50% when compared with control. Similarly, the extension of root and shoot length was severely suppressed from the T1 (10%) to T5 (100%) leaf leachates concentration (Tables 3-6). This result also coincided with the result of Rao and Reddy (1984), who found the inhibitory effect of leaf extracts of *Eucalyptus* (hybrid) on the germination of certain food crops. On the other hand, Zackrisson and Nilsson (1992) supported higher sensitivity of root growth than seed germination. It can be clearly pointed out that the leaf leachates of *Melia azadirach* L. have the potential to reduce the germination as well as the growth and development of some agricultural crops. The results also clearly indicated that the biomass production of fresh and dry weight of root and shoot were severely impeded with increased concentration of the leaf leachates. Even the complete inhibition rate in some cases were also recorded (100% concentration of leaf leachates of *Melia azadirach* L. on *Oryza sativa* L. (0.00 %

inhibition), in case of *Zea mays* L. the adverse effect increased as the percentage of leachates also increased (Tables 7 and 8).

It may be mentioned that almost all evaluation parameters of the test crops were significantly inhibited as the per cent of leaf leachates concentration increased. These findings were also in conformity with the results of Daniel (1999) and Uddin *et al.* (2000). All these studies supported that germination, root and shoot development was more sensitive and responded more strongly to the increasing concentration of the aqueous leaf leachates in comparison to control.

The adverse effect of *Melia azadirach* L. on the test crops might also be attributed to the phytotoxic chemicals such as Quercetin (flavonoid), nimbosterol as well as liminoids (Shyam Sunder, 2006) released from the leaves. Young leaves of *Melia azadirach* which has strong inhibitory activity against paddy and maize in seed germination and seedling growth. The exact mechanism by which germination was reduced by aqueous leachate of leaf stage of *Melia azadirach* L. likely involves inhibition of water uptake and also $\propto$ - amylase activity (Shyam Sunder, 2006) also reported that significant growth reduction was observed in seedlings due to toxicity of aqueous extracts obtained from young leaf tissues of *Melia azadirach* L.

Results were similar to those that reported shoot length was less sensitive to presence of phytotoxins extracted from allelopathic plants than radical length. A number of studies have suggested that degree of allelopathic inhibition generally increased with increasing extract concentration (Laosinwattana *et al*., 2007, 2010).

These findings were in agreement with Han *et al.* (2008) who reported that ginger aqueous extracts, especially stem and leaf extracts, inhibited imbibitions in seeds of chive and soybean. Most seeds require an adequate moisture level for activation of metabolism within seed (Chong *et al.,* 2002). Thus, the study provides the evidence of *Melia azadirach* L. having allelopathic potential on maize and paddy widely grown in Mizoram.

Table 5: Effect of aqueous leaf leachate of *Melia azadirach* L. on seed germination, root and shoot extension, biomass of fresh and dry weights of root and shoot of *Oryza sativa* L. under bioassay.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	100±0.00	16.696±0.149	13.51±0.062	0.013±0.000	0.039±0.000	0.004±0.00002	0.007±0.00002
T1 (10%)	90±0.00	7.794±0.019	9.978±0.078	0.007±0.00002	0.036±0.00004	0.004±00002	0.006±0.00001
T2 (30%)	70±0.00	7.498±0.036	9.904±0.057	0.005±0.00002	0.035±0.00002	0.003±0.004	0.007±0.00001
T3 (60%)	70±0.00	3.502±0.024	7.7794±0.028	0.008±0.00003	0.033±0.00004	0.002±0.00001	0.005±0.00001
T4 (90%)	70±0.00	3.502±0.029	4.425±0.025	0.003±0.00009	0.015±0.00002	0.00003±0.000006	0.002±0.00001
T5 (100%)	50±0.00	1.902±0.015	3.304±0.024	0.001±0.0	0.013±0.00009	0±0.00002	0.001±0.00009
CD at P ≤ 0.05	0.00	1.165	0.899	0.003	0.005	0.034	0.002

± SE. m, n= 4

Table 6: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Melia azadirach* L. on growth attributes of *Oryza sativa* L. under bioassay.

Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
T1 (10%)	3504.582***	1248.251***	210.615***	180.000***	1.482 ns	4.722 ns
T2 (30%)	3586.401***	1827.324***	211.524***	486.000***	0.528 ns	0.715 ns
T3 (60%)	7631.812***	7047.596 ***	12.522 ns	45.000***	72.710***	28.713***
T4 (90%)	7532.74***	18361.80***	5800.05***	3539.44***	257.29***	334.25***
T5 (100%)	7532.74***	18361.80***	5800.05***	3539.44***	257.29***	334.25***

*** significant at P<0.001, ns – non significant.

Table 7: Effect of aqueous leaf leachate of *Melia azadirach* L. on seed germination, root and shoot extension, biomass of fresh and dried weights of root and shoot of *Zea mays* L. under bioassay.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	75±0.00	22.057±0.155	21.725±0.088	0.102±0.00003	0.306±0.00003	0.015±0.00001	0.031±0.00002
T1 (10%)	50±0.00	7.76±0.04	10.88±0.058	0.022±0.00004	0.108±0.00004	0.008±0.00002	0.014±0.00004
T2 (30%)	50±0.00	5.82±0.025	10.3±0.041	0.016±0.00002	0.098±0.00004	0.005±0.00002	0.007±0.00002
T3 (60%)	30±0.00	4.12±0.033	9.178±0.029	0.014±0.00003	0.085±0.00003	0.005±0.00002	0.008±0.00002
T4 (90%)	30±0.00	3.304±0.034	3.79±0.04	0.015±0.00003	0.028±0.00003	0.005±0.00001	0.006±0.00001
T5 (100%)	20±0.00	0.898±0.031	8.004±0.070	0.008±0.00001	0.046±0.00003	0.0001±0.000004	0.008±0.00002
CD at P ≤ 0.05	0.00	1.252	1.040	0.005	0.006	0.003	0.004

± SE. m, n= 4

Table 8: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Melia azadirach* L. on growth attributes of *Zea mays* L. under bioassay.

Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
T1 (10%)	7955.3***	10491.1***	21059.0***	153889.4***	579.3***	1132.3***
T2 (30%)	10654.7***	13652.4***	44815.7***	170321.7***	1021.7***	5717.9***
T3 (60%)	12745.0***	18084.5***	32779.2***	252893.0***	1035.7***	3867.6***
T4 (90%)	13922.2***	34178.7***	33918.6***	389648.9***	2152.9***	10240.4***
T5 (100%)	17831.1***	14677.4***	68284.9***	307489.3***	8199.2***	5783.6***

*** Significant at P<0.001.

Fig.4a: Germination of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

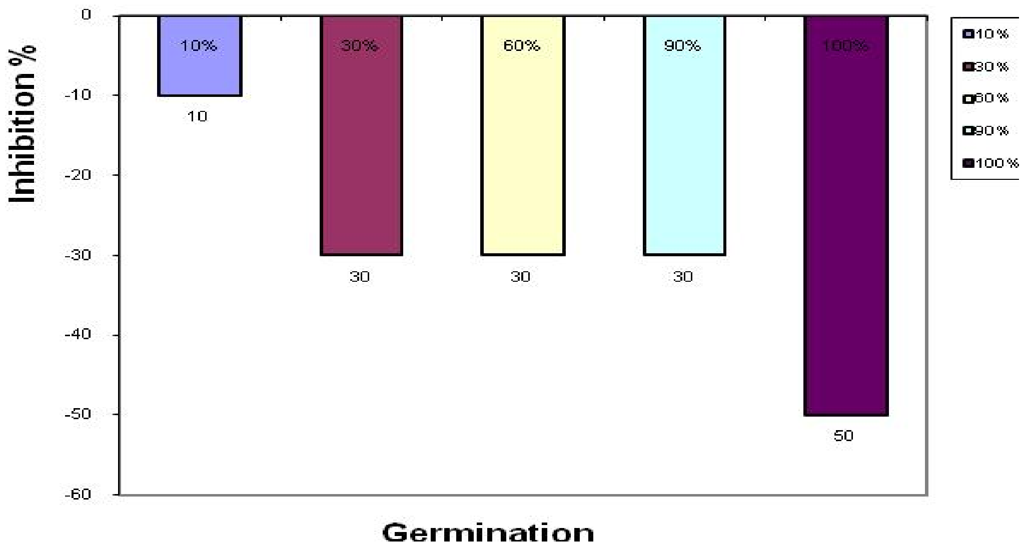


Fig.4b: Root length of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

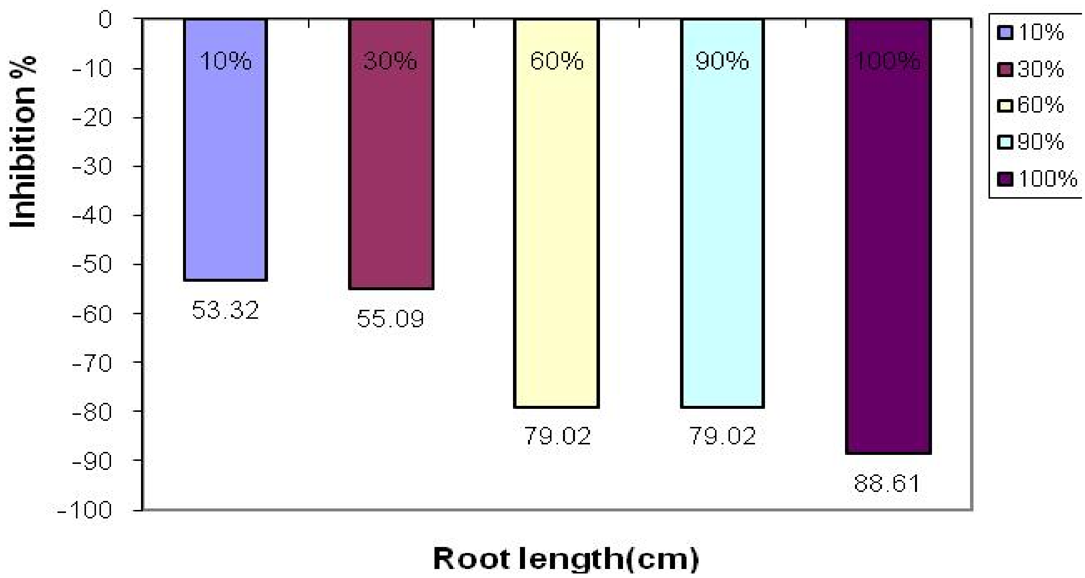


Fig.4c: Shoot length of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

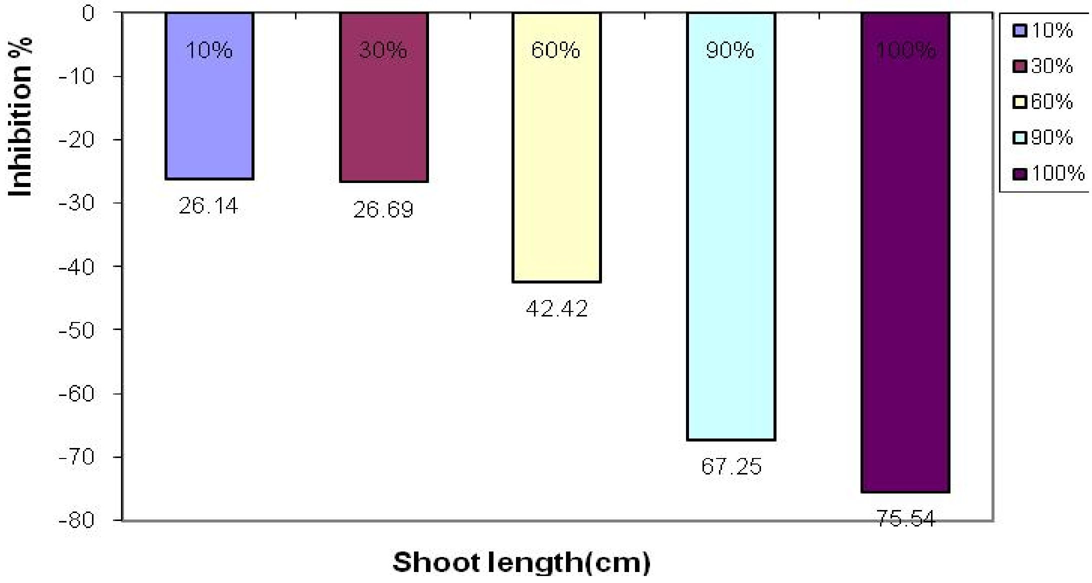


Fig.4d: Fresh root weight of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

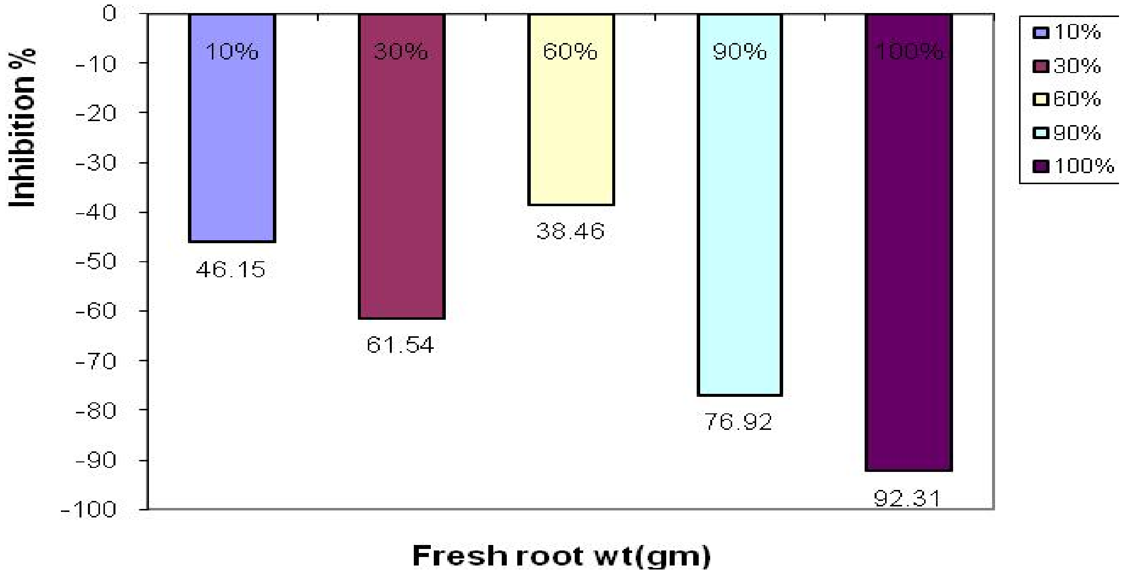


Fig.4e: Fresh shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Melia zadirach* L.

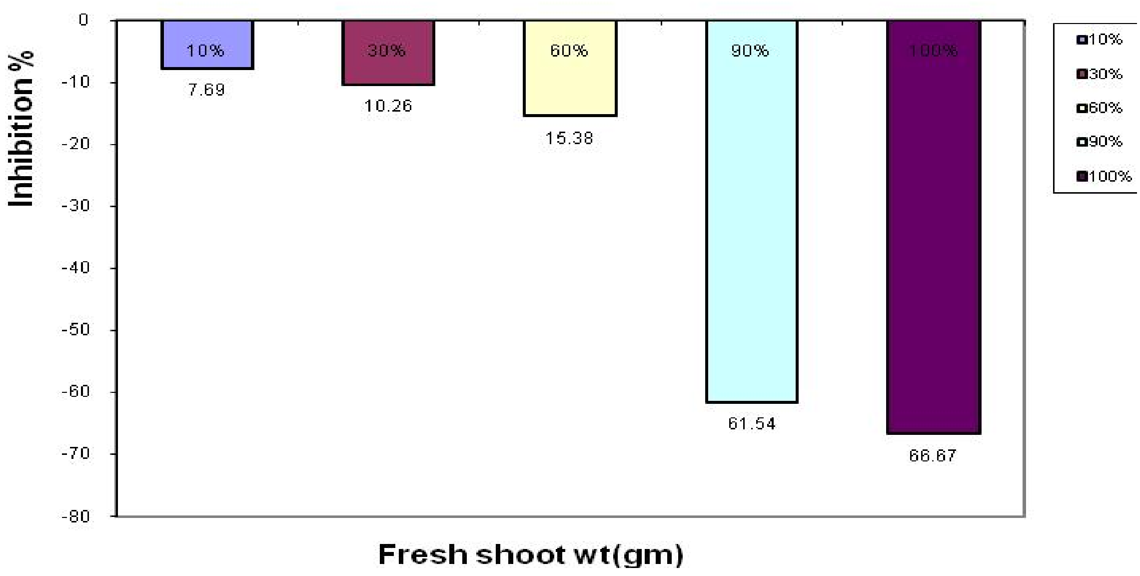


Fig.4f: Dry root weight of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

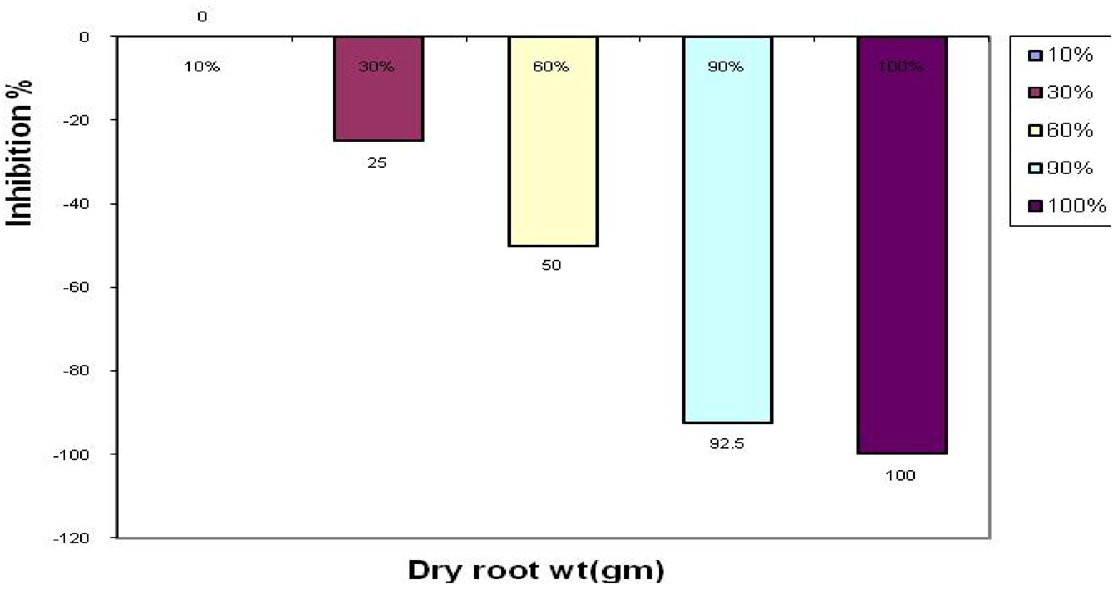


Fig.4g: Dry shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Melia azadirach* L.

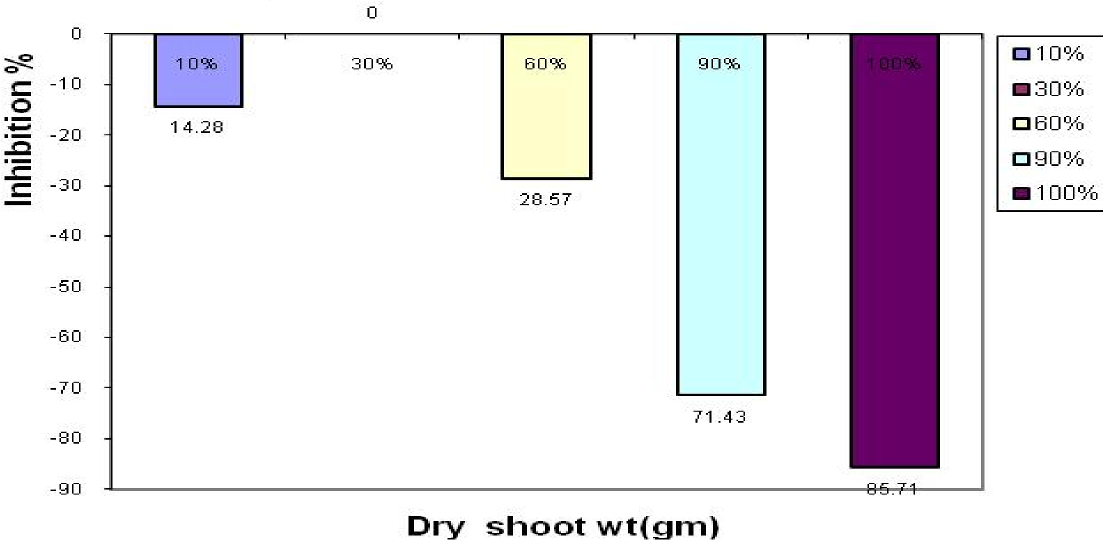


Fig.5a: Germination of *Zea mays* L. under aqueous leaf leachate of *Melia azadirach* L.

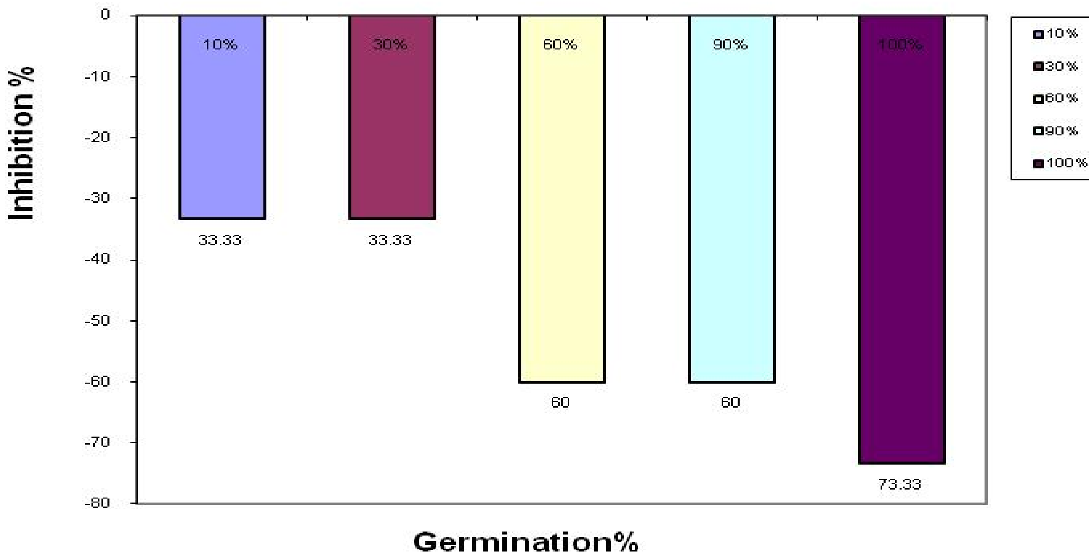


Fig.5b: Root length of *Zea mays* L. under aqueous leaf leachate of *Melia azadirach* L.

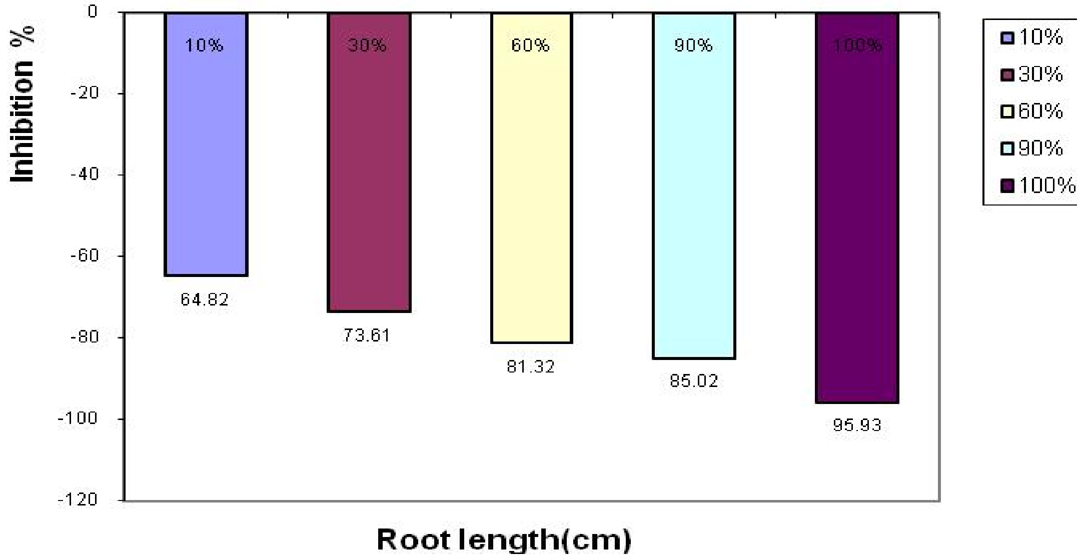


Fig.5c: Shoot length of *Zea mays* L. under aqueous leaf leachate of *Melia azadirach* L.

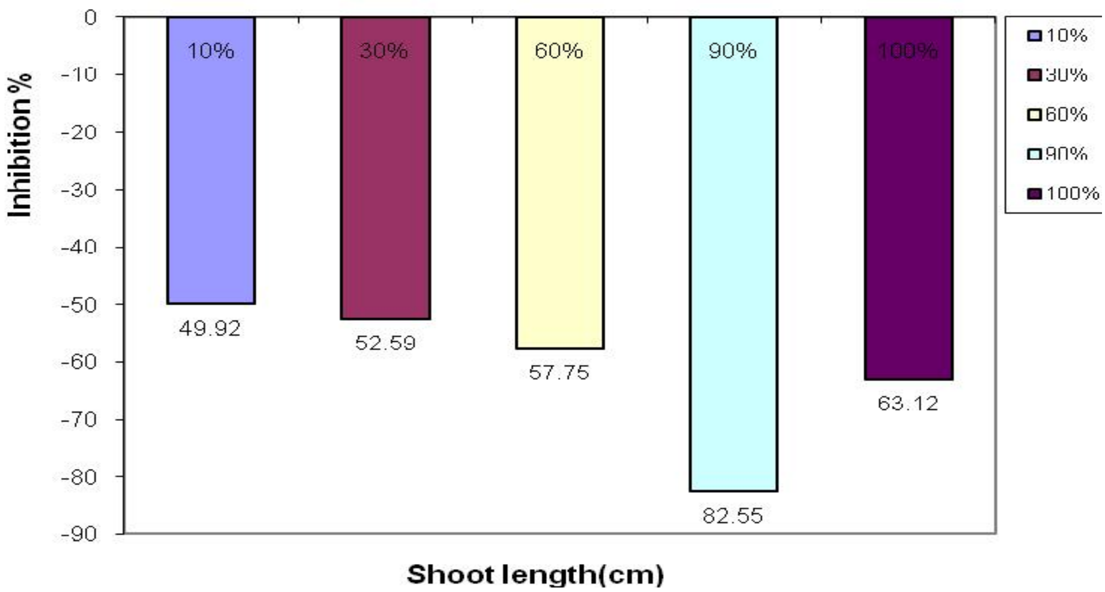


Fig.5d: Fresh root weight of *Zea mays* L. under leaf leachate of *Melia azadirach* L.

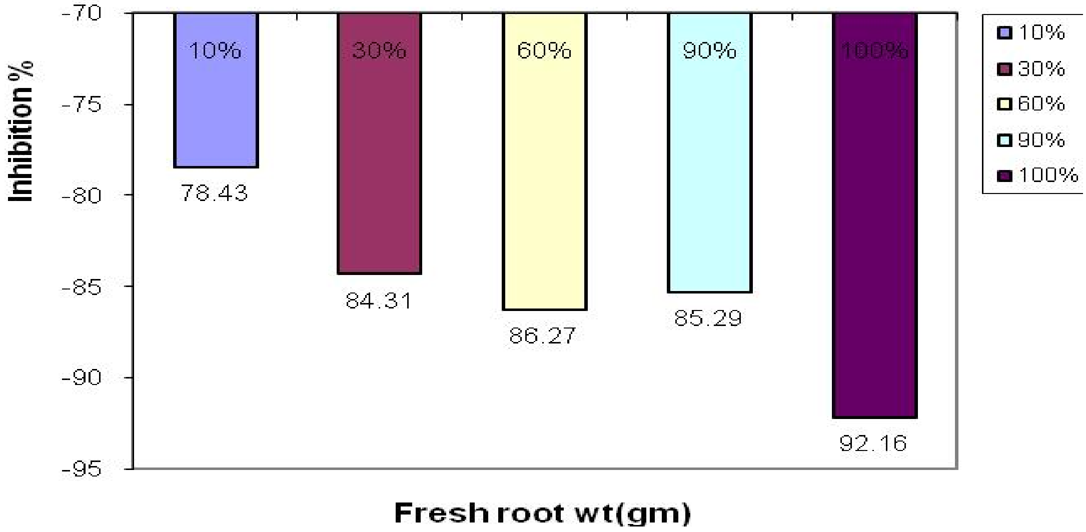


Fig.5e: Fresh shoot weight of *Zea mays* L. under leaf leachate of *Melia azadirach* L.

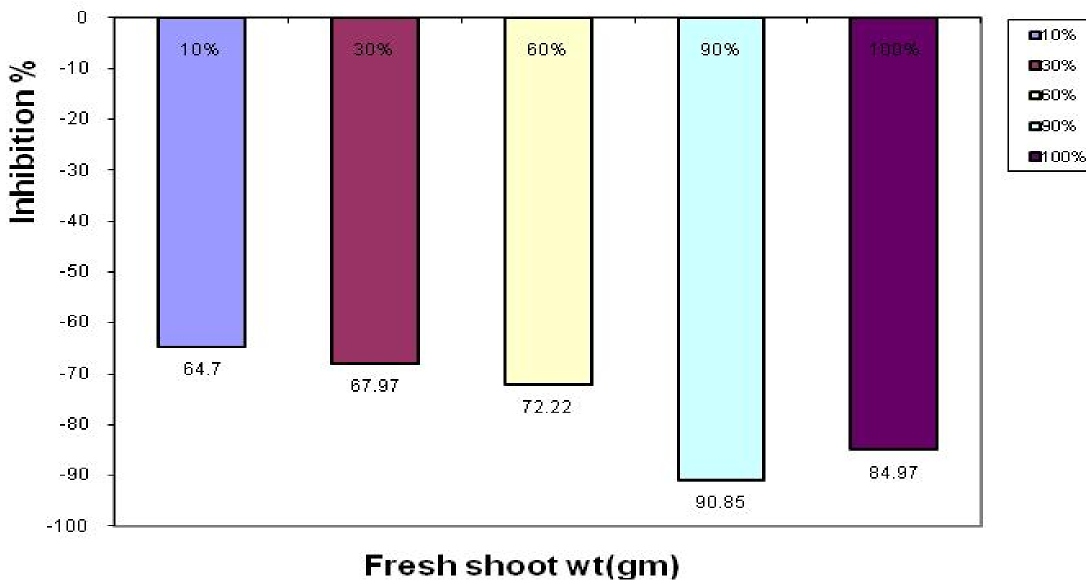


Fig.5f: Dry root weight of *Zea mays* L. under aqueous leaf leachate of *Melia azadirach* L.

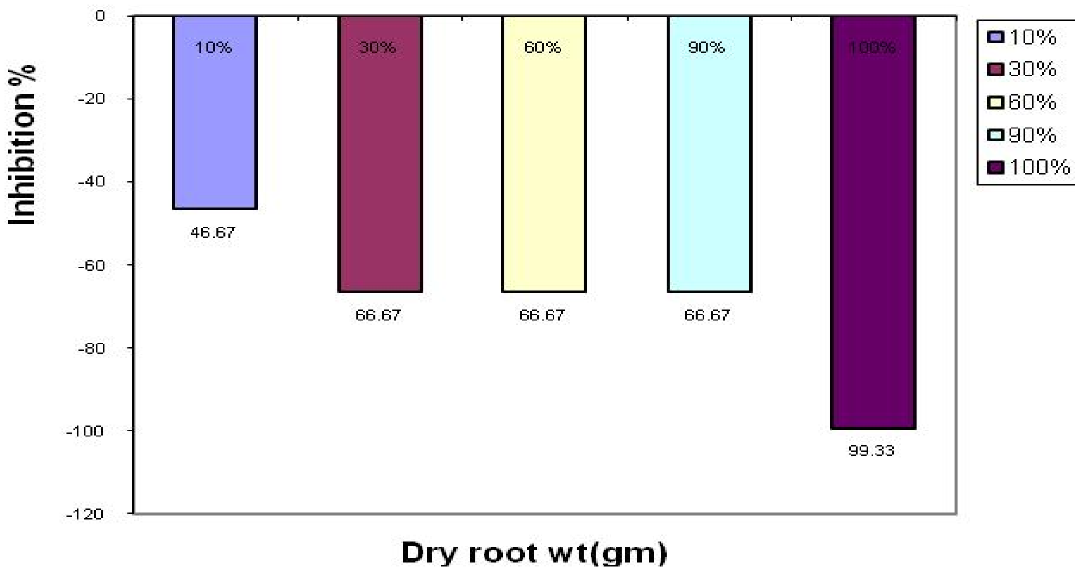
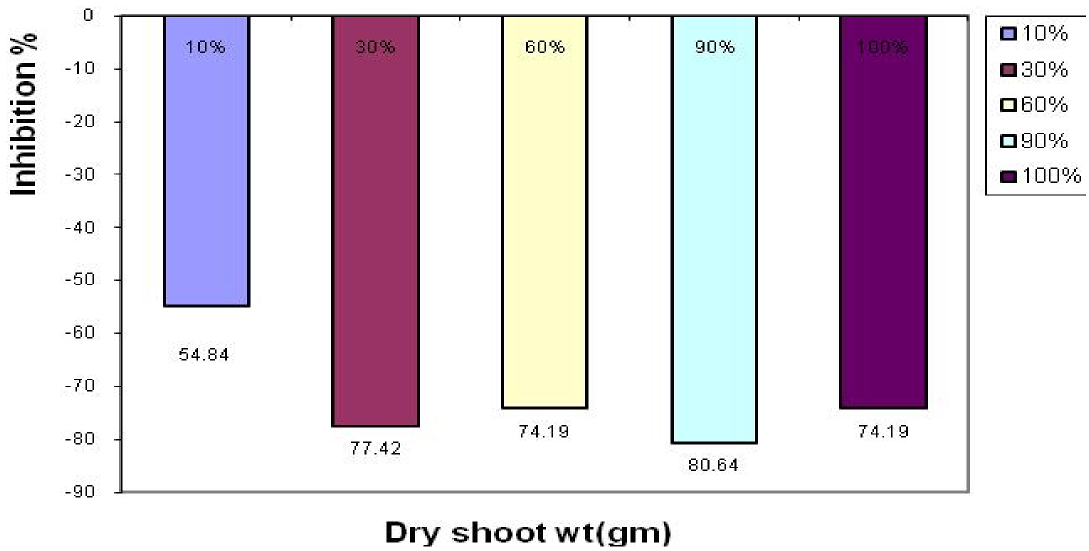


Fig.5g: Dry shoot weight od *Zea mays* L. under aqueous leaf leachate of *Melia azadirach* L.



4.3 Effect of aqueous leaf leachate of *Ageratum houstonianum* L. on seed germination, root and shoot extensions, biomass of fresh and dry weights of root and shoot on the test crops.

i) Seed germination:

The allelopathic effect of aqueous leaf leachates of *Ageratum houstonianum* L. on the seed germination of *Oryza sativa* L. and *Zea mays* L. was shown in the Tables 9 and 10 respectively. The percentage of seed germination of *Oryza sativa* L. was significantly low ($P<0.05$) at T1, T2, T3, T4 and T5 concentration. The percentages of inhibition on seed germination were 1%, 5% and 10% respectively when compared to control (Figure 6a).

In case of *Zea mays* L., the leaf leachates of *Ageratum houstonianum* L**.** severely affect the germination as shown in the Table 11 and Figure 7a. The percentage of inhibition were 53.33%, 60%, 73.33%, 80% and 86.67% at 10, 30, 60, 90 and 100% leaf leachates concentrations respectively and are significant at $P<0.05$. The result clearly indicated that the severity of effect was proportional to the extract concentration.

ii) Root and shoot length:

The data revealed that the root elongation of *Oryza sativa L***.** under different concentration significantly ($P<0.001$) inhibited from T2 concentration onwards (Tables 9 and 10, Figure 6b). At T2 and T3 the inhibitory percentage was 17.345% and 33.88 % while at T4 concentration, the inhibition percentage was minimized to 16.12% lower than T2 and T3 concentration. The highest inhibitory (70.64%) percentage was found at T5. Only T1 concentration had shown stimulatory effect.

Perhaps, lower leachate concentration favours root growth of paddy. The shoot elongation of *Oryza sativa L.* under different concentration had certain effect as shown on the Tables 9 and 10 and Figure 6c. The highest inhibitory effect (30.05%) was recorded in T3 while the lowest (8.51%) was in T1 concentration of leaf leachates. The per cent of inhibition was lesser in T5 (14.14%) and T4 (22.43%) than that of T3. On an average, the stimulatory and inhibitory effect on the root and shoot length were significant at $P<0.001$.

In the case of root extension of *Zea mays L.* under different concentrations of leaf leachates of *Ageratum houstonianum* L. (Tables 11 and 12, Figure 7b), the leaf leachates significantly ($P<0.001$) suppressed the elongation. The inhibitory effect was much pronounced and highest at T5 (95.02%) while the lowest (29.04%) was recorded from T1. Same was with the case in extension of shoot of *Zea mays* L. as presented in Tables 11 and 12, and in Figure 7c; the higher concentration here also caused severe inhibition in comparison to the Control. The highest and lowest inhibition of shoot elongation was recorded at T5 and T1 (88.54% and 7.412% respectively).

iii) Fresh weight of root and shoot:

The data revealed that the leaf leachates of *Ageratum houstonianum* L. did not have adverse effect on the fresh weight of root of *Oryza sativa* L. under T1, T2 and T4 but significantly ($P<0.001$) promoted by 61.54%, 130.77% and 84.61% respectively. The reduction in weight had been observed at T3 and T5 (30.77% and 53.85% inhibition) as shown on the Tables 9, 10 and Figurer 6d. The fresh weight of shoot under the treatments T1, T2, T4 and T5 shows significant ($P<0.001$) stimulatory effect as compared to control (7.69%, 7.69%, 25.64% and 17.95% promotion respectively). However, under the leaf leachates concentration of T3, reduction in the weight (17.95% inhibition) had been observed (Tables 9, 10 and Figure 6e).

Tables 11 and 12 clearly indicated that when the leaf leachates concentration of *Ageratum houstonianum* L. gradually increased, the fresh weight of root of *Zea mays* L. proportionately decreased. The minimum percentage of inhibition was found at T1 (10.78%) and maximum inhibition at T5 (91.18%). Similarly, the leaf leachates concentration also severely reduced the fresh shoot weight of *Zea mays* L. which were significant at $P<0.001$. (4.25%, 64.05%, 68.30%, 89.54% and 93.44% inhibition at T1, T2, T3, T4 and T5 respectively) (Figures 7d, e).

vii) Dry weight of root and shoot:

The leaf leachate concentration**s** at T3 and T5 had remarkable effect on the dry root weight of *Oryza sativa* L. (Table 9 and 10). Under the treatments of T1 and T2, neither inhibitory nor stimulatory effect was found, while T4 showed slight inhibitory effect (25%) when compared with control. Incase of dry weight of shoot, equal inhibitory effect was recorded under the treatments of T1, T2 and T3 (28.57%) where T1 and T3 showed significant at $P<0.001$. T4 and T5 did not show any adverse effect (Figures 6f, g) on the dry weight of root and shoot of *Oryza sativa* L. compared to control.

In the case of the dry weight of root and shoot of *Zea mays* L. under the leaf leachates of *Ageratum houstonianum* L., severe reduction in weight had been observed as compared to control. The dry weight of root decreased as the per cent of concentration of the leaf leachates increased, maximum reduction (86.67% inhibition) was recorded under T4 and T5 concentration and minimum reduction was recorded at

T_1 (20% inhibition) which were significant at P<0.001. The dry shoot weight of *Zea mays* L. showed significant (P<0.001) inhibition under different concentration of the leaf leachates. The highest inhibition was observed at T4 and T5 (87.09%) and lowest at T1 (9.68%) (Tables 11 and 12, Figures 7f, g).

Discussion:

The chemical compound exudates from *Ageratum houstonianum* L. exhibits an inhibitory effect on the crops as observed from the results shown above. From the Tables 9 and 10, the inhibition percentage of germination of *Oryza sativa* L. was less (1%, 5% and 10%) though significant at P<0.05. But in the case of germination percentage of *Zea mays* L. the leachates concentration inhibited significantly (P<0.05) from T1, T2, T3, T4 and T5 leachates concentration at the rate of 53.33%, 60%, 73.33%, 80% and 86.67% respectively. As compared to control the root and shoot length of *Oryza sativa* L. and *Zea mays* L. were significantly (P<0.001) inhibited by the increased in concentration. In the case of root length of *Oryza sativa* L., the leaf leachate concentration at T1 enhanced the growth by 9.06% and least (16.12%) inhibitory effect was found on T4 concentration, but the root length of *Zea mays* was inhibited gradually as the percent of concentration increased. Similarly, the shoot extension was also affected by the leaf leachates of *Ageratum houstonianum* L. on *Oryza sativa* L. and *Zea mays* L. On the whole, the leaf leachates concentration of *Ageratum houstonianum* L. suppressed the growth of seedlings, effect the biomass production of root and shoot as shown on the Tables 9-12. The present finding was also in agreement with the findings of Batish *et al*. (2005a, b); An *et al.* (2001); Khalid (2002); Kruidhof (2008); Batish *et al.* (2006, 2009). The findings coincided with

Daniel (1999) who reported that allelopathy includes both promoting and inhibitory activities and is a concentration dependent phenomenon.

The reduction in plant seed germination percent, root and shoot length and fresh weight with water extract of other plants has been reported by other researchers (Yasmin *et al*., 1999; Uremis *et al.,* 2005). Allelochemicals can lower the levels of hormones like G.A. and IAA (Kamal and Bano, 2008). Root and shoot length reduction with increasing concentration of leachates may be related to decreases in GA (Gibberelic acid) and IAA (Indole Acetic Acid) that reduce cell enlargement (Inderjit, 2002).

From the above results, the concentration of aqueous leaf leachates of *Ageratum houstonianum* L. on paddy and maize showed per cent concentration dependent. As the inhibition was moderate at the lower concentration and severe at higher concentration which revealed the allelopathic effect of different concentration of aqueous leaf leachates of *Ageratum houstonianum* L. under bioassay.

Table 9: Effect of aqueous leaf leachate of *Ageratum houstonianum* L. on seed germination, root and shoot extension, biomass of fresh and dry weights of root and shoot of *Oryza sativa* L. under bioassay.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	100±0.0	16.696±0.149	13.51±0.062	0.013±0.000	0.039±0.000	0.004±0.00002	0.007±0.00002
T1 (10%)	99±0.0	18.21±0.024	12.36±0.069	0.021±0.00003	0.042±0.00004	0.004±0.00003	0.005±0.00001
T2 (30%)	99±0.0	13.8±0.070	12.06±0.094	0.03±0.00003	0.042±0.00004	0.004±0.00003	0.005±0.00001
T3 (60%)	95±0.0	11.04±0.050	9.45±0.022	0.009±0.00001	0.032±0.00003	0.002±0.00001	0.005±0.00002
T4 (90%)	95±0.0	7.04±0.050	10.48±0.037	0.024±00003	0.049±0.00002	0.003±0.000008	0.007±0.00001

T5 (100%)	90±0.0	4.902±0.029	11.6±0.035	0.006±0.00001	0.046±0.00003	0.00009±0.000006	0.007±0.00002
CD at P ≤ 0.05	0.00	1.338	1.046	0.004	0.005	0.003	0.003

± SE. m, n= 4

Table 10: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Ageratum houstonianum* L. on growth attributes of *Oryza sativa* L. under bioassay.

Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
T1 (10%)	100.420***	152.011***	1210.000***	720.000***	0.183 ns	39.236***
T2 (30%)	308.044***	165.551***	4000.000***	1210.000***	1.407 ns	5.918 ns
T3 (60%)	1288.582***	3789.333***	21.376**	34.571***	27.587***	61.455***
T4 (90%)	3755.673***	1748.743***	1690.580***	5443.267***	2.657 ns	1.580 ns
T5 (100%)	6018.972***	715.314***	632.104***	2769.929***	192.157***	0.160 ns

** Significant at P<0.05, *** significant at P<0.001, ns – non significant.

Table 11: Effect of aqueous leaf leachate of *Ageratum houstonianum* L. on seed germination, root and shoot extension, biomass of fresh and dry weights of root and shoot of *Zea mays* L. under bioassay.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	75±0.00	22.057±0.155	21.725±0.088	0.102±0.00003	0.306±0.00003	0.015±0.00001	0.031±0.00002
T1 (10%)	35±0.00	15.652±0.045	20.114±0.061	0.091±0.002	0.293±0.003	0.012±0.00003	0.088±0.00003
T2 (30%)	30±0.00	9.71±0.055	12.692±0.031	0.031±0.00007	0.11±0.00008	0.005±0.00001	0.008±0.00005
T3 (60%)	20±0.00	8.914±0.024	12.364±0.027	0.028±0.00003	0.097±0.00003	0.005±0.00002	0.006±0.00003
T4 (90%)	15±0.00	2.37±0.037	3.614±0.049	0.013±0.00002	0.032±0.00004	0.002±0.00002	0.004±0.00001
T5 (100%)	10±0.00	1.098±0.047	2.49±0.064	0.009±0.00002	0.02±0.00004	0.002±0.00002	0.004±0.00001
CD at P ≤ 0.05	0.00	1.330	1.025	0.019	0.024	0.004	0.005

± SE. m, n= 4

Table 12: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Ageratum houstonianum* L. on growth attributes of *Zea mays* L. under bioassay.

Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
	F- Value	F- Value	F- Value	F- Value	F- Value	F- Value
T1 (10%)	1570.117***	223.698***	22.326**	17.788**	56.240***	27.630***
T2 (30%)	5605.96***	9267.03***	8474.19***	43310.96***	2072.37***	1669.61***
T3 (60%)	6996.3***	10240.0***	26594.1***	187335.6***	1068.8***	3843.9***
T4 (90%)	15202.7***	31978.3***	45694.2***	256405.4***	1736.1***	9703.8***
T5 (100%)	16665.9***	31062.1***	57677.9***	279284.4***	1437.5***	11099.4***

** Significant at $P<0.05$, *** significant at $P<0.001$.

Fig.6a: Germination of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

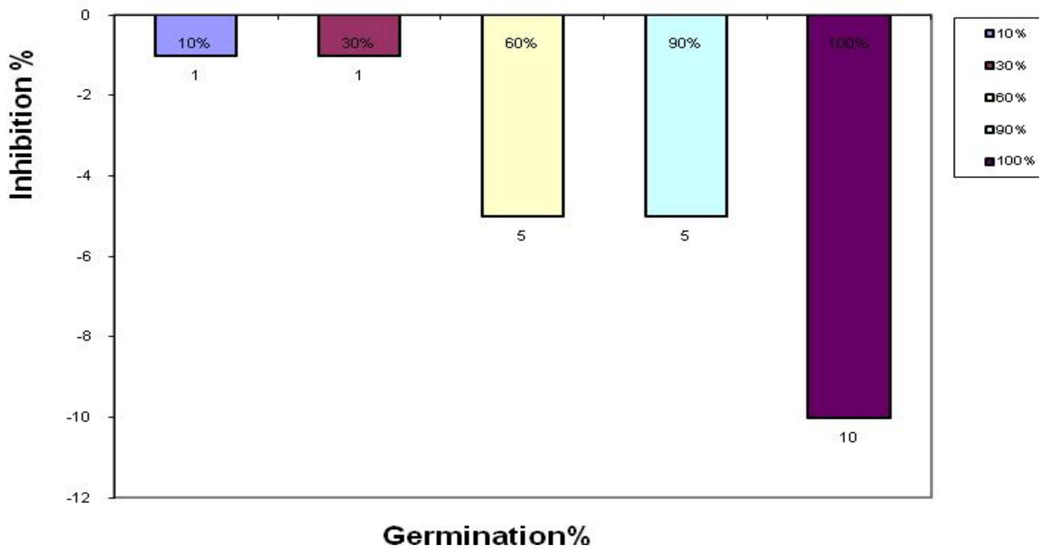


Fig. 6b: Root length of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

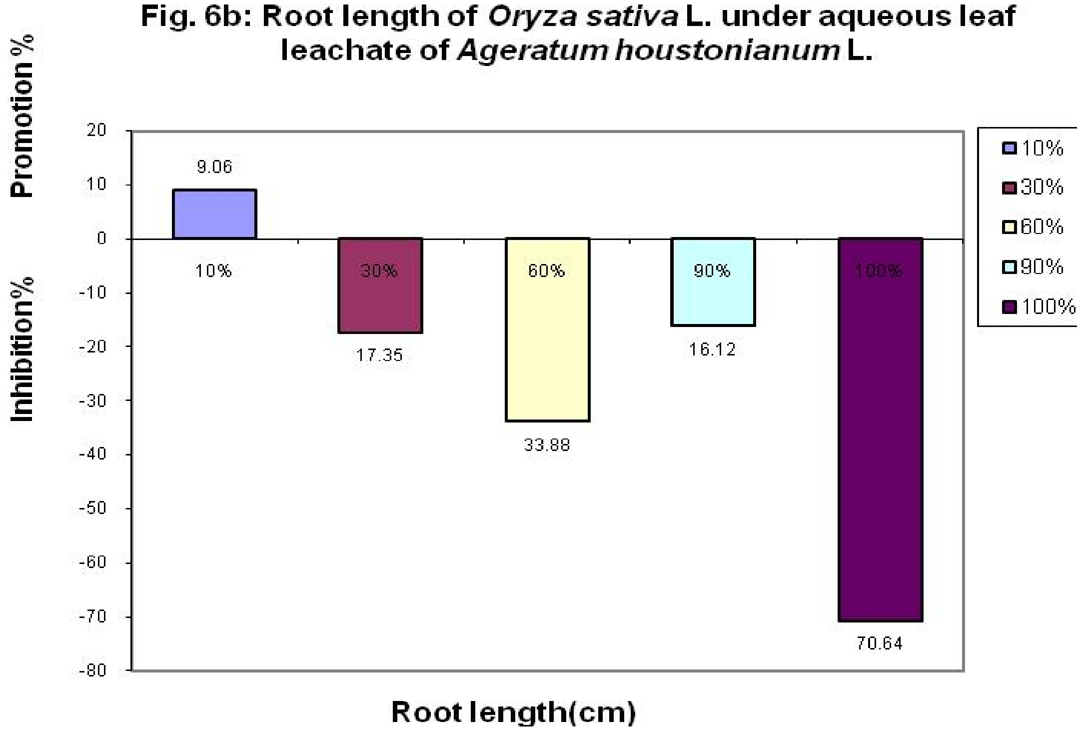


Fig.6c: Shoot length of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

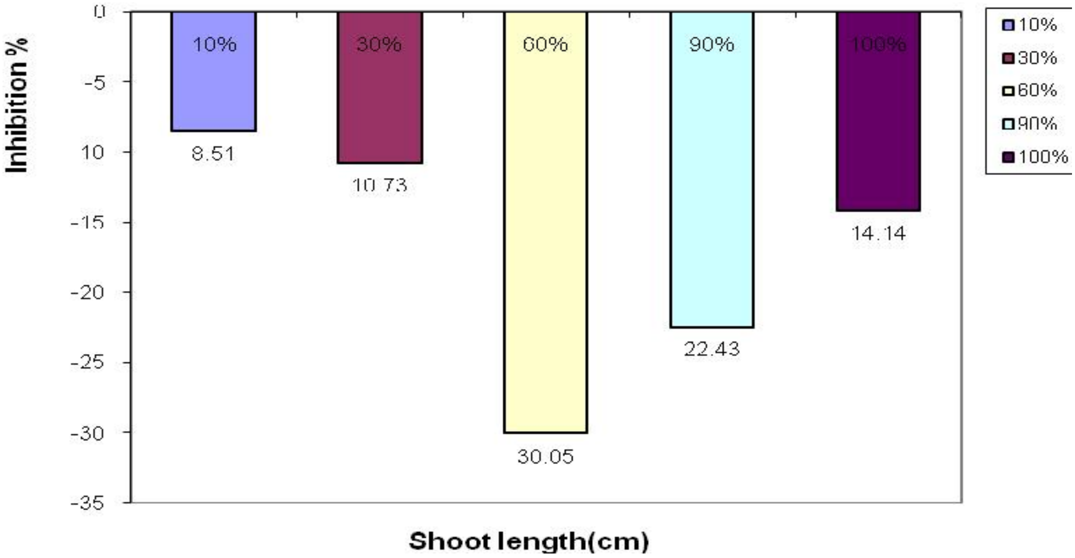


Fig. 6d: Fresh root weight of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

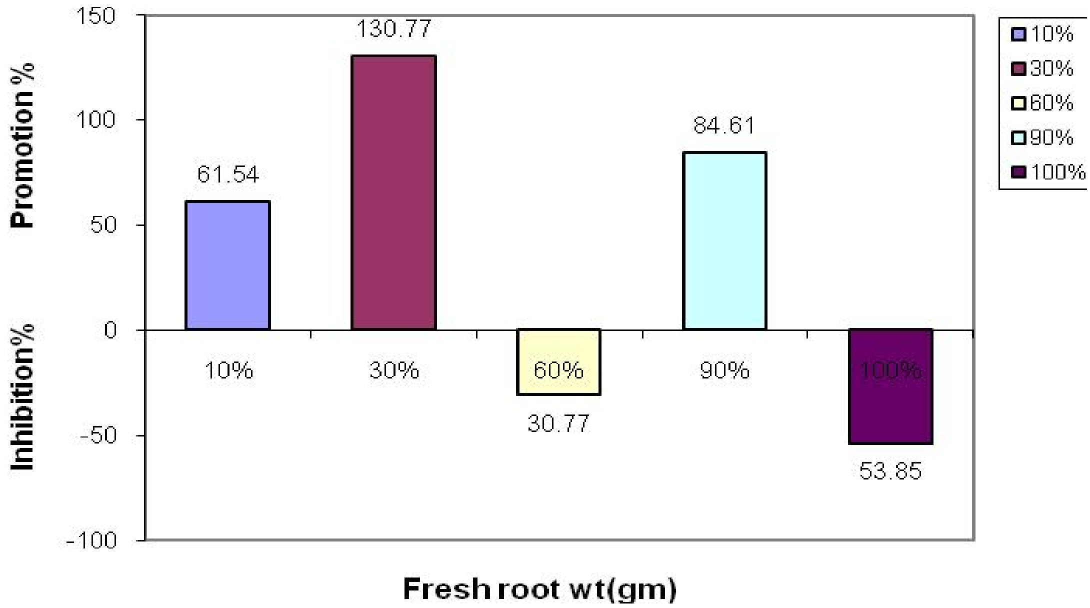


Fig.6e: Fresh shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

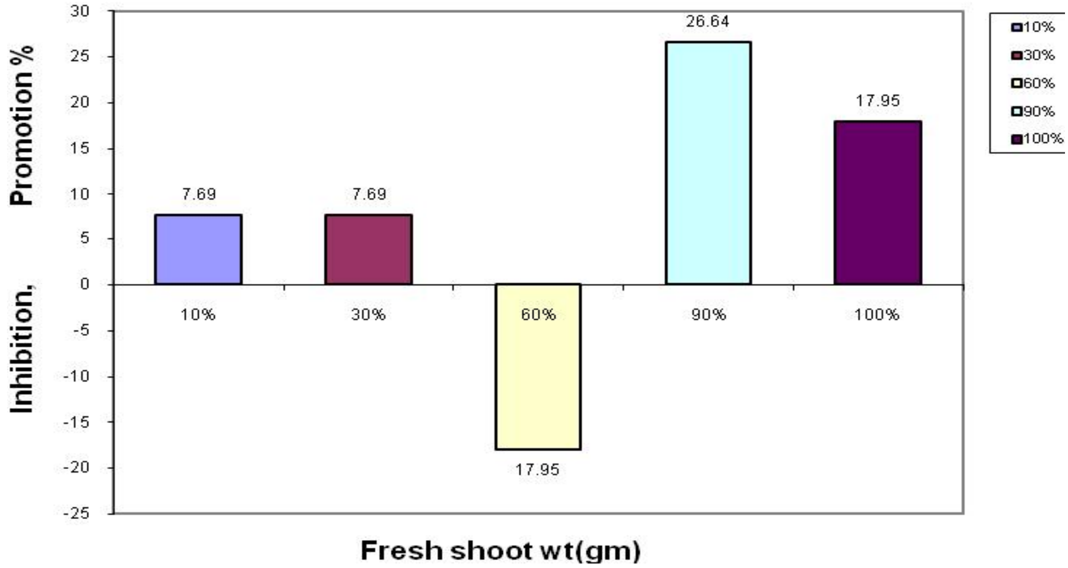


Fig.6f: Dry root weight of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

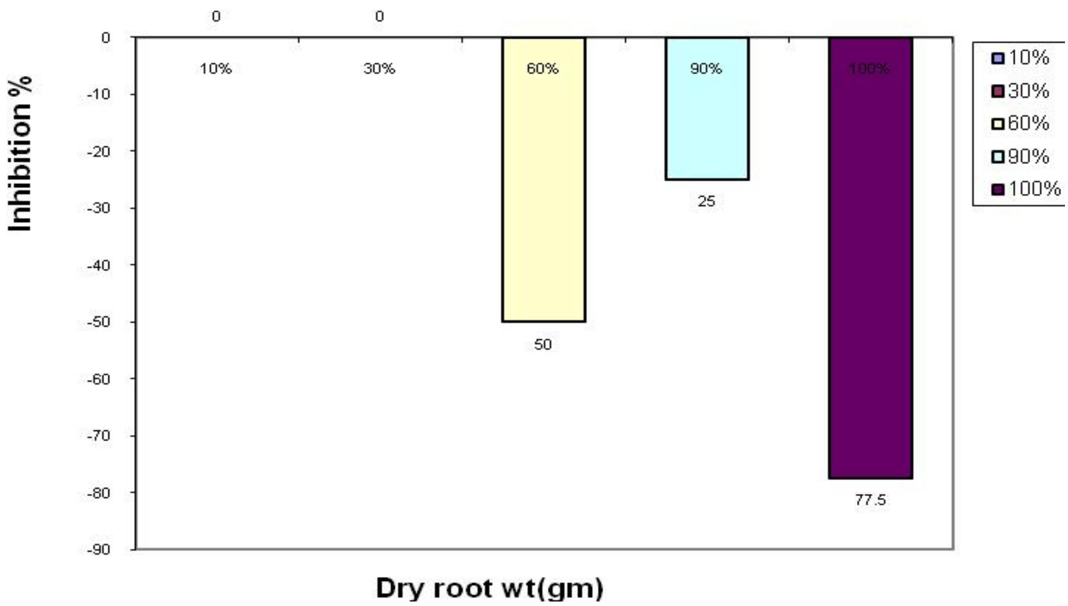


Fig.6g: Dry shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

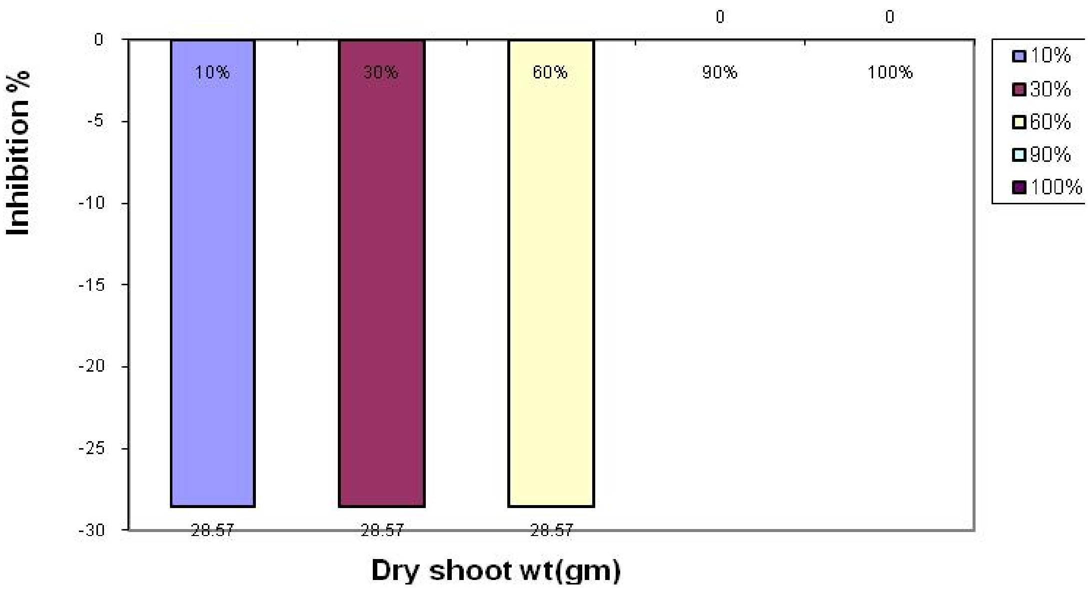


Fig.7a: Germination of *Zea mays* L. under aqueous leaf leachate of *Ageratum huostonianum* L.

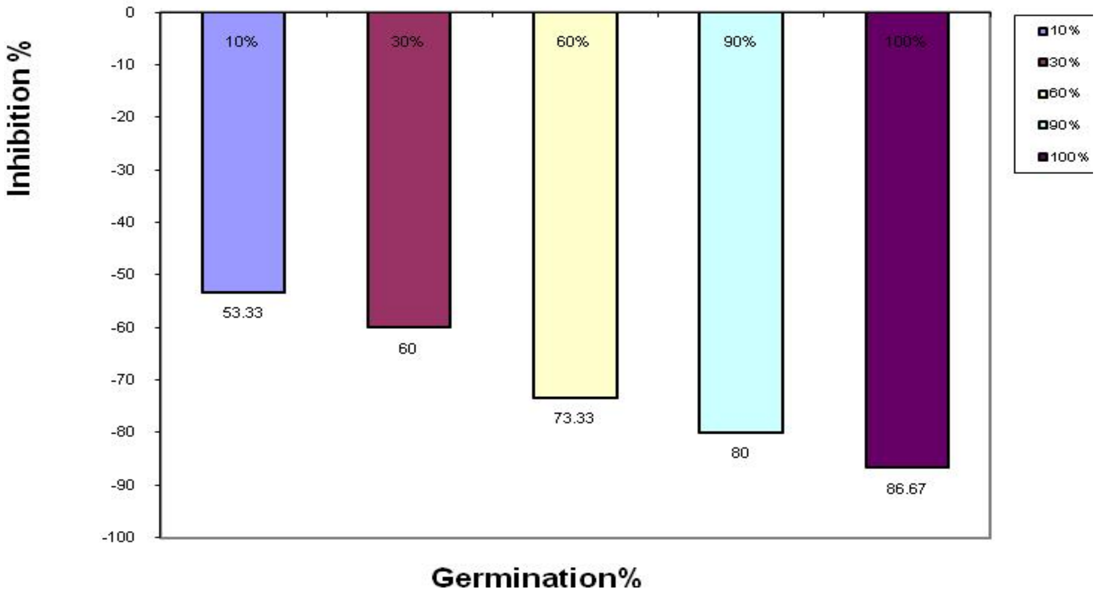


Fig.7b: Root length of *Zea mays* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

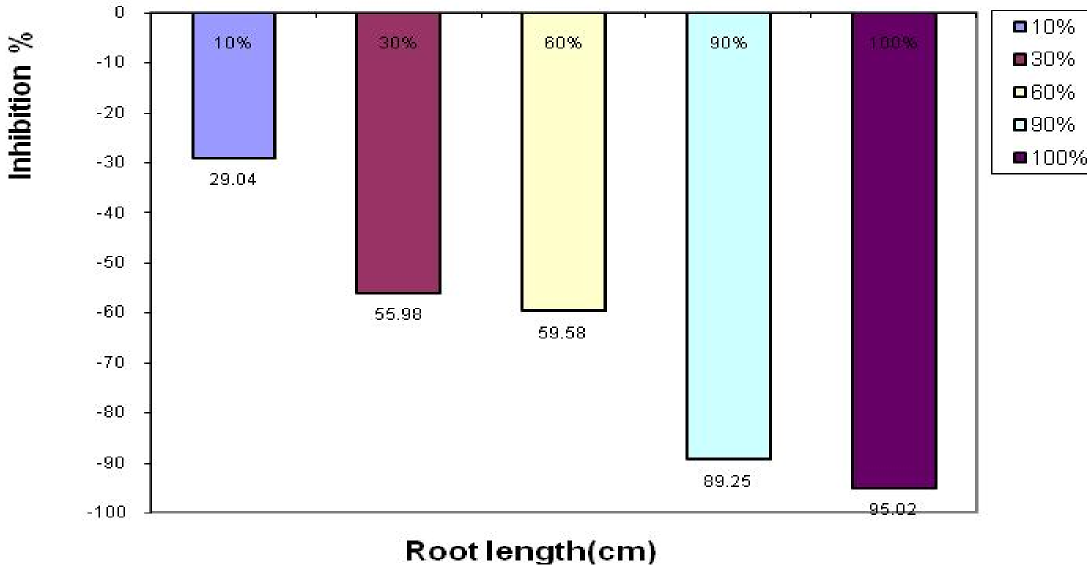


Fig.7c: Shoot length of *Zea mays* L. under leaf leachate of *Ageratum houstonianum* L.

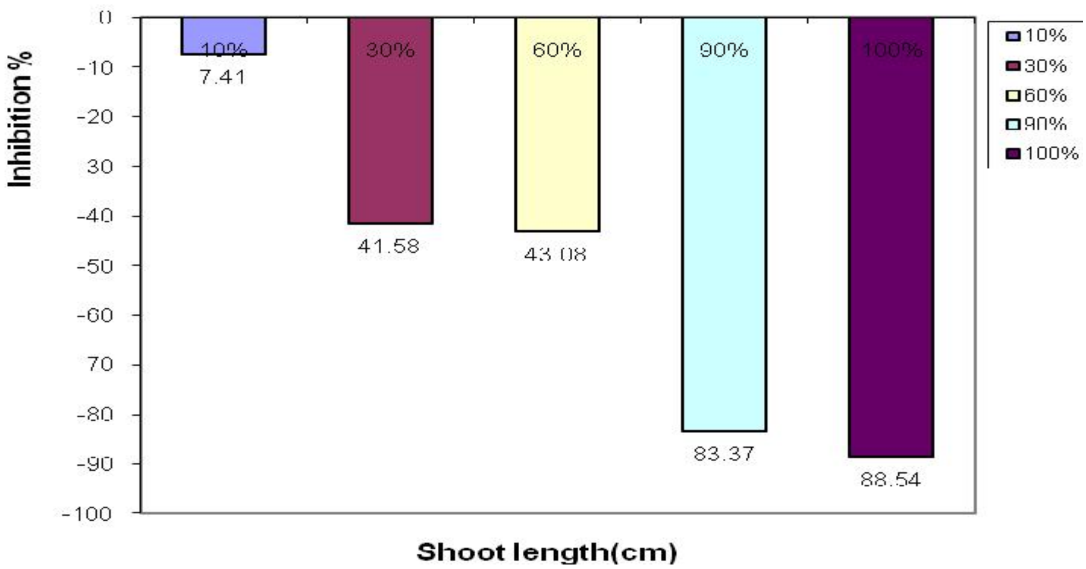


Fig.7d: Fresh root weight of *Zea mays* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

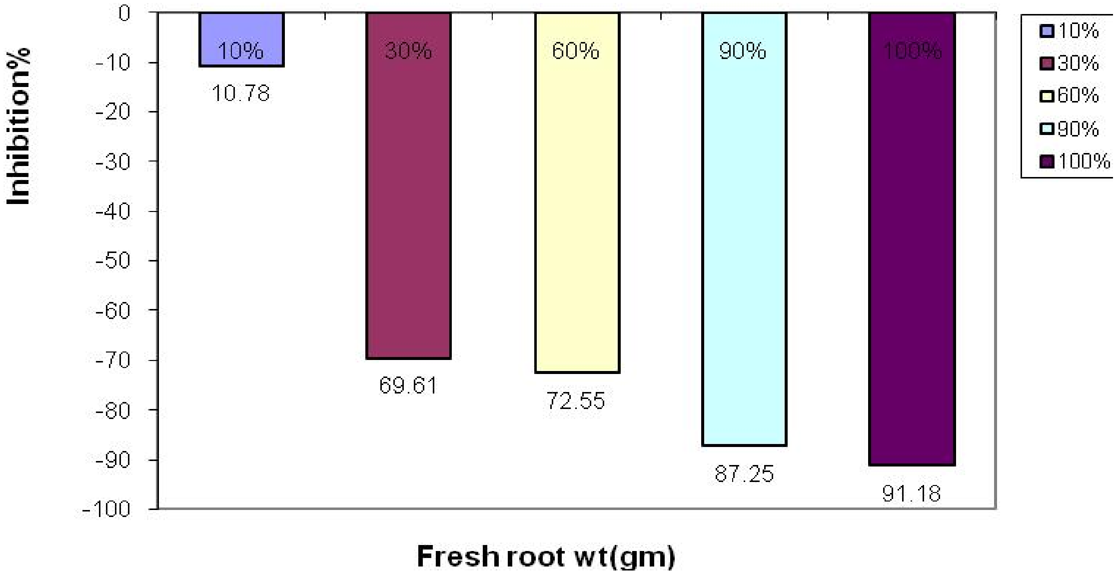


Fig.7e: Fresh shoot weight of *Zea mays* L. under aqueous leaf leachate of *Ageratum houstonianum* L.

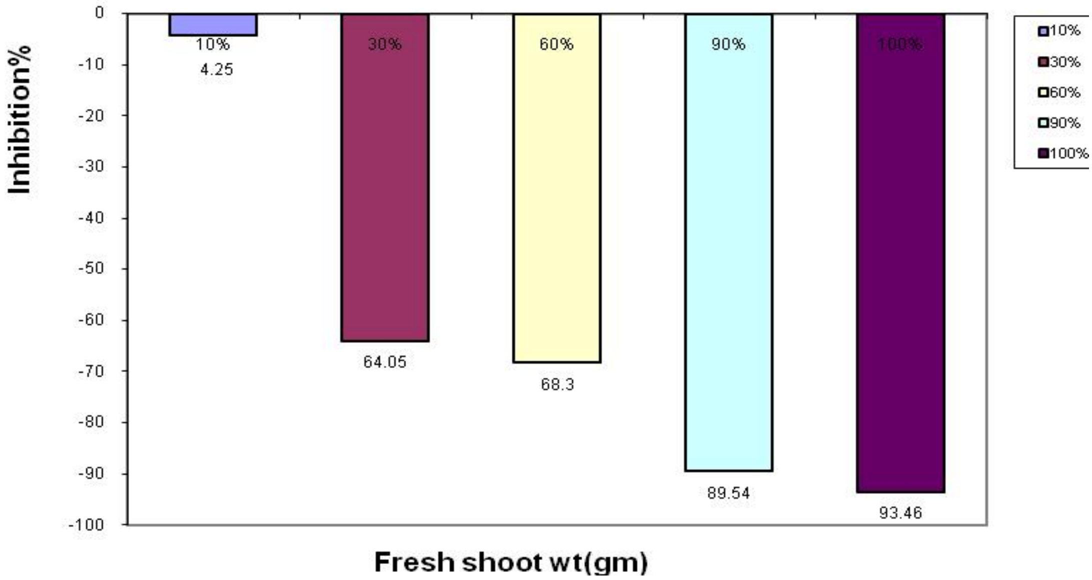


Fig.7f: Dry root weight of *Zea mays* L. under aqueous leaf leachate of *Ageratum huostonianum* L.

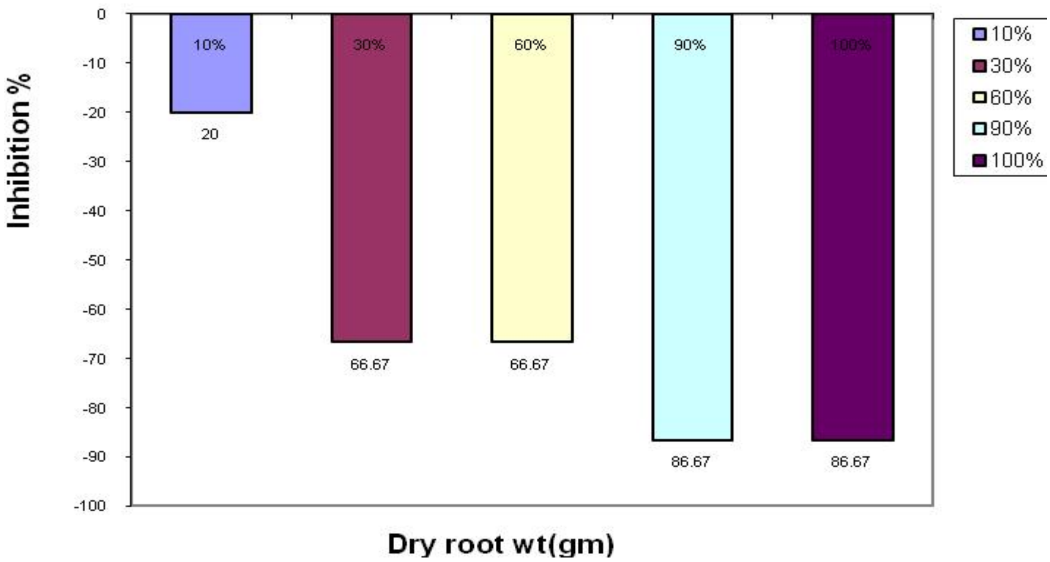
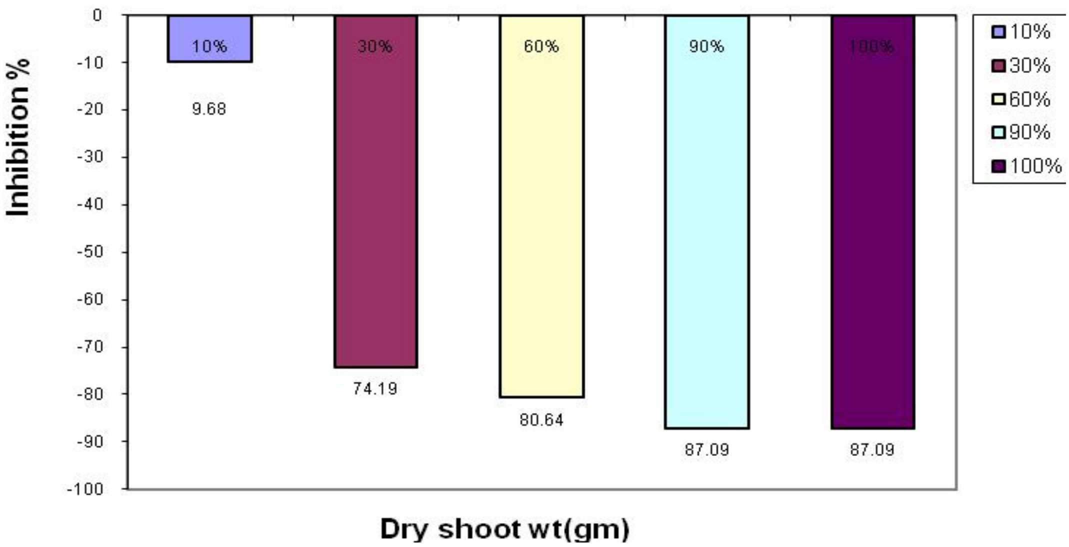


Fig.7g: Dry shoot weight of *Zea mays* L. under aqueous leaf leachate of *Ageratum houstonianum* L.



4.4 Effects of aqueous leaf leachate of *Mikania micrantha* L. on seed germination, root and shoot extension, biomass of fresh and dry weights of root and shoot of *Oryza sativa* L. and *Zea mays* L. under bioassay.

i) Seed germination:

It was observed from the Table 13 and Figure 8a, that the germination percentage of *Oryza sativa* L. was significantly inhibited by the aqueous leaf leachate at different concentration. At T1 leaf leachates concentration neither inhibition nor stimulation was observed and T2, T3 and T4 leachate concentration had least effect on the germination (10% inhibition) and T5 leaf leachates concentration had the highest (25% inhibition) effect in case of *Oryza sativa* L.

Similar was the case with *Zea mays* L. The leaf leachate of *Mikania micrantha* L. at T1 and T2 leaf leachates concentration had same inhibitory percentage (60% inhibition), while at both T4 and T5 leaf leachates concentration, maximum inhibition of seed germination by 80% was recorded and at T3 leaf leachates concentration (73.33%) inhibition of seed germination was recorded. The results showed that higher the concentration level of leachates, the reduction in germination in the test crop was also high (Table 15 and Figure 9a).

ii) Root and shoot lengths:

The effect of different concentrations of leaf leachates of *Mikania micrantha* L. on the root and shoot lengths of paddy is summarized in Tables 13 and 14. The root length of *Oryza sativa* L. was found to be significantly ($P<0.001$) affected by all the concentrations. The T1 leaf leachates concentration enhanced the growth of root by 5.44%, while other concentration had inhibitory effect on root growth. The lowest inhibitory (43.13%) effect on root length was observed at T2 leachate concentration while the T5 leachate concentration had maximum inhibition (96.11%). The shoot length was similarly affected by the aqueous leachate of *Mikania micrantha* L. at all concentrations. In general, the higher concentration caused more inhibition of shoot development. The highest and lowest shoot elongation was recorded as 79.13% and 21.43% respectively in T5 and T1 concentration of leaf leachates (Figures 8b, c).

The leaf leachate of *Mikania micrantha* L. also suppressed the root and shoot elongations of *Zea mays* L. Clear differences were observed when the data were compared between the different concentrations of the leaf leachates. The rate of suppression of root elongation increased with an increase in leaf leachates concentration, the lowest concentration (T1) sharing least effect (34.49%) and the highest concentration (T5 concentration) showing maximum inhibition (95.44%) during the study period. The results also indicated that the extension of shoot was stimulated by 2.53% at T1 leachate concentration indicating this concentration as favourable for shoot growth. Among the different concentrations, the absolute T5 concentration was most inhibitory (89.39%). In general, higher the concentration of leaf leachates, the greater was the inhibition in growth of root and shoot and *vice versa* (Tables 15 and 16, Figures 9b, c).

iii) Fresh weights of root and shoot:

The results in weight of fresh root and shoot of *Oryza sativa* L. were depended on the leaf leachate concentration. In case of root, T1 leachate concentration promoted its fresh weight by 38.46% compared to the control. On the contrary, other leaf leachate concentration gradually inhibited the fresh weight of root and the rate of inhibition was in direct proportion with the leachate concentration. Among the treatments, both T2 and T3 concentrations had the least (38.46%), while maximum

(92.31%) inhibition was observed at T5 concentration. The fresh weights of paddy shoot were inhibited by 5.13%, 17.95%, 23.076%, 56.41% and 66.67% at T1, T2, T3, T4 and T5 concentration respectively. The results showed a gradual upward inhibition with an increase in leachate concentration (Tables 13 and 14, Figures 8d, e).

The effects of leaf leachates of *Mikania micrantha* L. on the fresh weight of root and shoot of *Zea mays* L. were given in Tables 15 and 16. The fresh weight of *Zea mays* L. was significantly ($P<0.001$) inhibited by the absolute T5 concentration showing a maximum inhibition of 92.16% compared to the control. The corresponding value at T1 leachate was only 54.90%. Nevertheless, the fresh weight of root were significantly ($P<0.001$) inhibited with the increasing of concentration of the leaf leachates (Figure 9d). The highest (98.36%) and lowest (18.30%) inhibitions of shoot were recorded at T4 (absolute) and T2 leaf leachates concentrations respectively. However, at T1 concentration of the leaf leachates, the fresh weight of shoot was more than that of control by 20.91% showing a promotion in shoot weight at this leachate concentration.

viii) Dry weight of root and shoot:

The results of the dry weight of root and shoot of *Oryza sativa* L. as affected by different leachate concentration is summarized in Tables 13 and 14. At T1 leaf leachates concentration, no adverse effect was observed, but subsequent inhibition in dry weight was resulted with an increasing concentration and even a cent per cent inhibition had been observed under T5 concentration. In the case of dry weight of shoot, a low inhibitory (14.28%) was resulted at T1 concentration while at both T2 and T3 of leaf leachates concentration, 42.86% inhibition were observed. At T4 leaf leachates concentration, inhibition level peaked (87.14%) and then declined (85.71%) at absolute T5 concentration (Figures 8f, g).

Similarly, the dry weight of root and shoot of *Zea mays* L. was retarded significantly ($P<0.001$) as the leachates concentration increased from lower to higher (Tables 15, 16 and figures 9f, g). The inhibition was minimum (26.67%) at T1 concentration and maximum (100%) at T5 concentration. In most cases, the results were significant at $P<0.001$. Tables 15 and 16 showed that the dry weight of shoot was significantly ($P<0.001$) promoted at T1 concentration, but subsequent inhibition resulted from T2 onwards with the increasing concentration of aqueous leachates (Figures 9f, g).

Discussion:

Based on the laboratory experiment, the leaf leachates of *Mikania micrantha* L. highly suppressed the seed germination of *Zea mays* than *Oryza sativa* L. The results also revealed that the leaf leachates concentration had greater inhibitory effect on the extension of root and shoot length of *Zea mays* than *Oryza sativa* L. when compared to control. The root length and the fresh root weight of paddy at T1 concentration enhanced the growth and weight (5.44%, 38.46%) over control. However, from T2 concentration to T5 concentration, the inhibitory effect was increased as the concentration of leaf leachates increased. As in the case of maize, the shoot length, fresh shoot weight and dry shoot weight at T1 leaf leachate concentrations, promotion effect had been recorded by 2.53%, 20.91% and 41.93% respectively. However, at different concentrations (T2, T3, T4 and T5) significant ($P<0.001$) inhibition was observed with increase in leaf leachate concentration. These findings are in accordance with Sisodia and Siddiqui (2008, 2009) who stated that the inhibition effect was found to increase with increasing concentration at different aqueous extracts. However, according to Beck and Hanson (1989), germination was induced by lower concentration. From the findings of Zeng *et al*. (2008), it may be inferred that the allelopathic chemicals are distributed broadly among organs such as seeds, flowers, pollen, leaves, stems, and roots, however, just one or two of such organs inhibited germination, emergence and growth injury to certain food crops (Zeng *et al.*, 2008). Shajie and Saffari (2007) also reported that leaves and stems extract of *Xanthium strumarium* L. significantly reduced germination and seedling growth in maize, canola, sesame, lentil and chickpea. Extracts of *Mikania* slow the germination and growth of a variety of plant species. At least three sesquiterpenoids have been identified in the plant parts of this weed which produce this effect. Significant reductions in the growth of plumule and radical of various crops as affected by *Mikania* had also been observed (Ogbe *et al.,* 1994).

Earlier workers have reported that the effect of leaf leachates on seed germination and seedling growth was due to the presence of nutrients, growth regulators, alkaloids and toxins (Rice, 1984; Kaur *et al*., 1999). In laboratory, plant extracts and leachates are commonly screened for their effects on seed germination, with further isolation and identification of allelochemicals from greenhouse tests and field soil, confirming laboratory results (Ferguson and Rathinasabapathi, 2003). Ismail and Chong (2002) reported that aqueous extracts of *Mikania micrantha* plant leaves retarded germination of tomato and Chinese cabbage, but did not affect germination of long bean. The aqueous leaf leachates of *Mikania micrantha* L. at different concentrations under laboratory condition evidence the allelopathic effect on the seed germination and growth parameters of paddy and maize.

Table 13: Effect of aqueous leaf leachate of *Mikania micrantha* L. on seed germination, root and shoot extension, biomass of fresh and dried weights of root and shoot of *Oryza sativa* L. under bioassay.

Treatments	Germination (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	100±0.0	16.696±0.149	13.51±0.062	0.013±0.000	0.039±0.000	0.004±0.00002	0.007±0.00002
T1(10%)	100±0.0	17.605±0.02	10.614±0.081	0.018±0.00002	0.037±0.00003	0.004±0.00003	0.006±0.00003
T2 (30%)	90±0.00	9.495±0.041	9.8±0.044	0.008±0.00001	0.032±0.00003	0.0001±0.0	0.004±0.00002
T3 (60%)	90±0.00	4.62±0.050	7.285±0.046	0.008±0.00001	0.030±0.00001	0.0001±0.0	0.004±0.00002
T4 (90%)	90±0.00	1.815±0.050	3.78±0.060	0.001±0.00001	0.017±0.00001	0.0003±0.00007	0.0009±0.00005
T5 (100%)	75±0.00	0.65±0.032	2.82±0.031	0.001±0.00001	0.013±0.00003	0.0±0.0	0.001±0.00001
CD at P ≤ 0.05	0.00	1.270	1.009	0.002	0.004	0.002	0.003

± SE. m, n= 4

Table 14: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Mikania micrantha* L. on growth attributes of *Oryza sativa* L. under bioassay.

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Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
T1 (10%)	36.519***	800.002***	1214.464***	362.823***	0.980 ns	2.539 ns
T2 (30%)	2166.151***	2378.246***	34.571***	37.607***	192.667***	100.820***
T3 (60%)	5877.034***	6445.010***	128.000***	1.530 ns	192.667***	100.820***
T4 (90%)	8942.36***	12518.73***	6561.00***	4589.11***	174.49***	704.56***
T5 (100%)	11055.85***	23745.68***	6561.00***	2897.19***	322.67***	427.97***

*** significant at P<0.001, ns – non significant.

Table 15: Effect of aqueous leaf leachate of *Mikania micrantha* L. on seed germination, root and shoot extension, biomass of fresh and dried weights of root and shoot *of Zea mays* L. under bioassay.

Treat ments	Germina tion (%)	Root length (cm)	Shoot length	Biomass			
				Fresh weight (gm)		Dry weight (gm)	
				Root	Shoot	Root	Shoot
Control	75±0.00	22.057±0.155	21.725±0.088	0.102±0.00003	0.306±0.00003	0.015±0.00001	0.031±0.00002
T1(10%)	30±0.00	14.45±0.054	22.275±0.037	0.046±0.00004	0.370±0.002	0.011±0.000007	0.044±0.00002
T2 (30%)	30±0.00	14.254±0.087	15.841±0.149	0.038±0.00004	0.250±0.00003	0.007±0.00001	0.008±0.00001
T3 (60%)	20±0.00	3.71±0.052	6.694±0.138	0.019±0.00003	0.097±0.00005	0.007±0.000006	0.007±0.00001
T4 (90%)	15±0.00	1.250±0.003	2.948±0.004	0.012±0.00003	0.005±0.00003	0.005±0.00003	0.001±0.00001
T5 (100%)	15±0.00	1.005±0.009	2.305±0.024	0.008±0.00001	0.030±0.00002	0.0±0.0	0.005±0.00003
CD at P ≤ 0.05	0.00	1.410	1.329	0.006	0.019	0.002	0.003

± SE. m, n= 4

Table 16: Analysis of Variance (ANOVA) due to effect of aqueous leaf leachate of *Mikania micrantha* L. on growth attributes of *Zea mays* L. under bioassay.

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Treatments	Root length (cm)	Shoot length	Biomass			
			Fresh weight (gm)		Dry weight (gm)	
			Root	Shoot	Root	Shoot
T1 (10%)	2140.70***	32.66***	11920.91***	598.55***	627.45***	1726.60***
T2 (30%)	1914.83***	1144.57***	14141.80***	15008.82***	1955.35***	6399.21***
T3 (60%)	12522.08***	8384.51***	33552.09***	96268.91***	2347.07***	11087.58***
T4 (90%)	17957.5***	44998.2***	35163***	414878.8***	732.8***	16456.2***
T5 (100%)	18327.5***	44903.5***	60458.0***	562542.1***	9078.6***	4070.1***

*** Significant at P<0.001

Fig.8a: Germination of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

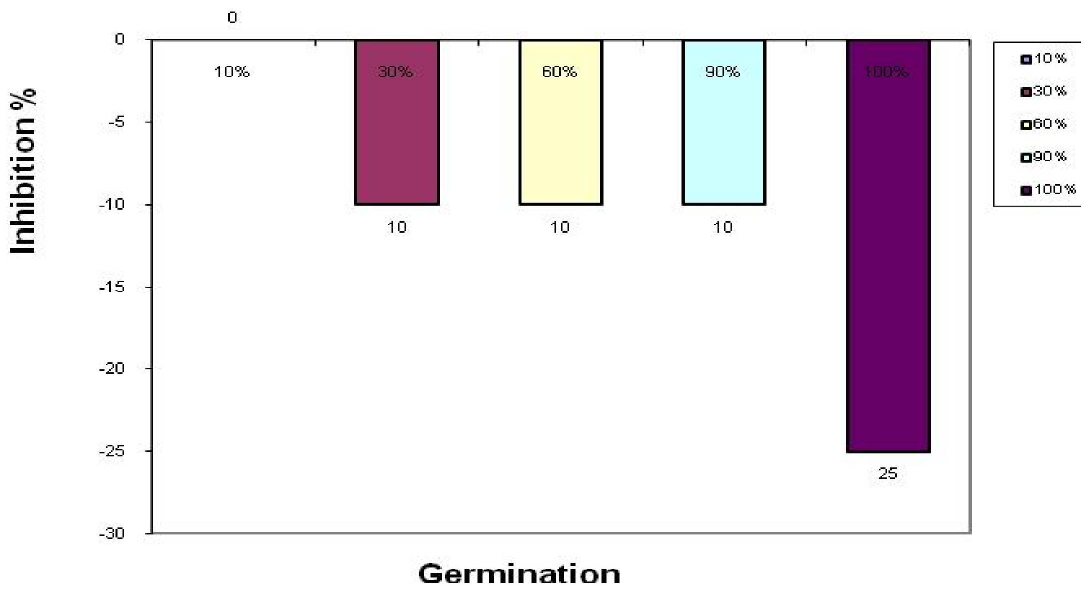


Fig.8b: Root length of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

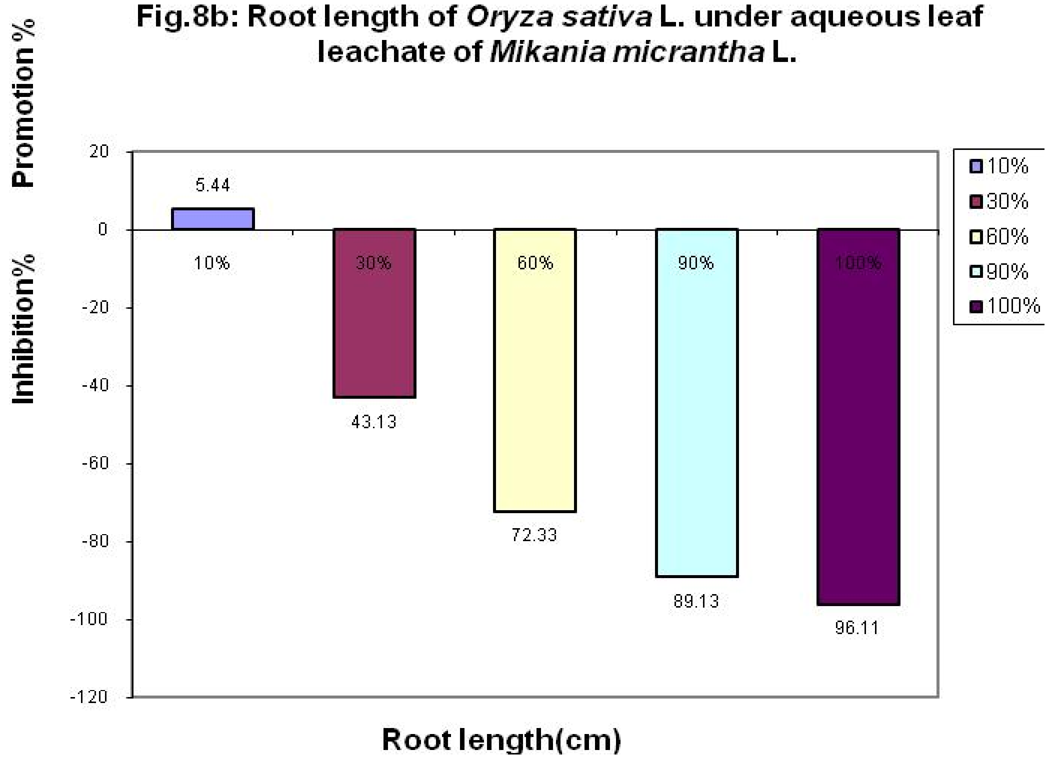


Fig.8c: Shoot length of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

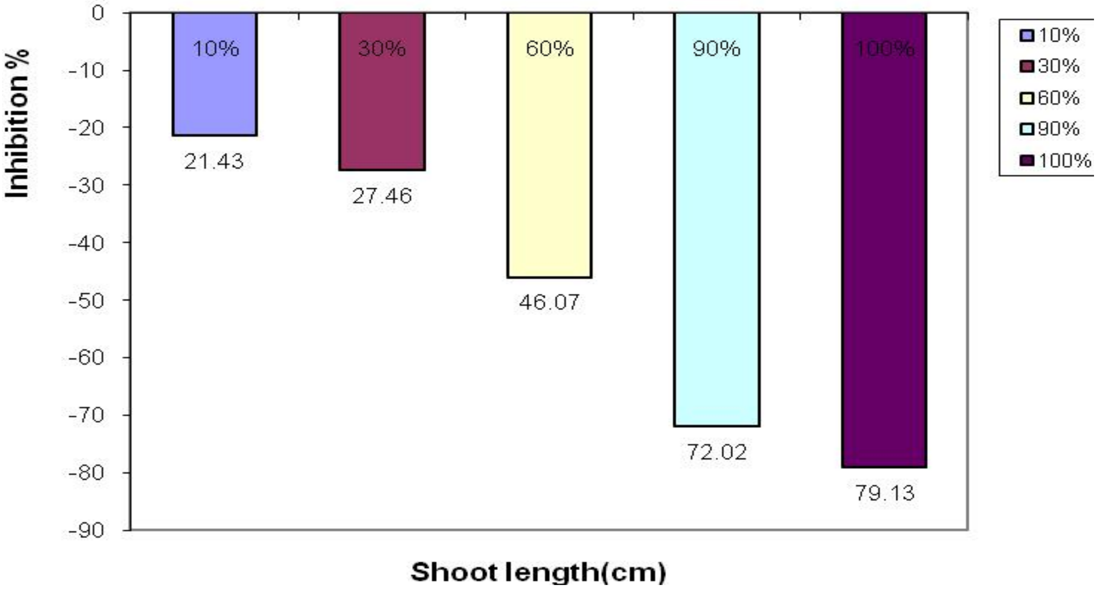


Fig.8d: Fresh root weight of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

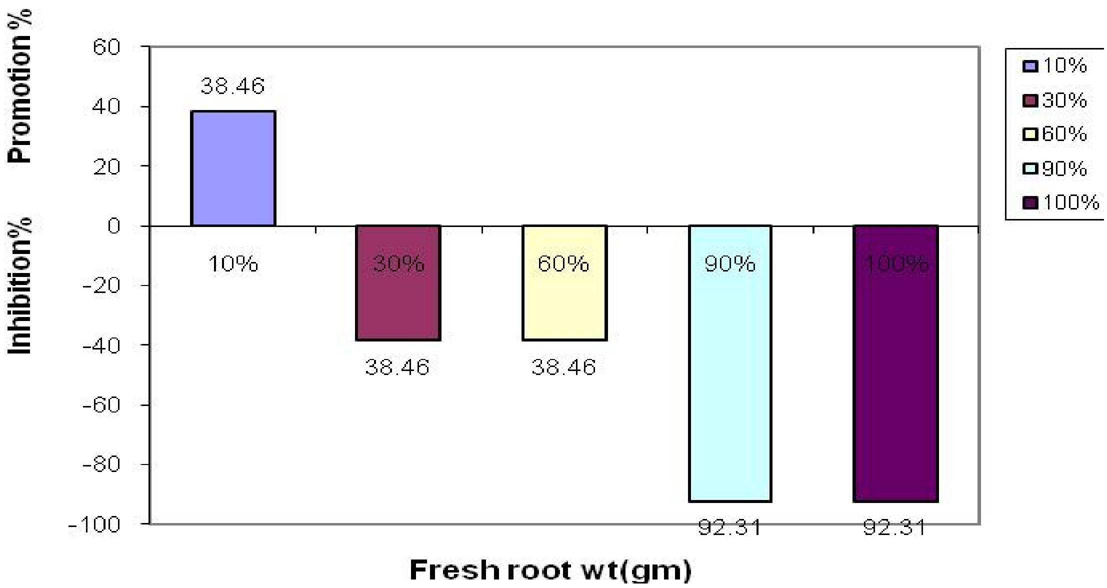


Fig.8e: Fresh shoot weight of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

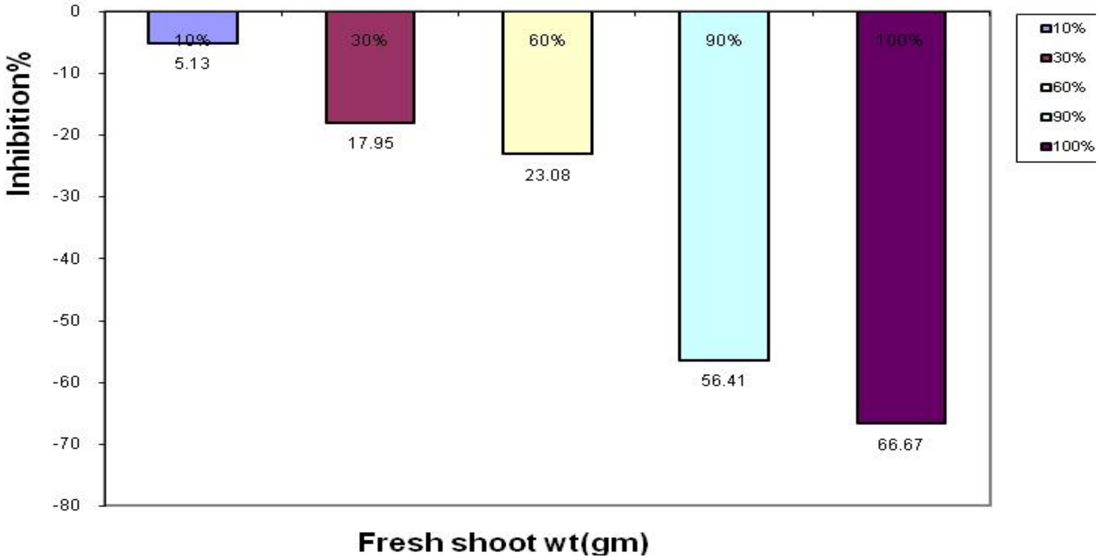


Fig.8f: Dry root weight of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

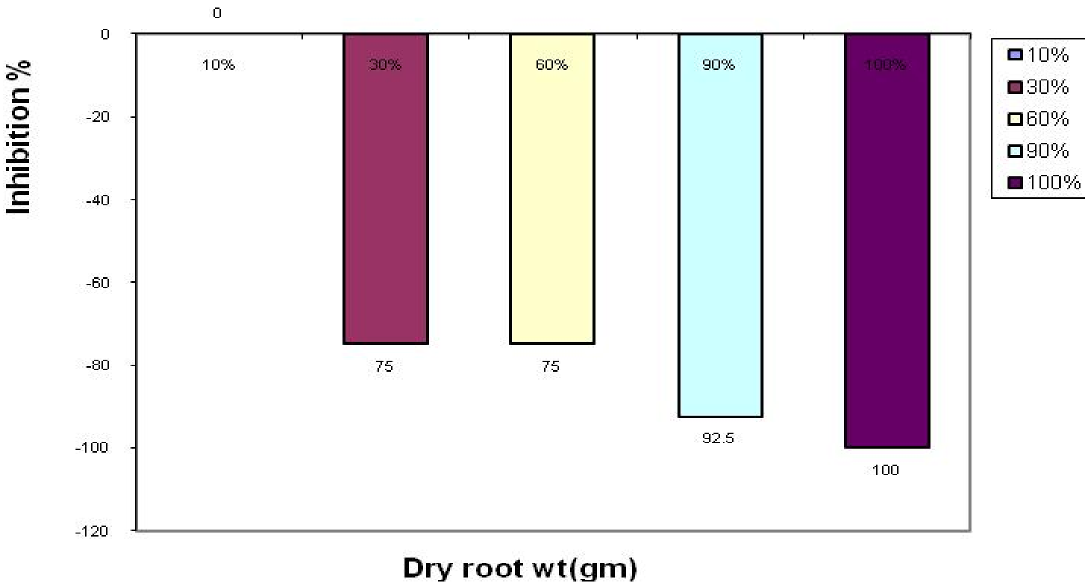


Fig.8g: Dry shoot weight of leaf leachate of *Oryza sativa* L. under aqueous leaf leachate of *Mikania micrantha* L.

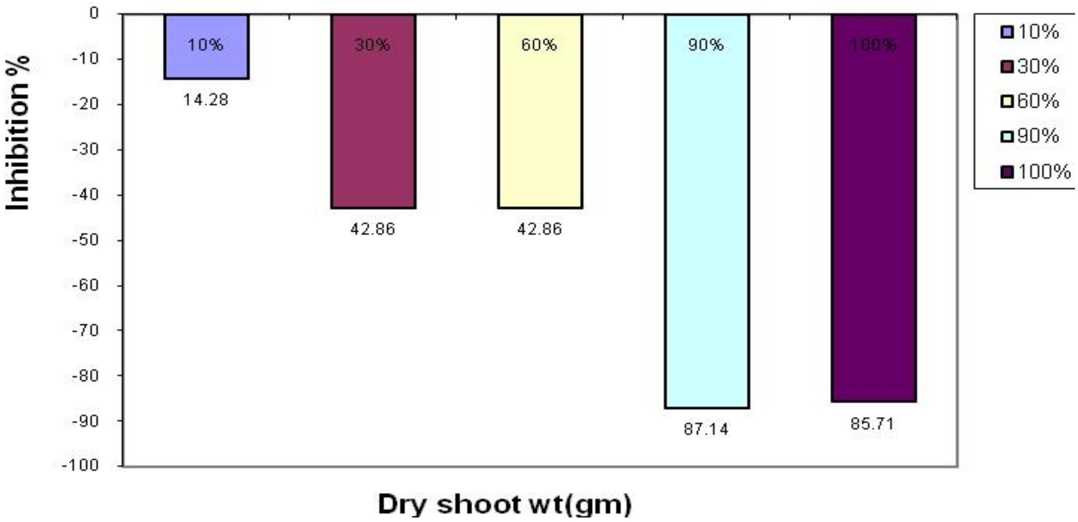
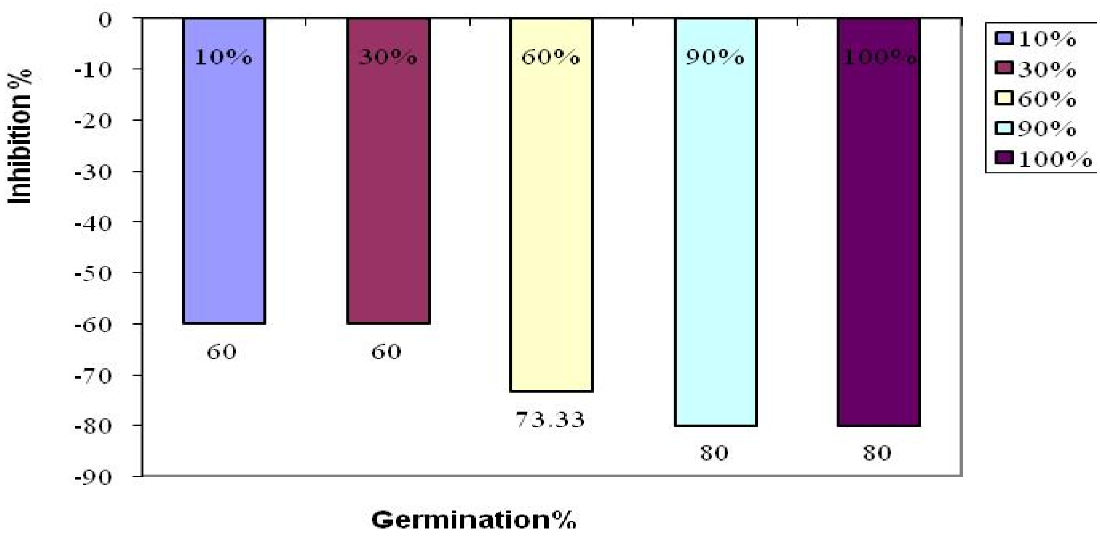


Fig.9a: Germination of *Zea mays* L. under aqueous leaf leachate of *Mikania micrantha* L.



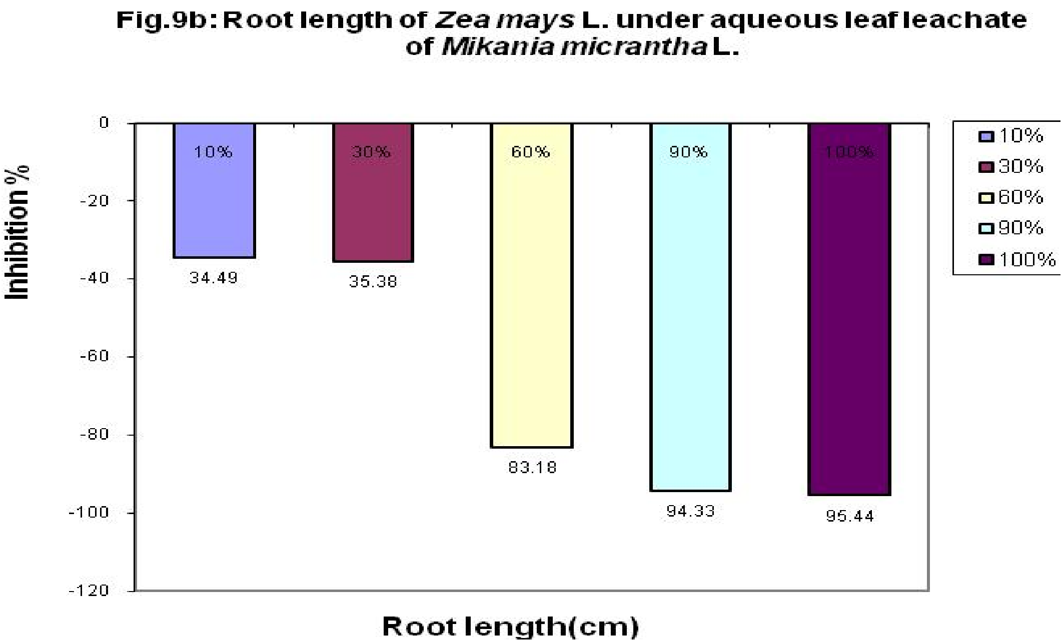


Fig.9b: Root length of Zea mays L. under aqueous leaf leachate of Mikania micrantha L.
Inhibition %
0
-20
-40
-60
-80
-100
-120
10%
30%
60%
90%
100%
34.49
35.38
83.18
94.33
95.44
Root length(cm)

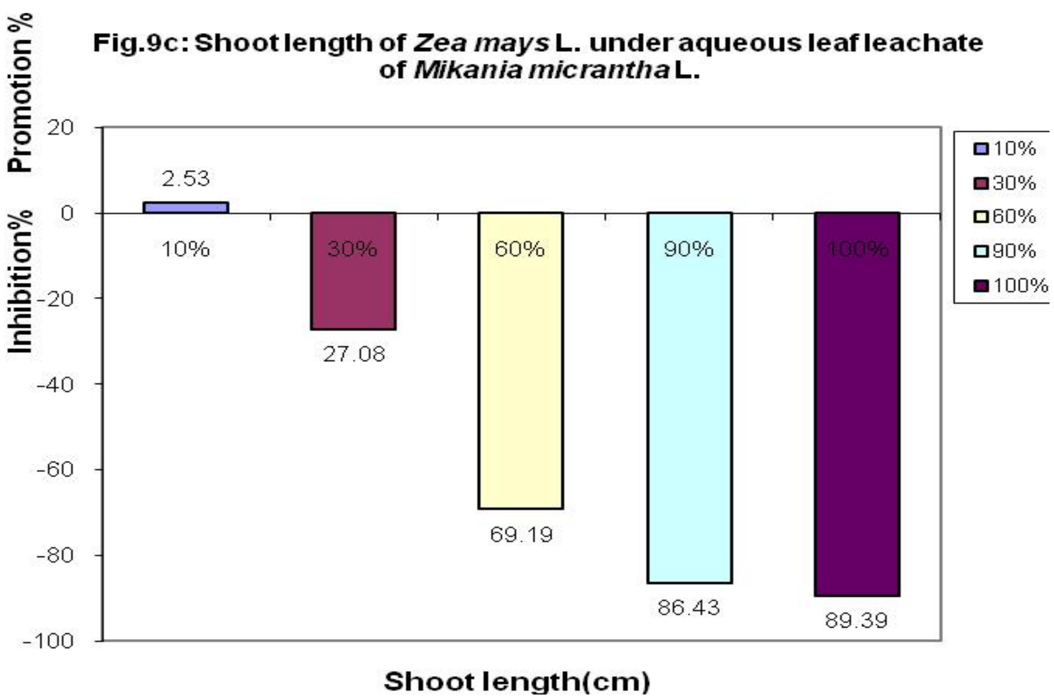


Fig.9c: Shoot length of Zea mays L. under aqueous leaf leachate of Mikania micrantha L.
Promotion %
Inhibition%
20
0
-20
-40
-60
-80
-100
2.53
10%
30%
60%
90%
100%
27.08
69.19
86.43
89.39
Shoot length(cm)

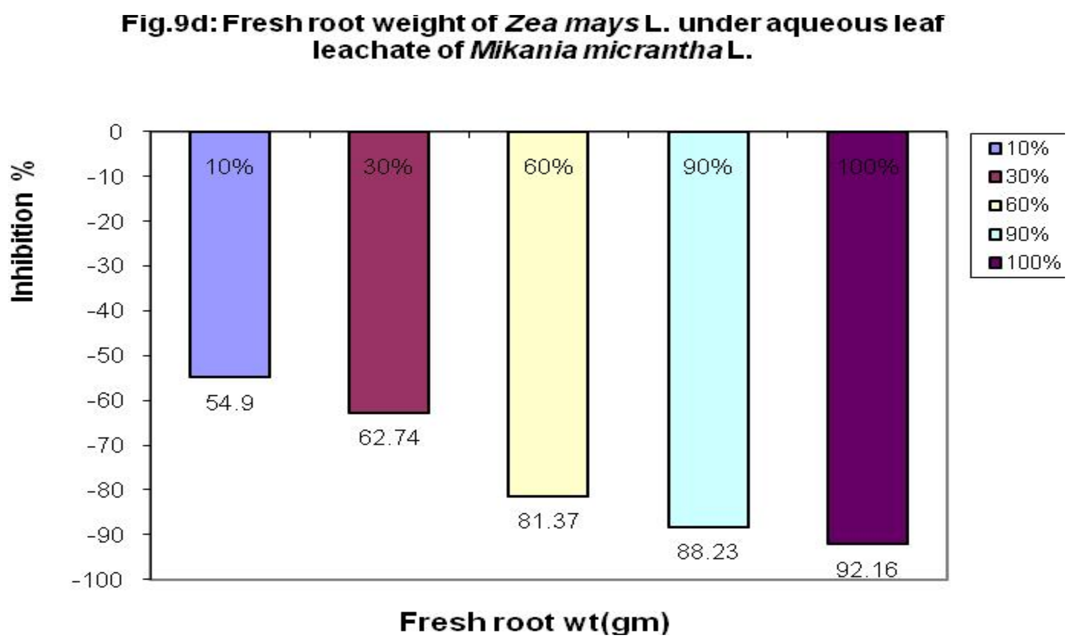


Fig.9d: Fresh root weight of Zea mays L. under aqueous leaf leachate of Mikania micrantha L.
Inhibition %
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
10%
30%
60%
90%
100%
54.9
62.74
81.37
88.23
92.16
Fresh root wt(gm)

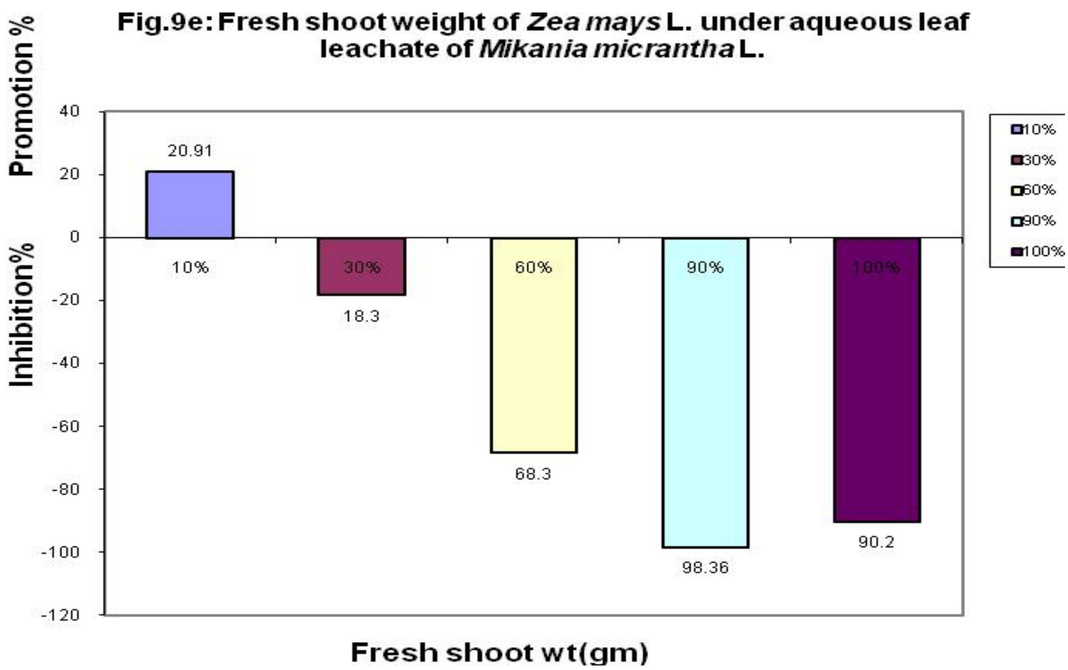


Fig.9e: Fresh shoot weight of Zea mays L. under aqueous leaf leachate of Mikania micrantha L.
Promotion %
Inhibition%
40
20
0
-20
-40
-60
-80
-100
-120
20.91
10%
30%
60%
90%
100%
18.3
68.3
98.36
90.2
Fresh shoot wt(gm)

Fig.9f: Dry root weight of *Zea mays* L. under aqueous leaf leachate of *Mikania micrantha* L.

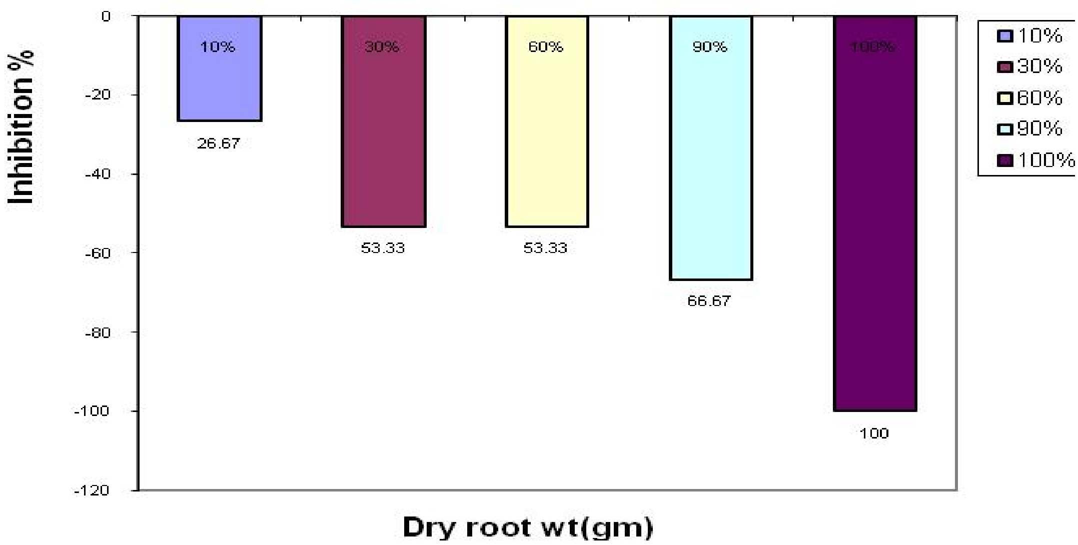
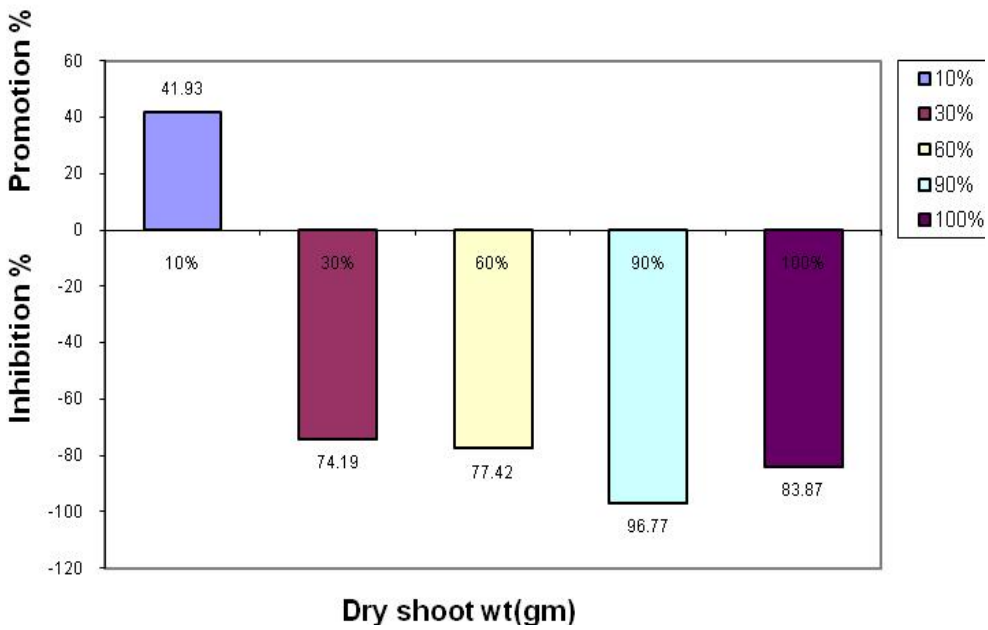


Fig.9g: Dry shoot weight of leaf leachate of *Zea mays* L. under aqueous leaf leachate of *Mikania micrantha* L.



Chapter-5

EFFECT OF LEAF LEACHATES OF TREES AND WEEDS ON TEST CROPS UNDER POT CULTURE

5.1 Effect of different treatments on the germination, and initial growth parameters of *Oryza sativa* L. and *Zea mays* L. under pot culture experiment:

i) Seed germination:

The seed germination of *Oryza sativa* L. under ST, DT and SN was significantly (P<0.05) inhibited by 10%. Under DN and DA the germination percentage was inhibited by 5% and the greatest inhibitory percentage was recorded under DM (15%) over control (Table 17, Figure 10a).

Table 19 shows that the highest inhibition percentage of *Zea mays* L. was observed under DM (20%). Neither inhibitory nor stimulatory effect was found under DT and SN. Under ST and DN, 2% inhibition was observed, while under DA, 6% inhibitory was recorded as compared to the control.

ii) Plant height:

The results clearly indicated that growth of *Oryza sativa* L. was significantly suppressed by 13.03% under DT, while all the other treatments *viz.,* ST, SN, DN, DM and DA showed significant (P<0.00) stimulatory effect by 43.84%, 72.36%, 30.46%, 62.71% and 31.51% on plant height respectively over control. The highest (72.36%) stimulatory effect was recorded at SN, while the lowest (30.46%) stimulatory effect recorded was under DN (Tables 17 and 18, Figure 10b).

Similar trend was also observed in case of growth of *Zea mays* L., only the treatment under DT showed significant ($P<0.05$) inhibition by 1.74%. However, all the other treatments showed promotion in growth of this crop at $P<0.001$. The percentage of promotion over control recorded were 23.08%, 54.14%, 64.88%, 49.35% and 29.61% under ST, SN, DN, DM and DA respectively (Tables 19 and 20, Figure 10b).

iii) Number of leaves:

It is evident from Table 17 and 18 that, *Oryza sativa* L. under ST, SN and DN showed higher number of leaves (17.86%, 14.28% and 14.28% respectively) over control. Treatment under DT shows inhibition (7.14%), while DM and DA gave neither inhibition nor promotion affects (0%) as compared to control.

Number of leaves in *Zea mays* L. under all the treatments had been promoted significantly at $P<0.01$, $P<0.05$ and $P<0.001$ level. The maximum (71.43%) increased in number of leaves was found under ST and DN. The lowest (14.28%) number of leaves was recorded under DM (Tables 19 and 20, Figure 10c).

iv) Diameter of stem:

It is evident from Tables 17 and 18 that the stem diameter of *Oryza sativa* L. was suppressed by 9.09% under DT, while the stem diameter was significantly greater in all the other treatments when compared with control (Figure 10d).

Tables 19 and 20 revealed that, DT did not show any adverse effect on the stem diameter of *Zea mays* L. ST resulted in lowest crop diameter (8.0%), while maximum stem diameter was observed under DN which was significantly ($P<0.05\%$) increased (44.0%) over control (Figure 10d).

v) Number of grains:

The grain yield of *Oryza sativa* L. was higher by 2.56% and 7.69% under SN and DM though non-significant as compared to control. However, all the other treatments showed an inhibition effect on the number of grains of paddy; the least (0.64%) inhibitory effects were observed under DN, while the maximum (45.51%) inhibition was resulted under DT (Tables 17 and 18, Figure 10e).

In case of *Zea mays* L., under Tables 19 and 20, the number of grains under SN and DN showed stimulatory effect to an extent of 0.4% and 0.8% respectively over control. ST, DT, DM and DA significantly ($P<0.001$) reduced the number of grains of maize by 11.73%, 20.27%, 9.33% and 16.27% respectively (Figure 10e).

vi) Weight of grains:

An inhibitory effect on grain yield of paddy was observed under ST (17.97%) and DT (21.87%). However, the other treatments showed significant ($P<0.01$) promotion, the highest (69.53%) being recorded under DM while the least (55.47%) under DA compared to control (Figure 10f).

The cob weight of *Zea mays* L. showed significant inhibitory effect (5.60%) under ST, under SN (17.56%) and under DA (9.75%). On the contrary, the cob weight increased under SN, DN and DM by 10.08%, 11.26% and 4.4% respectively over control (Figure 10f).

vii) Fresh root weight:

The fresh root weight of *Oryza sativa* L. showed promotion effect under all the treatments except DA by 12.31%. The extent of promotion under different treatments were 53.85%, 38.46%, 100%, 1.54% and 4.61% at ST, DT, SN, DN and DM respectively. There was an increase in root fresh weight of root by 100% in paddy under SN (Tables 17 and 18, Figure 10g).

The fresh root weight of *Zea mays* L. was inhibited under all the treatments. The highest inhibition (44.66%) was ST while the lowest (2.81%) inhibition was under the DT (Tables 19 and 20, Figure 10g).

viii) Fresh shoot weight:

The results indicated that the fresh shoot weight of *Oryza sativa* L. was significantly promoted under all treatments except under DT where there was an inhibition to an extent of 40.79% over control. The highest (26.31%) promotion was observed under SN while the lowest promotion (10.53%) was recorded under DT (Tables 17 and 18, Figure 10h).

On the contrary, the fresh shoot weight of *Zea mays* L. had been affected adversely under all the treatments, the range of inhibition was 16.91% by DN to 23.84% by ST (Tables 19 and 20, Figure 10h).

ix) Dry root weight:

The dry root weight of *Oryza sativa* L. was found promoted under all the treatments. The lowest stimulatory (19.72%) effect was observed under DM, the respective value for DT was 40.84%. The treatment SN showed an increase in weight of root to an extent of 322.53%, followed by DA (111.27%), the value being significant at $P<0.01$ (Figure 10i).

In case of *Zea mays* L. the dry weight of root got promoted by all treatments except under DT. The extent by which the promotion occurred for the dry root weight of maize was as follows: ST (62.39%), SN (88.12%), DN (105.13%), DM (58.12%) and DA (62.39%). Under DT, however, it showed inhibition to an extent of 31.62% compared to the control (Tables 19 and 20, Figure 10i).

x) Dry shoot weight:

A comparatively higher dry shoot weight of Oryza sativa L. was observed under ST followed by DA, DN, SN, DM and DT. The respective promotion values on dry shoot weight of *Oryza sativa* L. were 237.35%, 189.16%, 153.01% 140.96 %, 140.96% and 56.63% (Tables 17 and 18, Figure 10j).

On the contrary, the dry shoot weight of maize was adversely affected by all the treatments (Tables 19 and 20). The phytotoxic effect of different treatments from the lowest to highest order was DN (19.98%) > SN (22.27%) > DT (23.04%) > ST (25.84%) > DA (27.62%) > DM (33.74%) (Figure 10j).

Discussion:

Trees and crops growing together in a system compete for light, nutrient and moisture, which often retard the growth and yield of crops. In order to know the extent to which the trees are harmful, experiments under controlled sets are important to be undertaken. Pot culture experiment provides a condition that the plant can grow alone without disturbing other crops. In the present case, selected test crops *viz.,* maize and paddy were grown in polypots (size of 25cm x 15cm) with different combinations to prove whether there is any allelopathic effect (either harmful or in beneficial) on crops. However, well-known problem that could arise under these conditions is the possibility that the plants may become 'root bound'. The plant debris incorporated into the soil is often used in bioassay for allelopathy (Inderjit and Dakshini, 1994; Blum, 1999). Evaluation for the control pot (without added any inert material) was also done to determine the allelopathic responses in debris addition and to observe the degree of interferences. In the present study, the seed germination of paddy and maize crops showed minimum effect (5%, 10% and 15% in case of paddy, 2%, 6% and 20% in case of maize) and in some cases, no adverse effect was observed. The soil beneath the trees had decomposed leaves which exhibited less inhibitory effect on the germination of crops. Further, incorporation of litter in the soil might have improved and reduced the compactness of soil which in turn helped the shoot and root tip to penetrate the soil easily, as can be seen for better elongation of these parts. This is attributed to the beneficial impact of organic matter on the rhizosphere (Mandal *et al.,* 2003). Shukla and Tyagi (2009) also observed that organic matter increased germination, due to a more conducive environment and also showed that the organic materials have no allelopathic effects, and therefore could promote germination of mungbean (*Vigna radiata*). The various parameters studied under pot culture showed significant increase in growth, number of leaves and diameter of stem over control in paddy and maize. Except under DT, the growth of paddy in terms of number of leaves and diameter of stem was significantly suppressed by 13.03%, 7.14% and 9.09%. Similarly, the plant height of maize under DT was also suppressed by 1.74% while the diameter of stem in maize showed positive effect under all the treatments. The grain yield in both the test crops under SN and DM was enhanced over control by 2.56% and 7.69% in case of paddy over control. The yield of grains in maize was also increased by 0.4% and 0.8% under SN and DN when compared with control, the other treatments gave inhibitory effect in respect of yield of grains in maize and paddy. The present study indicated that different treatments on the selected crops *viz*., paddy and maize exhibited several inhibitory and stimulatory factors. This stimulatory effect perhaps was due to the beneficial effect of the organic matter which enhanced relative growth of both roots and shoots significantly; especially when incorporated. The ability of the organic materials to supply nutrients may differ, as they relate to the rates of decomposition, nutrient release rates and patterns (Kumar and Goh, 2004), their incorporation thus could help improve soil characteristics to a greater extent, and also help develop root systems, which are important in maximizing nutrient and moisture uptake. In organic systems where inorganic fertilizers are not used, the replenishment of nutrients and soil quality maintenance is dependent on organic materials due to beneficial impacts in terms of soil physical, chemical and biological properties (Rawls *et al.,* 2003). The distribution of the organic biomass within the soil profile by incorporation attributed to facilitates the development of soil pores (Kay and Munkholm, 2004) and confirms similar reports on rice soils (Mandal *et al*., 2003). Organic matter also improves nutrient availability (Seiter and Horwath, 2004).

On the other hand the average plant height, yield and biomass production under pot culture experiments had been reduced when compared with field experiments. The findings also corroborated with numerous studies which have shown a general reduction in plant growth associated with smaller pot sizes (Peterson *et al.,* 1984; Townend and Dickinson, 1995), however, the mechanisms are not unknown (Carmi, 1993). Pot size affects many physiological processes including nutrient efficiency (Huang *et al*., 1996) and photosynthetic rates which may increase (Carmi *et al*., 1983) or decrease (Herold and McNeil, 1979), or may not change (Krizek *et al*., 1985) with decreasing pot size.

Incorporation of decomposed weeds under pot culture also caused reduction in growth and yields where weeds have been known as very tough competitors of crops for resources. Besides competition, weeds may also cause biochemical inhibition of the growth of crop plants (Chashtai *et al.,* 1988). Crops have also reportedly shown allelopathic effects (Yenish *et al.,* 1995). Suppression of crop growth and yield loss caused by *Mikania* has been reported in rubber [*Hevea brasilensis* (A. Juss)] and oil palm (*Elais guineensis* Jacq.) Caunter and Lee (1996) in Malaysia and in tea (*Camellia sinensis* L. Kuntze) (Barbora, 2001; Singh, 2008), pineapple (*Ananas comosus* L. Merr. and banana (*Musa* spp., Abraham *et al.,* 2002) in India. *Mikania* can harbor insect pests and its vegetative matter may contaminate plucked tea shoots (Barbora, 2001; Abraham *et al.,* 2002a; Rajkhowa *et al.,* 2005). In addition, *Mikania* affects most crops but was most severe in banana, coconut (*Cocos nucifera* L.), tea, coffee (*Coffee arabica* L.), and cocoa (*Theobroma cacao* L.), cassava, pineapple (*Ananas comosus* L. Merr), ginger (*Zingiber officinale* Roscoe) crops (Sreenivasan and Sankaram, 2001; Abraham and Abraham, 2005). In Malaysia, *Mikania* has been reported to compete aggressively with young cocoa, coconut, rubber (*Hevea brasiliensis* Mull. Arg), and oil palm (*Elaeis guineensis* Jacq.) crops for resources and has resulted in economic losses in rubber and oil palm (Teoh *et al.,* 1985). Most plant residues contain or produce substances which are inhibitory to plant growth to some extent. The degree of toxicity depends on the type of residue, maturing and extent of weathering. Reviewing literature both recent and old, it is evident from the contradictory results often obtained, substances highly toxic, non-toxic, stimulatory to plants can be obtained during the decomposition of similar plant residues (Shahida *et al.,* 2002). A great variety of organic compounds are released by numerous plant species, each having an active life in the soil that is determined by factors such as volatility, leaching, adsorption and microbial action (Shahida *et al.,* 2002). Among factors responsible for low yield, weeds are considered to be the most important one. Weed interference in Maize leads to 37-68% reduction in crop yield (Adigun and Lagoke, 2003).

The extent of reduction in *kharif* crops due to weeds is also reported by Jain and Tiwari (1993) and Agrawal *et al.* (1995). These weeds pose serious threats in upland rice fields. Rice is reported to be the most sensitive crop to weed competition ranging from 43.5 to 55.5 % (Choudhary *et al.,* 1995). Many weeds, including *Mikania micrantha* L., *Ageratum houstonianum* L. interfere with plants through production of allelochemicals, commonly cited effects of allelopathy include reduced seed germination and seedling growth (Ferguson and Rathinasabapathi, 2003).

Allelochemicals disrupt the plants through changes in cell wall structure and functions and by preventing all division, seed germination, seedling growth, development, and yield and biomass production. Different plant parts including flowers, leaves, leaf litter and leaf mulch, stem, bark, root, soil and soil leachates and their derived compounds, can have allelopathic activity that varies over a growing season. The present study also confirms the allelopathic effect of soil beneath neem and teak plantation and the respective decomposed leaf litter of trees and weeds (*Ageratum* and *Mikania*) incorporated in the soil irrigated with respective diluted leaf leachates. The grain yield of paddy was found to be promoted under soil beneath neem tree (SN) and under decomposed leaf litter of *Mikania* (DM), in case of maize, the soil beneath neem tree (SN) and decomposed leaf litter of neem (DT) enhanced the grain yield which indicated that, neem acts as an organic manure and help in improving the yield of crop in paddy and maize compared to other treatments.

Table 17: Growth parameters of paddy (*Oryza sativa* L.) as affected by different treatments under pot culture.

Growth parameter	Treatments							CD at P≤ 0.05
	Control	Soil beneath Teak tree (ST)	Decomposed leaf of Teak (DT)	Soil beneath Neem tree (SN)	Decomposed leaf of Neem (DN)	Decomposed leaf of *Mikania* (DM)	Decomposed leaf of *Ageratum*(DA)	
% of germination	100.00 ± 0.000	90.00 ± 0.000	90.00 ± 0.000	90.00 ± 0.000	95.00 ± 0.000	85.00 ± 0.000	95.00 ± 0.000	0.00
Plant height (cm)	56.80 ± 0.129	81.70 ± 0.201	49.40 ± 0.358	97.90 ± 0.158	74.10 ± 0.248	92.42 ± 0.278	74.70± 0.108	3.62
No. of leaves	7.00± 0.408	8.25 ± 0.250	6.50 ± 0.645	8.00 ± 0.408	8.00 ± 0.408	7.00 ± 0.408	7.00 ± 0.408	6.86
Girth (cm)	2.20 ± 0.040	2.80 ± 0.091	2.00 ± 0.182	2.60 ± 0.129	2.60 ± 0.057	2.40 ± 0.177	2.40 ± 0.070	1.89
No. of grain per sheaves	39.00 ±2.857	28.75 ± 1.493	21.25 ± 1.493	40.00 ± 2.738	38.75 ± 4.905	42.00± 4.301	32.00 ± 2.380	49.54
Weight of grain per tiller (gm)	1.28 ± 0.150	1.05 ± 0.0178	1.00 ± 0.003	2.00 ± 0.129	2.10 ± 0.406	2.17 ± 0.303	1.99 ± 0.119	3.34
Fresh wt. of root	0.65 ± 0.064	1.00 ± 0.091	0.90 ± 0.071	1.30 ± 0.182	0.66± 0.017	0.68± 0.023	0.57± 0.018	1.36
Fresh wt. of shoot	3.80 ± 0.129	4.20 ± 0.238	2.25 ± 0.193	4.80± 0.158	4.56± 0.296	4.58 ± 0.326	4.24 ± 0.044	3.45
Dry wt. of root	0.142 ± 0.022	0.25 ± 0.028	0.20 ± 0.057	0.60 ± 0.040	0.22± 0.047	0.17± 0.025	0.30± 0.040	0.62
Dry wt. of shoot	0.415 ± 0.048	1.40 ± 0.19	0.65 ± 0.095	1.00 ± 0.108	1.05 ± 0.170	1.00 ± 0.248	1.20 ± 0.145	2.49

± SE. m, n= 4.
ST = Soil beneath Teak tree, DT = Decomposed leaf of Teak, SN = Soil beneath Neem tree, DN = Decomposed leaf of Neem, DM = Decomposed leaf of *Mikania*, DA = Decomposed leaf of *Ageratum*.

Table 18: Analysis of variance (ANOVA) as affected by treatments on different growth parameters of paddy (*Oryza sativa* L.)

Treatments	Plant height (cm)	No. of leaves	Girth (cm)	No. of grain/ tiller	Weight of grain/ tiller (gm)	Biomass			
						Fresh wt. of Root	Fresh wt. of Shoot	Dry wt. of Root	Dry wt. of shoot
	F- Value	F-Value	F- Value	F- Value	F- Value	F- Value	F- Value	F- Value	F- Value
ST	10054.22***	6.82**	36.00***	10.11*	2.37 ns	9.80*	2.18 ns	8.74*	23.83**
DT	377.6552***	0.4286 ns	1.1429 ns	30.3066**	3.3045 ns	6.8241**	44.3538***	0.8649 ns	4.7848 ns
SN	40541.04***	3.00 ns	8.73**	0.06 ns	13.13*	11.27*	24.00**	97.07***	24.37*
DN	3820.723***	3.000 ns	32.000***	0.002 ns	3.564 ns	0.035 ns	5.574**	2.447 ns	12.784*
DM	13507.48***	0.00 ns	1.20 ns	0.34 ns	6.94**	0.19 ns	5.04 ns	0.95 ns	5.34 ns
DA	11308.59***	0.00 ns	6.00**	3.54 ns	13.62*	1.42 ns	10.40*	11.50*	26.34**

* significant at P<0.01, ** significant at P<0.05, *** significant at P<0.001, ns -non significant

Table 19: Growth parameters of maize (*Zea mays L.*) as affected by different treatments under pot culture.

Growth parameter	Treatments							CD at P≤ 0.05
	Control	Soil beneath Teak tree (ST)	Decomposed leaf of Teak (DT)	Soil beneath Neem tree (SN)	Decomposed leaf of Neem (DN)	Decomposed leaf of *Mikania* (DM)	Decomposed leaf of *Ageratum* (DA)	
% of germination	100.00 ± 0.000	98.00 ± 0.000	100.00 ± 0.000	100.00 ± 0.000	98.00 ± 0.000	80.00 ± 0.000	94.00 ± 0.000	0.00
Plant ht .(cm)	68.90 ± 0.129	84.80 ± 0.324	67.70 ± 0.402	106.20 ± 0.302	113.60 ± 0.254	102.90 ± 0.129	89.30± 0.204	4.23
No. of leaves	7.00± 0.408	12.00 ± 0.408	10.50 ± 0.645	11.00 ± 0.408	12.00 ± 0.408	8.00 ± 0.408	10.00 ± 0.707	7.92
Girth (cm)	2.50 ± 0.108	2.70 ± 0.177	2.50 ± 0.070	3.40 ± 0.267	3.60 ± 0.234	3.10 ± 0.141	3.35 ± 0.232	2.99
No. of cob	01.00 ±0.00	1.00 ± 0.00	1.00 ± 0.000	1.00 ± 0.000	1.00 ± 0.000	1.00 ± 0.000	1.00 ± 0.000	0.00
Weight of cob (gm)	59.50 ± 0.491	56.17 ± 2.339	49.05 ± 0.531	65.50 ± 1.723	66.20 ± 1.331	63.90 ± 1.683	53.70 ± 0.273	22.11
No. of grain	187.50 ± 1.554	165.50 ± 0.020	149.5 ± 2.217	188.25 ± 3.637	189.00 ± 4.301	170.00 ± 1.779	157.00 ± 3.082	44.77
Fresh wt. of root	8.90 ± 0.267	4.925 ± 0.175	8.65 ± 0.193	6.30 ± 0.402	6.40± 0.353	6.05± 0.132	5.10± 0.147	4.08
Fresh wt. of shoot	89.42 ± 0.286	68.1 ± 1.215	68.60 ± 0.633	73.80± 1.466	74.30± 1.130	68.75 ± 1.175	69.20 ± 0.708	14.58
Dry wt. of root	1.17 ± 0.193	1.90 ± 0.108	0.800 ± 0.158	2.20 ± 0.129	2.40± 0.234	1.85± 0.155	1.90± 0.091	2.52
Dry wt. of root	19.62 ± 0.507	14.55 ± 0.25	15.10 ± 0.316	15.25 ± 0.184	15.70 ± 0.248	13.00 ± 0.147	14.20 ± 0.238	4.61

± SE. m, n= 4

ST = Soil beneath Teak tree, DT = Decomposed leaf of Teak, SN = Soil beneath Neem tree, DN = Decomposed leaf of Neem, DM = Decomposed leaf of Mikania, DA = Decomposed leaf of Ageratum.

Table 20: Analysis of variance (ANOVA) as affected by treatments on different growth parameters of maize (*Zea mays* L.)

Treatments	Plant height (cm)	No. of leaves	Girth (cm)	Weight of cob (gm)	No. of grain	Biomass			
						Fresh wt. of root	Fresh wt. of shoot	Dry wt. of root	Dry wt. of shoot
ST	2077.890 ***	75.000 ***	0.923 ns	1.943 **	74.462 ***	154.466 ***	291.393 ***	10.736*	80.539 ***
DT	8.0748 **	21.0000 **	0.0000 ns	208.3355 ***	196.9091 ***	0.5725 ns	896.1115 ***	2.2575 ns	57.3079 ***
SN	12842.68 ***	48.00 ***	9.72 ***	11.20*	0.04 ns	28.97 ***	109.29 ***	19.47**	65.67 ***
DN	24466.41 ***	75.00 ***	18.15 **	22.30 **	0.11 ns	31.78 ***	168.13 ***	16.26**	48.30 ***
DM	34680.00 ***	3.00 ns	11.37*	6.30 **	54.85 **	91.09 ***	3778.61 ***	7.41**	157.34 ***
DA	134.171 ***	13.500*	10.975*	106.232 ***	78.063 ***	154.714 ***	700.479* **	11.521*	93.741 ***

* significant at P<0.01, ** significant at P<0.05, *** significant at P<0.001, ns – non significant.

Fig. 10a: Germination of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

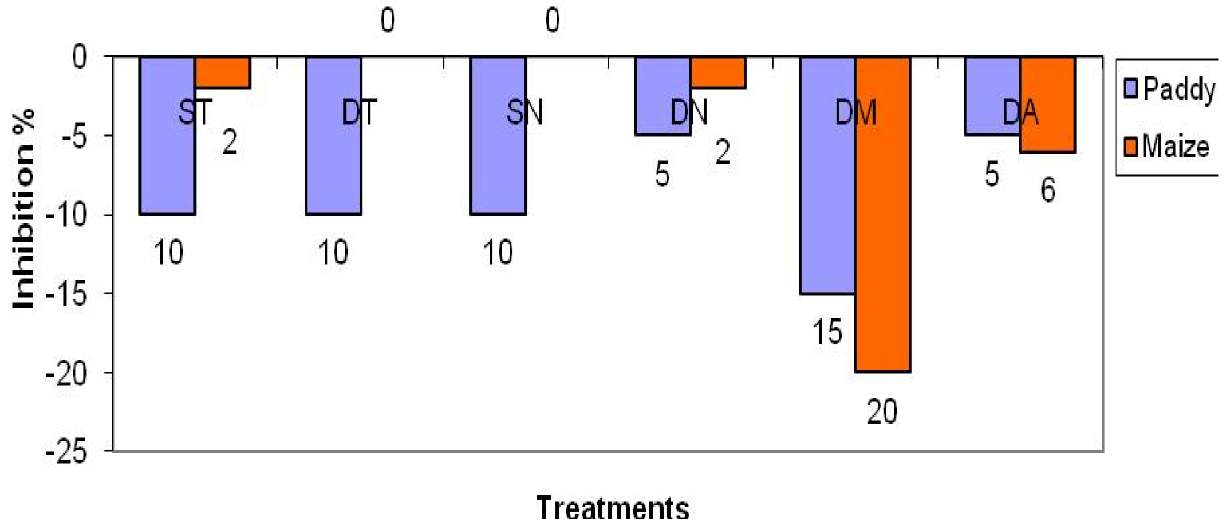


Fig. 10 b: Plant height of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

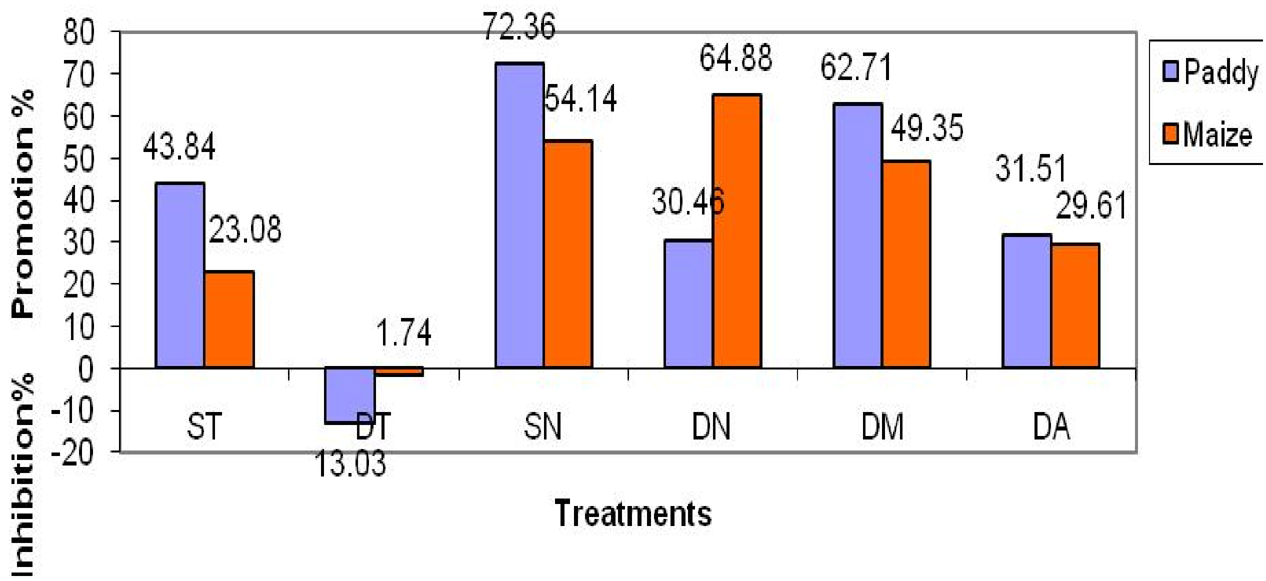


Fig. 10c: No. of leaves of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

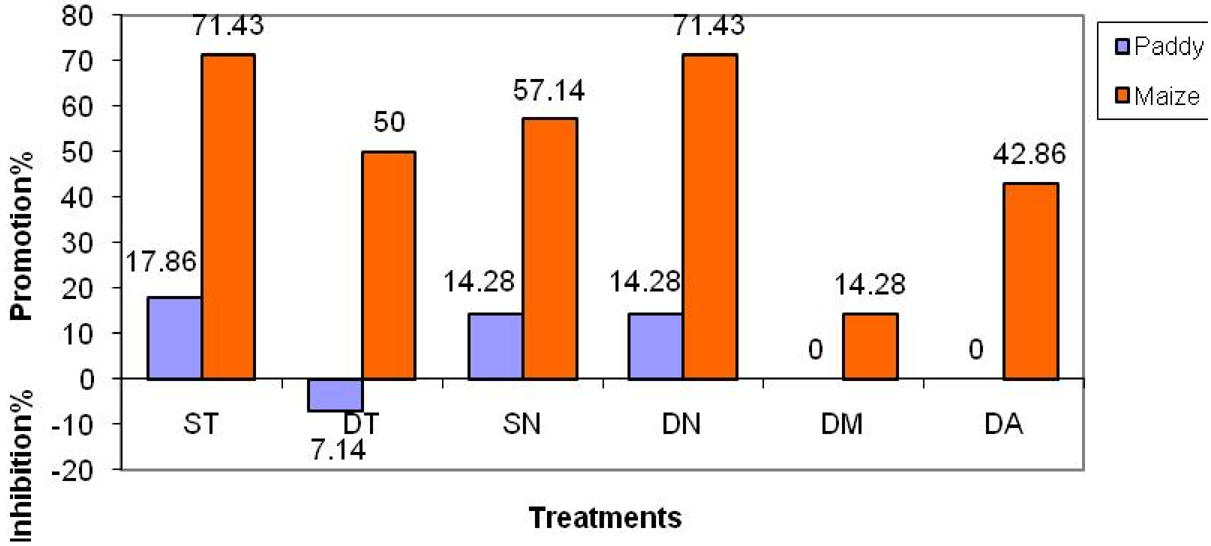


Fig. 10d: Girth of stem in *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

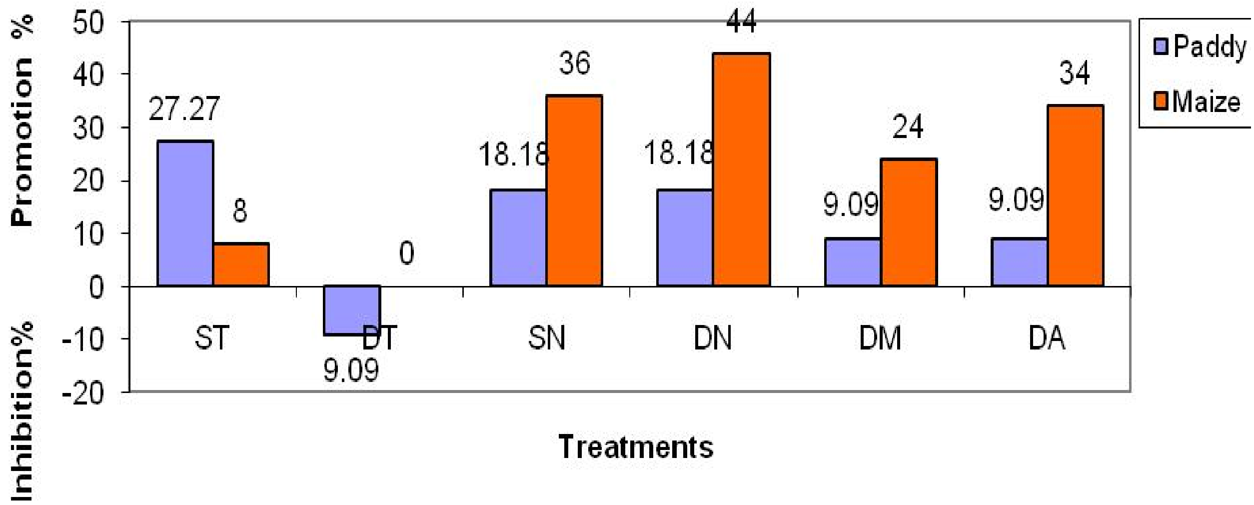


Fig. 10e: No. of grains per sheaves/cobs in *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

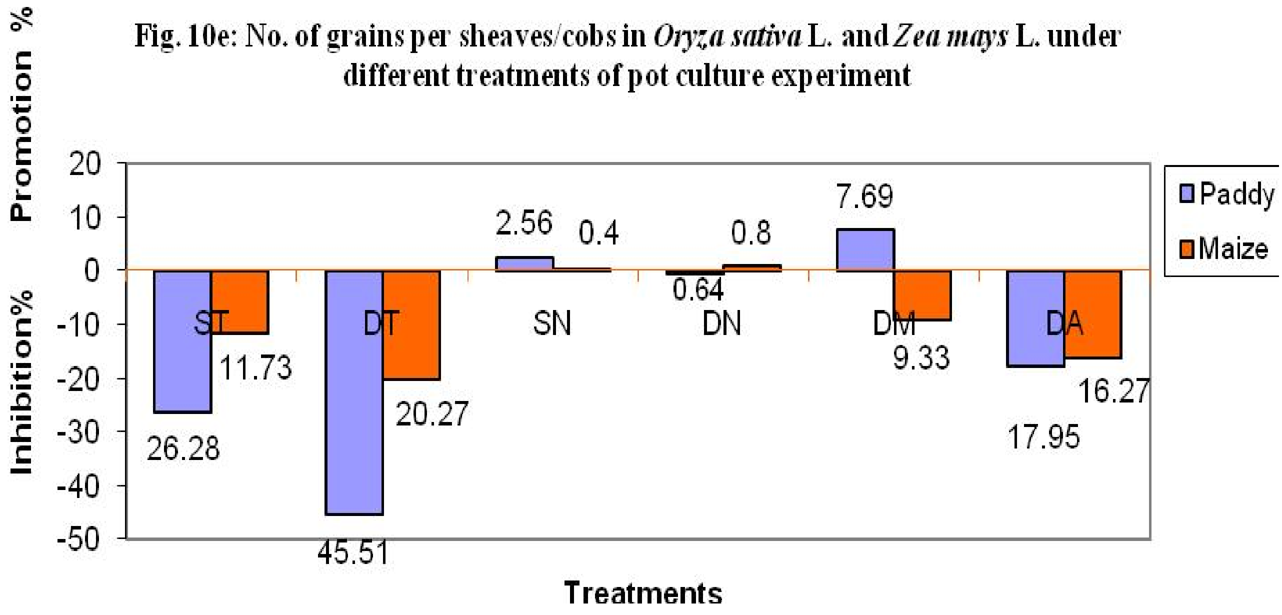


Fig. 10f: Weight of grains per sheaves/cobs in *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

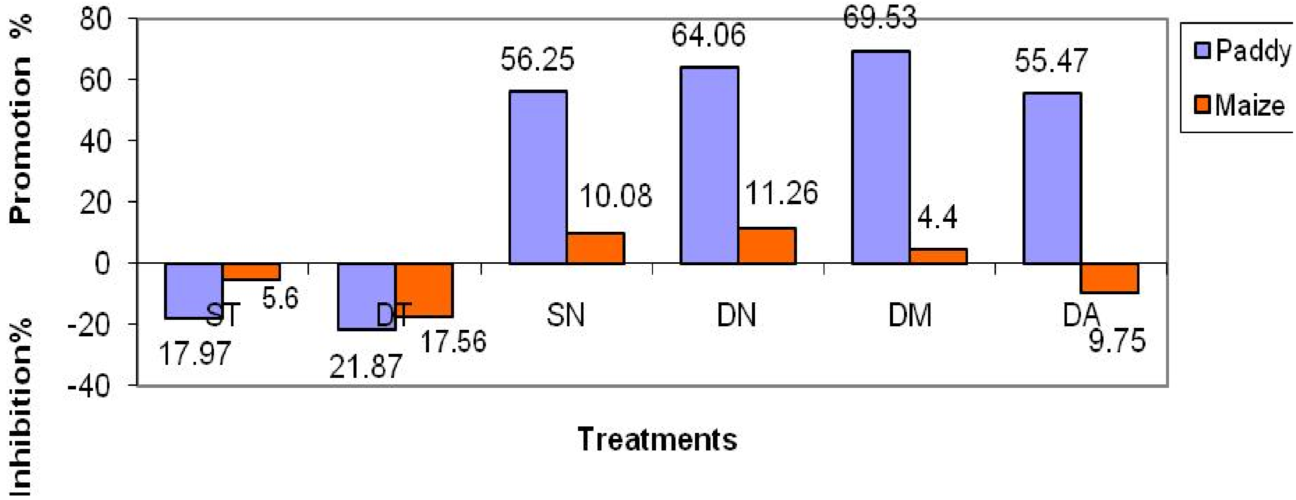


Fig. 10g: Fresh root weight of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

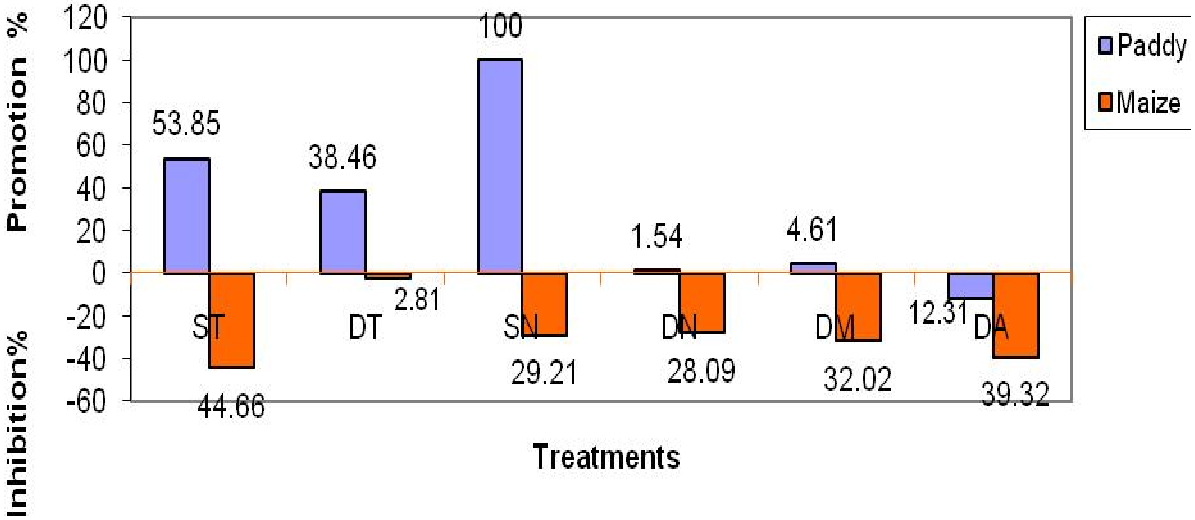


Fig. 10h: Fresh shoot weight of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

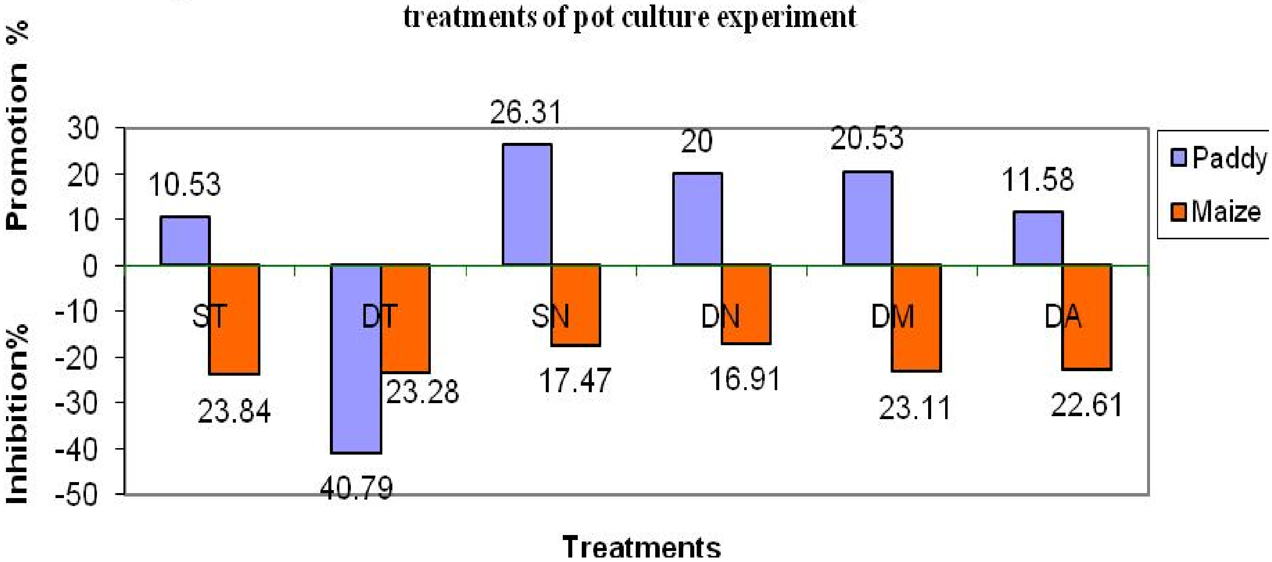


Fig. 10i: Dry root weight of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment

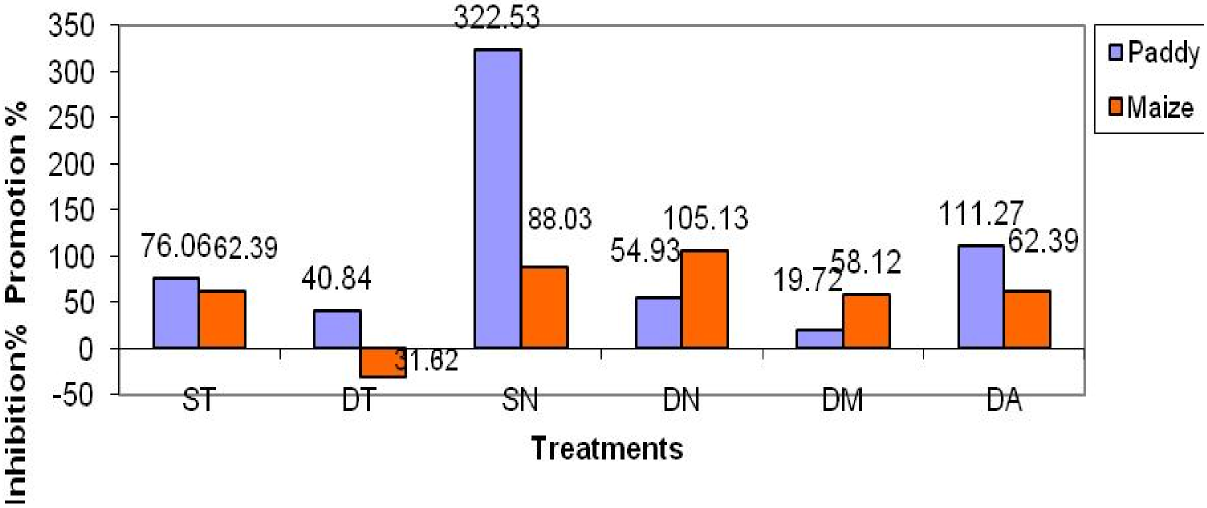
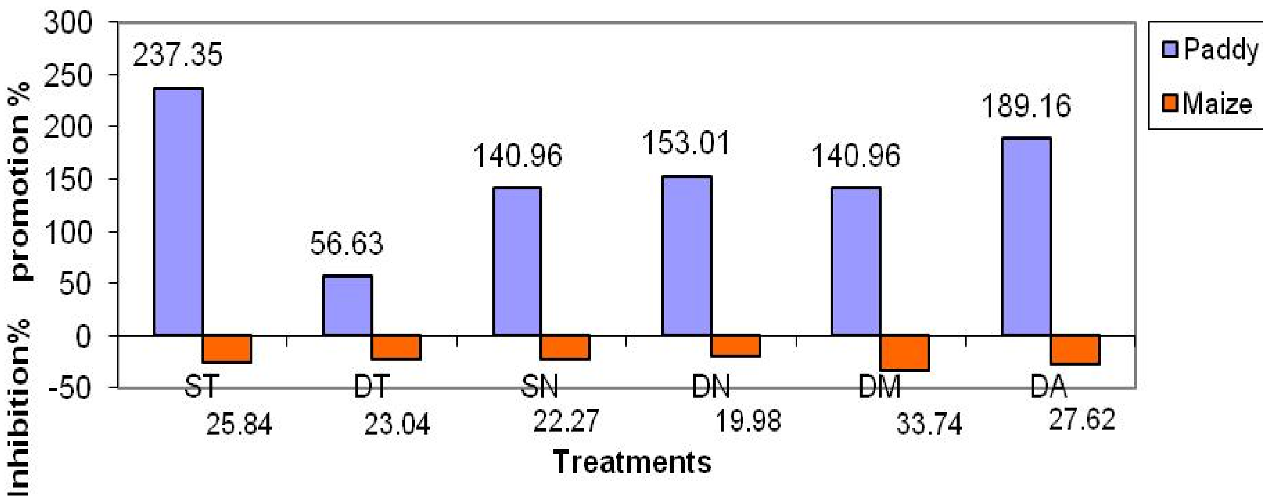


Fig. 10j: Dry shoot weight of *Oryza sativa* L. and *Zea mays* L. under different treatments of pot culture experiment



Chapter-6

EFFECT OF TREES ON TEST CROPS UNDER FIELD CONDITIONS

6.1 Effect of trees on seed germination and initial growth parameters of the test crops under field conditions

i) Seed germination:

The seed germination of paddy was fairly similar under both neem and teak as well as under control sets of experiment, although there was a trend of paddy seeds getting promoted under teak and inhibited under neem, but these changes had been very low and insignificant (Table 21, Figure 11a).

The data also revealed that, the germination of maize was not affected by neem and teak (Table 23, Figure 12a). 100% germination was obtained for maize seeds irrespective of the treatment.

ii) Plant height:

The results indicated that the percentage of plant height of paddy under neem was significantly ($P<0.001$) high (86.8cm) when compared with control (72.00cm). As in the case of paddy grown under teak, the plant height was comparatively low (26.50cm) when compared with control and neem. The teak litters acts as toxic chemicals which detrimentally retarded the growth in paddy (Tables 21 and 22, Figure 11a).

Plant height of maize recorded after four months was 183.20cm under control while the corresponding values under neem and teak were 160.30cm and 45.8cm respectively (Tables 23 and 24, Figure 12a).

iii) Number of leaves:

The number of leaves of *Oryza sativa* L. under the plantation of neem showed neither inhibition nor stimulation effect as compared to control, while under the plantation of teak, the number of leaves was significantly ($P<0.001$) suppressed by 50% over control (Tables 21 and 22, Figure 11a).

In the case of *Zea mays* L. shown on the Tables 23 and 24, inhibitory effect (7.14%) was recorded under neem (Figure 12a) though it was not statistically significant. However, the number of leaves recorded under the plantation of teak was very low (5).

iv) Diameter of stem:

Tables 21 and 22 also revealed that the diameter of stem in paddy under neem had shown an increased by 11.43% over control. The growth of crop under teak was retarded. The diameter of stem in paddy under teak plantation was significantly ($P<0.001$) inhibited by 65.71% when compared with control (Figure 11a).

It is evident from the Tables 23 and 24 that the diameter of maize was significantly ($P<0.01$) inhibited by 9.23% under neem when compared with the control. During the early stages, the growth and development were almost similar but becomes varied with time. In case of collar thickness of maize under teak, 70.77% inhibition was observed which was comparatively high over control and under neem (Figure 12a).

v) Number of grains:

A comparatively higher yield (79.41%) of paddy grains was recorded under neem when compared with control. Maximum number of grains (122 nos. per sheave) was recorded under neem. There was a remarkable difference in number of grains per sheave among the treatments, the number of grains (3 nos. per sheave) harvested under teak was extremely low (95.59% inhibition) which certainly shows the negative effect of teak on paddy (Tables 21 and 22, Figure 11a).

Tables 23 and 24 also revealed that the yield of grains in maize under neem was significantly ($P<0.001$) inhibited (46.60% inhibition) over control. As in the case of maize under teak, the growth and development after the second months had stopped and start to decline, even led to the complete failure of crop in the next month (ie. in the third month of growth) (Figure 12a).

vi) Weight of grains per sheave and cob:

The weight of grains in paddy under neem as depicted in Tables 21 and 22 showed that the percentage of grains as compared to control was high (17.48% promotion), while the grains of paddy under teak was significantly ($P<0.001$) low (97.74% inhibition). The variation of grain yield per sheave was comparatively low under neem and teak (Figure 11a).

Tables 22 and 23 depicted that weight of grains/cob in maize was found to be significantly ($P<0.001$) inhibited by 35.59% under neem compared with the control. As the maize plants died out after the second month under teak, no further record was observed under teak (Figure 12a).

vii) Fresh weight of root and shoot:

The analysis of variance for fresh weight of root and shoot of paddy showed significant ($P<0.001$) inhibitory effect on both the treatment (Tables 21 and 22). However, paddy under neem showed least effect (25.17% and 13.72%) in fresh weight of root and shoot, but detrimental effect of fresh weight of root and shoot of paddy under teak were observed as (95.88% and 97.20%) when compared with the control (Figure 11b).

The fresh weight of root and shoot of maize under neem were also significantly ($P<0.001$) inhibited by 58.13% and 35.70% when compared with control. Surprisingly, all the maize plants grown under teak died out after the second month of germination (Figure 12b).

viii) Dry weight of root and shoot:

Tables 21 and 22 revealed that the dry weight of root and shoot of paddy under neem and teak showed some degree of differences when compared with control. Dry weight of root and shoot of paddy under neem showed least inhibitory (2.70% and 1.43%) effect while the dry weight of root and shoot of paddy under teak perform more inhibitory (92.97% and 96.31%) effect than the other treatments (Figure 11b).

In case of dry weight of root and shoot of maize under neem when compared with control, significant ($P<0.001$) inhibitory effect were observed and the respective reduction were by 58.82% and 49.33% respectively (Figure 12b).

However, there was no observation recorded in the case of maize under teak since all crops died out after the second month of germination under teak.

Discussion:

Though the laboratory bioassays and pot culture served as important tools to understand a particular component of allelopathy, field studies test to corroborate the effect of allelopathy on tree-crop-weed interactions under Agroforestry system. The field experiments conducted under neem and teak and in control condition revealed that the trees had least allelopathic effect on the field crops germination, but effect the growth and yield of paddy and maize subsequently and were significant as shown on the Tables 21-24. It may be due to the slower decomposition of organic matter in terms of leaf fall which retain soil moisture and thus stimulate root growth and organic matter increased germination, due to a more conducive environment.

The yield of grains in paddy under neem has the highest production when compared with control and those planted under teak. Paddy yield in terms of grains under teak was comparatively low which could be due to severe shading and allelopathic chemicals exhibited by the teak plants. In case of maize, the maximum grain yield was found in control plot followed by those planted under neem. The effect of allelochemicals exhibited by the teak plants and severe shading and soil type inhibit the growth of maize crop which even leads to complete failure of crops in the present case. Paddy crops grown under teak also showed retardation and stunted growth which drastically reduced the yields of grains when compared with control condition and under neem. The results corroborated with the study of Fritz *et al*. (2009) that severe leaf shading led to smaller plants with fewer panicles and fewer tillers. While reducing growth will eventually limits its ability to produce seed, preventing or severely suppressing panicle production. Growth of panicle production declined with increasing levels of shading. Invasive species have been shown to negatively impact ecosystem biodiversity levels and function through direct and indirect effects. Breland (1996) suggests that retarded germination observed in the fields is mainly caused by phytotoxic substances indigeneous to fresh crop residues. In addition to the mortality, the reduced seedling vigour is attributed to the accumulation of toxic or poisonous chemicals of the donor in the soil which is harmful for the recipient plants both in the laboratory and field condition (Chou and Kuo, 1984; Rho and Kil, 1986). The allelochemicals are present in the shoot, root and leaf of the plants. Such chemicals are species specific and these characteristics may influence the density of the composition of individual plant communities. Allelochemicals may directly prevent (stunted or inhibited) or promote germination, growth and yields when environmental conditions are conducive to growth and establishment, therefore, influencing the number of plants of each species in a community. In terms of ecological interactions, the roots of one plant can compete in the rhizosphere with their neighbour for space, water, nutrients, gases and organic materials that serve as metabolic substrates (Ryan and Delhaize, 2001; McCully, 2005). Roots can release metabolites over time, and they may play roles in defence and rhizosphere signaling (Uren, 2000; Watt and Weston, 2009). Secondary products from root exudates and leachates can also influence soil microbial dynamics in the rhizosphere (Mathesius and Watt, 2011). They also repel herbivores and pathogens, stimulate symbiotic relationships, after soil properties, and inhibit the growth of competing plants (Nordi *et al.,* 2000; Bertin *et al*., 2003; Walker *et al.,* 2003).

Although agroforestry trees are rich sources of secondary metabolites (allelochemicals), they may also have harmful effects on the agricultural crops due to release of organic chemicals as root exudates, plant leachates and as a by-product of death organic matter decomposition (Kaur and Rao, 1998). Allelochemicals of different tree species are known to affect germination and seedling growth of agricultural crops (Srivastava *et al.,* 1996), and it was well documented that, release of allelochemicals occurs at the time of germination or at the early developmental stage, as the plants are more susceptible in terms of competition with their neighbouring plants for light, nutrients and water (Chou, 1992). Darier and Youssef (2000) reported significant effect of soil types on germination rate of (69.9% in sandy soil as against 19% in clay soil) *Lepidium sativum*. Hampson and Simpson (1990) also reported that seed germination, seedling growth and physiological activities of some cultivated plants were strongly affected by soil type and salinity stress.

It was well established that, plant parts contain allelochemicals which they released into the soil and these are known to inhibit or sometimes promote germination, growth, development, distribution and propagation of plant spp. (Tawaha and Turk, 2003). It is accepted that in some situation in agricultural fields, there are huge crop losses due to excessive and unmanaged weed growth. It is well known that allelopathic interaction by a plant is possible through leaching volatilization from aerial parts, decay of fallen parts and/or exudation in the rhizosphere (Rice, 1984). In general, though the average seed germination, growth and development of *Oryza sativa* L. and *Zea mays* L. might be inhibited by the treatments under pot and field condition, the overall yield of *Oryza sativa* L. grains under *Melia azadirach* L. was found to be enhanced in comparison with the control. The yield of maize under neem was also not much affected when compared with control condition.

This increase in yield of *Oryza sativa* L. (paddy) under *Melia azadirach* L. (neem) in agroforestry system should be recommended and suggested to the farmers for improving their production especially in respect of *Oryza sativa* L. (paddy). This intercropping will not only increase the yield but will also help in maintaining the soil productivity, decreasing harmful effect of shifting cultivation, leaching losses of plant nutrients, supplying fodder for livestock and maintaining pollution free environment, etc.

These studies determine and corroborate the effects of allelochemicals present in the soil beneath the neem and teak on paddy and maize in comparison with control condition. It is evident that, the cultivation of paddy under neem could enhance the yield of grains while the crop under teak not only reduced the seedlings vigour and growth, it also reduced the yields drastically in comparison with control and crop under neem plantation. Maize under neem did not show any adverse effect, while mortality was observed in case of maize plant under teak.

Table 21: Growth parameters of paddy (*Oryza sativa* L.) under Neem and Teak under field condition

Growth parameter	Treatments			CD at P≤ 0.05
	Control	Neem	Teak	
Percentage of germination	99.00 ± 0.000	98.00 ± 0.000	100.00 ± 0.000	0.00
Plant height (cm)	72.00 ± 0.559	86.8 ± 0.177	26.50 ± 0.234	6.66
No. of leaves	10.00± 0.408	10.00 ± 0.408	5.00 ± 0.408	7.45
Girth (cm)	3.50 ± 0.108	3.9 ± 0.177	1.20 ± 0.129	2.58
No. of grains/sheave	68.00 ±4.915	122.0± 31.241	3.00 ± 0.408	33.32
Weight of grains per sheave (gm)	2.036 ± 0.011	2.392 ± 0.286	0.046 ± 0.005	3.02
Fresh weight of root (gm)	0.898 ± 0.001	0.672 ± 0.017	0.037 ± 0.003	0.00
Fresh weight of shoot (gm)	5.894 ± 0.001	5.115 ± 0.107	0.165 ± 0.015	1.138
Dry weight of root (gm)	0.185 ± 0.002	0.180 ± 0.005	0.013 ± 0.001	0.00
Dry weight of shoot (gm)	1.953 ± 0.012	1.925 ± 0.085	0.072 ± 0.002	0.91

± SE. m, n= 4

Table 22: Analysis of variance (ANOVA) due to different treatments on growth parameters of paddy (*Oryza sativa* L.)

Treat ments	Plant height (cm)	No. of leaves	Girth (cm)	No. of grain	Weight of grain per tiller (gm)	Biomass			
						Fresh wt. of root	Fresh wt. of shoot	Dry wt. of root	Dry wt. of shoot
Neem	568.1159 ***	0.0000 ns	3.6923 ns	0.7533 ns	1.5468 ns	164.7613 ***	52.3625 ***	0.5032 ns	0.1051 ns
Teak	5820.0 ***	75.0 ***	186.7 ***	173.6 ***	22956.7 ***	41184.5 ***	141014.5 ***	3480.5 ***	20812.7 ***

*** significant at P<0.001, ns- non-significant.

Table 23: Growth parameters of maize (*Zea mays L.*) under Neem and Teak under field condition

Growth parameter	Treatments			CD at P≤ 0.05
	Control	Neem	Teak	
% of germination	100.00 ± 0.000	100.00 ± 0.000	100.00 ± 0.000	0.00
Plant height (cm)	183.20 ± 1.234	160.30 ± 0.491	45.8	41.36
No. of leaves	14.00± 0.408	13.00 ± 0.577	5	22.00
Girth (cm)	6.50 ± 0.091	5.90 ± 0.250	1.9	8.28
No. of cobs	1.75 ± 0.25	1.75 ± 0.25	**	11.00
Weight of Cob (gm)	112.4 ± 0.786	72.40 ± 1.047	**	40.75
No. of grains/Cob (gm)	404.5 ± 2.50	216.00 ± 2.738	**	115.39
Fresh weight of root (gm)	33.25 ± 0.898	13.92 ± 0.366	**	30.19
Fresh weight of shoot (gm)	279.50 ± 0.595	179.7 ± 0.570	**	25.66
Dry weight of root (gm)	11.90 ± 0.147	4.50 ± 0.216	**	8.13
Dry weight of shoot (gm)	111.4 ± 0.742	56.45 ± 1.196	**	43.81

± SE. m, n= 4 ** All plants died out after the second month.

Table 24: Analysis of variance (ANOVA) due to different treatments on growth parameters of maize (*Zea mays* L.)

Treat ments	Plant height (cm)	No. of leaves	Girth (cm)	No. of cob	Weight of cob (gm)	No. of grain	Fresh wt. of root	Fresh wt. of shoot	Dry wt. of root	Dry wt. of shoot
Neem	296.84 ***	2.00 ns	10.20*	0.00*	932.94 ***	2584.16 ***	396.53 ***	14647.12 ***	801.37 ***	1523.08 ***
Teak	****	****	****	****	****	****	****	****	****	****

* Significant at P<0.01, *** significant at P<0.001

**** All plants died out.

Fig.11a: Growth parameters of *Oryza sativa* L. under *Melia azadirach* L. (neem) and *Tectona grandis* L. (teak) under field condition.

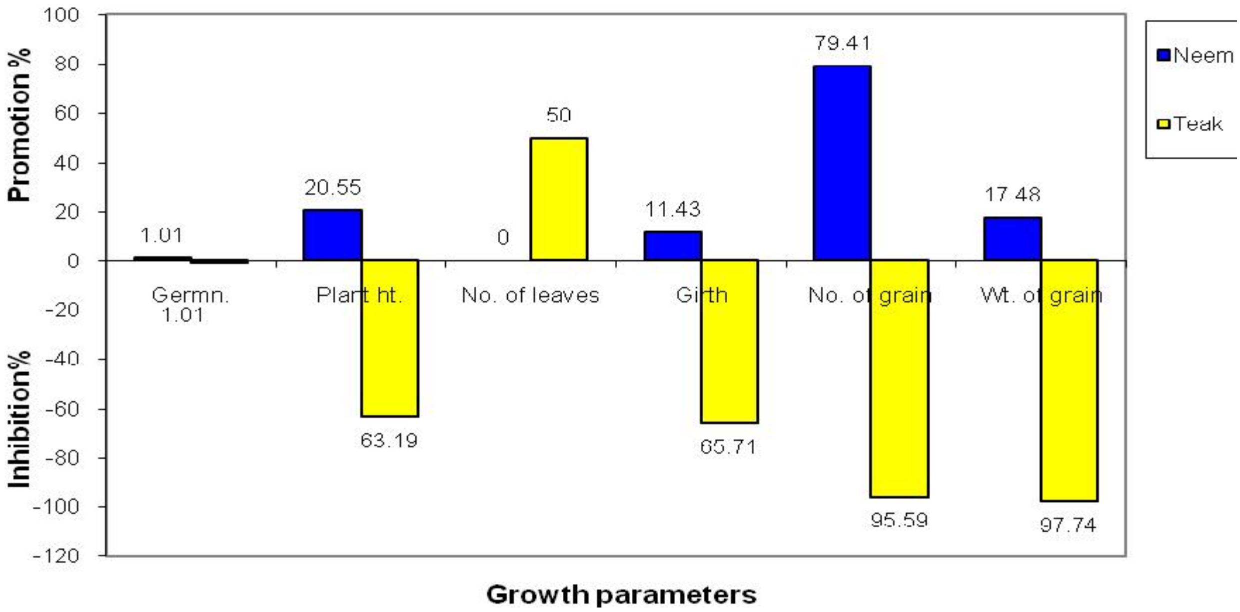


Fig.11b: Growth parameters of *Oryza sativa* L. under *Melia azadirach* L. (neem) and *Tectona grandis* L. (teak) under field condition.

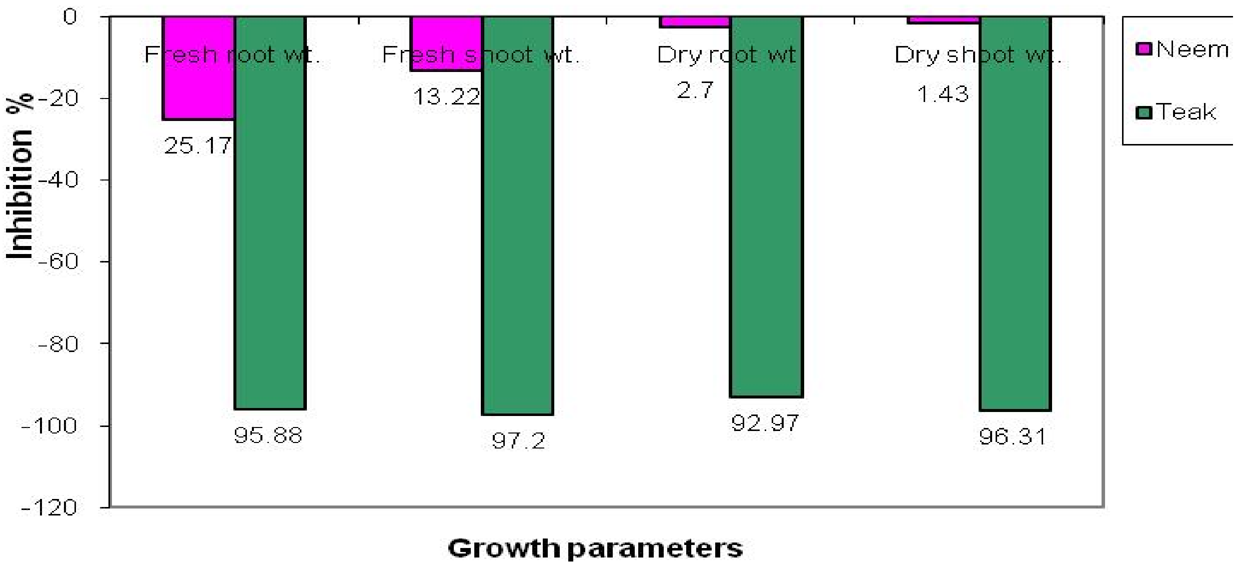


Fig.12a: Growth parameters of *Zea mays* L. under *Melia azadirach* L. (neem) and *Tectona grandis* L. (teak) under field condition.

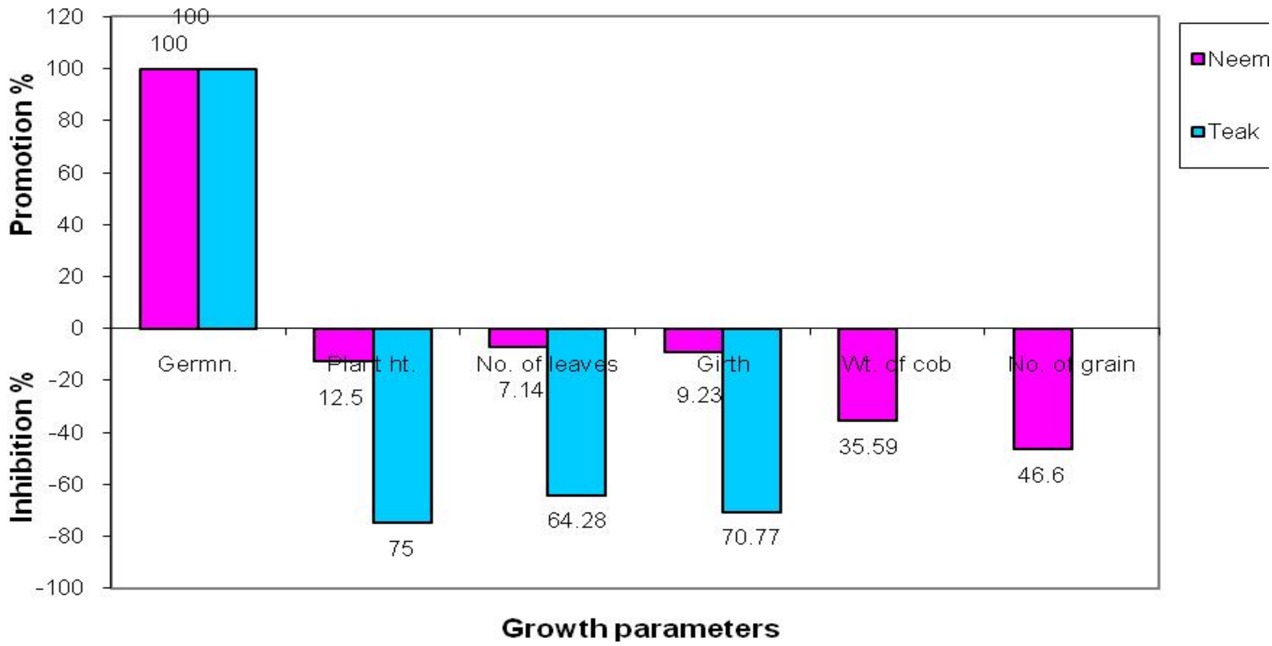
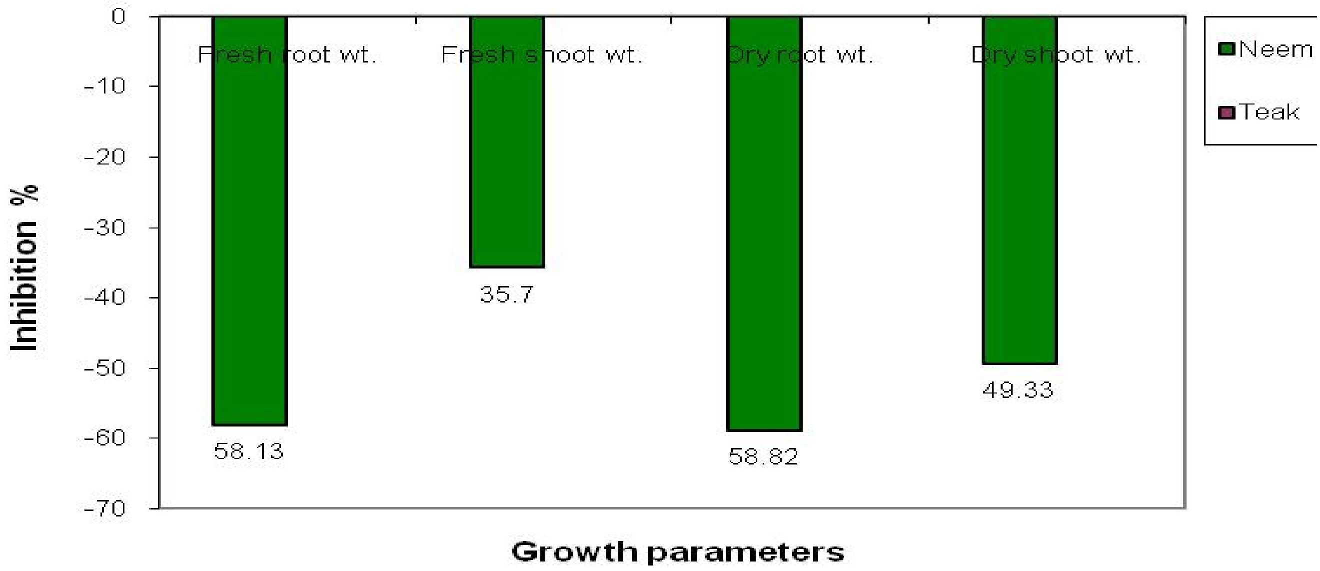


Fig.12b: Growth parameters of *Zea mays* L. under *Melia azadirach* L. (neem) and *Tectona grandis* L.(teak) under field condition.



Chapter-7

GENERAL DISCUSSION

Certain plant species and their residues selectively inhibit the growth and development of a particular species. In this study, different inhibitions and promotions observed in the laboratory with leaf leachates of selected trees and weeds, pot culture with decomposed leaf litter and powder of selected trees and weeds, and field experiments with the residues of selected trees had been studied and recorded.

The allelopathic effects of aqueous leaf leachates of trees and weeds on seed germination of paddy and maize examined under bioassay revealed that the aqueous leaf leachates of the selected trees and weeds species brought about considerable inhibitions on both the crops when compared with the control. The seed germination on both the crops did not show any positive effect, rather decreased with the increase in percentage of the leachate concentrations. In case of paddy the maximum reduction in seed germination was at the highest concentration coming from leaf leachates of neem when compared with all the other treatments while minimum inhibition was observed under the aqueous leaf leachates of teak and *Mikania* followed by *Ageratum*. The germination percentage of maize was severely inhibited when compared with paddy. The highest inhibition (86.67%) of maize seed germination was found under the high concentration of aqueous leaf leachates of teak and *Ageratum* while the lowest inhibition (33.33%) was recorded under low concentration of neem leaf leachates which was in agreement with Sharma *et al.* (1987) who also observed allelopathic effect of four commonly grown farm trees on seed germination of

Brassica, Triticum, Pisum and *Lens*. Kaur and Rao (1998) found similar results on germination of various crops with increase in leaf leachate concentration.

The effects on different growth parameters of paddy and maize seedlings were concentration dependent and statistically significant ($P<0.001$). Under control and low concentration of leaf leachates, increase in root length had been observed which confirm the findings of Soni *et al.* (1991), Purushotham *et al.* (1992) and Bhagat *et al.* (1992). Singh (1999) also noticed improvement in specific root length, root length density and green and dry matter yield. Joaquin *et al.* (2001) reported increase in green and dry matter yield of guinea grass through positive effect of nitrogen on number of vegetative tillers. As compared to germination and shoot growth, the inhibition was more pronounced in root growth under high concentration which was in agreement with the study of Tefera (2002) that, hypocotyls and shoot growth are less sensitive to allelopathic effect compared to roots. Such an effect of leaf extract was also reported by Alam (1990) and Kaur and Rao (1998).

Fresh weight of root and shoot of paddy and maize significantly ($P<0.001$) decreased as the concentrations of leaf leachates of trees and weeds increased. In each leaf leachate concentrations, maximum inhibition of fresh root and shoot weights was recorded from neem and *Mikania* leaf leachates. The inhibitory effect of different leaf leachates on fresh and dry root weight of paddy followed the order: Teak > *Ageratum* > Neem > *Mikania*.

The dry weights of root and shoot of paddy and maize were also inhibited significantly under higher concentrations, even a cent per cent inhibition were also observed under higher concentration of *Mikania* and neem. In general, inhibition percentage increased as the concentration of leaf leachates increased when compared with control. In general, the seed germination and initial growth parameters of both paddy and maize was a per cent concentration dependent. The findings were in agreement with Sisodia and Siddiqui (2008, 2009) that the inhibition effect was found to increase with the increasing concentrations of different aqueous extracts. In bioassay with leachates revealed significant reduction in germination over control, in all the cases, 12 days after sowing, the inhibition of seed germination was species and concentration dependent (Einhelling, 1996), Turk *et al.* (2003) found that the degree of inhibition increased with increased extract concentration.

The bioassays result also correlated with the finding of Macias *et al.,* (2007) which showed that the bark extract of teak have higher phytotoxic levels. Reduced seed germination rate, stem length, root length and seedling dry weight has also been reported by extracts from pigweed stems and roots (Khan *et al.,* 2005). The similar study for aqueous extract of *Azadirachta indica*, *Mangifera indica*, *Cymbopogan citrates* and *Morinda lucida* have been reported in *Allium cepa* (Haider *et al*., 2004, Al-Moaraf *et al*., 2005). Turk and Tawaha (2003) found that aqueous extracts of black mustard (*Brassica nigra*) caused the reduction in germination, hypocotyl and radicle length of *Avena fatua*. Irshad and Cheema (2004) asserted that allelochemicals inhibit seed germination by blocking hydrolysis of nutrients reserve and cell division. Water extracts of herbage of several allelopathic species have been reported to adversely affect seed germination of recipient plants (Kalburtji and Mosjidis, 1993b; Assaeed and Al-Doss, 1997). The tree leaf leachates on various concentrations had inhibited the seed germination percentage which might be due to the phenolic acids shown to be toxic to germination and plant growth processes (Einhelling, 1995). Rajangam and Arungam (1999) also found that the use of Z-aqueous extract of *Excoecaria agallocha* leaves inhibited seed germination and plumule and radical elongation of rice. Allelopathic effects of aqueous leachates of *Brassica nigra* (Tawaha and Turk, 2003), *Raphanus raphanistrum* (Norsworthy, 2003) and *Ageratum conyzoides* (Batish *et al*., 2002; Singh *et al*., 2003) has been indicated.

The variable effect observed on paddy and maize might also be due to the change in concentration of the leachates. The difference in germination at various concentration of the leaf leachates might be explained that the compounds affecting the grain seeds of paddy and maize were different or the concentration levels inhibitory to paddy and maize were different which was in agreement with the report of Einhelling (1996) stated that the allelopathic effect is species specific and concentration dependent. The variation in seed germination and initial growth parameters of different crops might also be due to the variation genetics of the tested crops which were also in agreement with those of Singh *et al.* (1992), Nandal *et al*. (1999a, b) and Patel *et al*. (2002), who all observed reduction in germination percentage with leachates application to paddy and maize.

Ismail and Chong (2002) reported that aqueous extract of *Mikania* plant leaves retarded germination of tomato and Chinese cabbage, but did not affect germination of corn and long bean, similarly Wu *et al.* (1998) noticed that wheat extract affected differently the germination of ryegrass weed, this indicates that crop varieties have different susceptibility to allelopathic effect and in this study maize seed seems to be more sensitive to allelopathic effect of leaf leachates than that of paddy when compared with the control.

The seed germination of paddy and maize under various treatments and concentrations showed different inhibiting effect, this unequal susceptibility to different leachates could be due to inherent differences in various biochemical involved in the process. There was a variation in germination of seed between undiluted (90-100%) and diluted (10-60%) leachates when compared with control, which indicates that seed germination decreased with an increase in the concentration of the leachates but would reduce normal seedling even in low concentration. The results were also in conformity with those reported by Mc Whorter (1984) and Nandal *et al.* (1999a, b). Similarly, allelopathic influence of *Quercus* species on *Triticum aestivum*, *Brassica compestris* and *Lens culinaria* suppressed the germination, plumule and radicle length of all food crops (Bhatt and Chauhan, 2000). Sazada *et al*. (2009) also reported the aqueous leaf extract of *Acacia nilotica* have depressive allelopathic effect on seed germination and radical length of *Triticum aestivum* var-Lok-1. However, Tawaha and Turk (2003) stated that an indirect relation between lower germination rate and allelopathic inhibition may be the consequences of inhibition of water uptake and alteration in the synthesis or activity of the Gibberelic acid (GA_3) (Olofsdotter, 2001).

In this study, the aqueous leaf leachates of teak, neem, *Mikania* and *Ageratum* have resulted in reduction of a seed germination percentage and seedling growth of the paddy and maize as a whole which were also in agreement with most of the previous results obtained by many other researchers, which emphasized that extracts of many plants inhibit germination of many other plants (Noor *et al*., 1995; Von Rencose, 1997). Nandal and Dhillon, (1999) reported the aqueous extracts of poplar leaves adversely affected the germination and seedling growth of some wheat varieties at high extract concentration. The gradual decrease in germination percentage and seedling growth of plants was due to allelopathic effects of trees and weeds species leachates from low concentrations (10%) to higher concentration (100%) when compared with control. Tongma *et al*. (1998) also reported that germination percentage of tested plant species decreased. It can be summarized from the result of leaf leachates concentration under bioassay condition that leachates having any concentration of allelochemical will reduce the seed germination and seedling growth. Results from the present study confirms the findings of Bansal *et al*. (1992), who reported that the suppressed seed germination and seedling growth in all associated crops/weeds and the suppressive effect increased with an increase in per cent content of trees and weeds leaf leachates. Anjum *et al*. (2005) Javaid *et al*. (2005) found that aqueous extracts of allelopathic grasses *Imperata cylindrica* and *Desmostachya bipinnata* suppress the germination. These findings also were in accordance with the results of Alam (1990) and Nilsson (1994) in which root growth was more sensitive and responded more strongly to the increasing concentration of the aqueous leachates. Several reports address the importance of allelopathic effect of various trees *Excoecaria camaldulensis*, *Prosopis juliflora* and *Acacia nilotica* significantly affected seed germination and seedling growth of several crops and weed species (Khan *et al*., 2004), Lisanework and Michelsen (1993) who discovered that the leaf extract of *Excoecaria camaldulensis* decreased root growth of the majority of the crops in their studies. Similar findings were also reported by Rafique Haque *et al.* (2003) and Siddiqui *et al.* (2009) in leaf extracts of different agroforestry trees in common agricultural crops and also found inhibitory effect in seed germination and radical length and other initial growth parameters, they suggested that these aqueous extract contain (Zn), Copper (Cu), Manganese (Mn), Iron (Fe), Cadmium (Cd) and Lead (Pb) at different concentrations, these metals have been implicated in inhibition of root growth in *Allium cepa* (Boroffice, 1990), cucumber, lettuce and millet (Gorsuch *et al.,* 1995). It might be possible that the aqueous leaf leachates of *Melia azadirach* L. and

Tectona grandis L., *Ageratum houstonianum* L. and *Mikania micrantha* L. contain some chemicals and metals which inhibited the seed germination, growth and development of paddy and maize.

The seed germination of paddy and maize under different treatments in pot culture showed significant reduction, while the growth and development of crop plants under all the treatments showed promotion effect when compared with control which might be perhaps the decomposed litter added into the soil acted as soil nutrients and conditioner that enhanced the growth of crops, however, plant sizes and yields were low in comparison with field crops. Raising plants in polythene bags and grafting them while in bags, ensured cent per cent establishment on account of undisturbed root system (Tewari and Bajpai, 2002). In respect of grains and weight of grains per sheaves and cob when compared with control, stimulatory effect had been found under SN, DN and DM in both the crops, while inhibitory effect had been recorded under ST, DT and DA. The fresh and dry weight of root and shoot had shown pronounced inhibitory effect in maize than paddy under different treatments when compared with control condition. Promotion effect in fresh and dry weight had been recorded against paddy under ST, DT, SN, DN, DM and DA.

Decomposition of the plant residue is important in toxin production. Unless the residue is decomposed no phytotoxins can be produced, but recent evidence has also suggested potential of plants and their essential oils as safe natural herbicides, growth promoter and other agents (Brud and Gora, 1990). Neem granules applied in soil during sowing or planting as a top dressing acts as soil conditioner (Shyam Sunder, 2006). The leaves and roots of subabul are very rich in nutrients like N, P, K, Ca and Mg (NAS, 1979) which can add substantial amount of nutrients to the soil through leaf litter.

In many instances, the chemicals leached from the plants had allelopathic influence on the germination and growth of subsequent crops. The result found in this study is congruent with the findings of many researchers. Sundaramoorthy *et al.* (1995) found that *Prosopis juliflora* significantly inhibited the seed germination in pearl millet. According to Rice (1984), plants are known to exhibit allelopathy by releasing water soluble phytotoxins from leaves, stem, root, fruit and seeds and such metabolites play an inhibitory role in delay or complete inhibition of seed germination, stunted growth and injury to root systems of plants. More delay in seed germination and lower germination index with other parts extracts could be attributed to a more inhibitory effect of allelochemicals present in leaves (Kadioglu and Yanar, 2004). The allelopathic effect of extracts from teak leaves has been tested on Solanaceae species such as the tomato (*Lycopersicum esculentus*), egg plant (*Solanum melongena*) and pepper (*Capsicum annum*) (Krishna *et al*., 2003). The extracts significantly inhibited germination and growth of these plant species. *Tectona grandis* has also shown high allelopathic activity on wheat (*Triticum aestivum*) (Krishna *et al*., 2003). Menges (1987) also observed that incorporation of residues of *Palmer amaranth* in the soil inhibited the growth of carrot and onion. Weeds are major impediment to direct seeded rice (DSR) production through their ability to compete for resources and their impact on product quality (Rao and Nagamani, 2007; Rao *et al*., 2007; Kumar and Ladha, 2011). Foliar leachates of *Mikania* have been regarded to be the most phytotoxic in nature (Xuan *et al*., 2004) probably owing to their proportionately greater biomass and with greater metabolic activity or production of more metabolites (Xuan *et al*., 2004). Importantly, when mixed with the soil, *Mikania* vine debris produces toxins that inhibit the growth of other vegetation, such as native plants and agricultural crops. The presence of *Mikania* in crop production systems negatively impacts crop production. Some recent studies indicating the phytotoxic/allelopathic effect of aqueous extracts of weeds include *Mikania micrantha* (Ismail and Kumar, 1996), *Vulpia* spp. (An *et al*., 1999), *Cyperus rotundas* (Quayyuam *et al*., 2000), *Cardaria draba* (Kiemnec and McInais, 2002), *Parthenium hysterophorus* (Batish *et al*., 2002; Singh *et al*., 2003a). *Mikania* is rarely managed (Macanawai *et al.,* 2011b). Recently, *Mikania* was reported to be infesting taro (*Colocasia esculenta* L.) Schott and Cassava (*Manihot esculenta* Cardtz) ((Macanawai *et al.,* 2010a). When this plant is growing in a cropping situation, various physical and environmental factors (such as the degree of shading, the levels of soil moisture and nutrients) may affect its vegetative growth (Kami *et al.,* 2010; Sugiyama and Gatoh, 2010). There is an evident that allelochemicals from weeds inhibit crop growth (Florentine *et al*., 2006).

Under field condition, paddy grown under neem showed promotion effect on seed germination, plant growth and yield of crop than those grown under teak and in sole condition. According to Shyam Sunder (2006) neem gives better yields, it is ideal for crops like cereals, pulses, oilseeds, vegetables, fodder crops and plantation crops. Much research has been done on neem in different aspect such as manure and soil conditioner (Ahmed and Grainage, 1985, 1986; National Research Council, 1992), Uses (Alam, 1990; Vandenbeldt, 1990; Hedge, 1991; Harsh *et al*., 1992; Gill and Deb Roy, 1993).

Though there was a remarkable decrease in plant growth and yield under teak, the crop yield has been increased under neem. In respect of maize grown under control condition, best result was obtained followed by those planted under neem.

Surprisingly, all the maize plants grown under teak plantation died after the second month which could be due to the detrimental effect of teak on crops. The detrimental reduction in yield of paddy may also be due to that, the litter fall on the ground formed a matrix on floor that not only prevented penetration of light but also acted as a physical barrier to the crop plants (Joshi and Prakash, 1992) which resulted in retardation of plant growth and development. Moreover, the litter decomposed into the soil might have changed the C: N ratio of the soil and created nutrient deficient environment (Ralhan *et al*., 1996). Further, the decomposing litter released phytotoxins harmful for plant growth (Kohli *et al.,* 1996). Report by Dagar *et al*. (1995) stated that reduction in yield of wheat crop under *Tectona grandis* in comparison with sole wheat crop. In conformity to the present results Mutanal *et al*. (2000) also reported that the groundnut pod production was reduced under *Tectona grandis* and higher yield was obtained in sole groundnut crop. *Tectona grandis* has also shown high allelopathic activity on wheat (*Triticum aestivum*) (Krishna *et al*., 2003). Narwal (1996) stated that poplar in its early stage caused no harmful effect on the alley crops but older trees may reduce the plant stand, growth of understorey and adjacent natural vegetation due to more production of leaf litter. From the emanation of allelochemicals, plants can regulate the soil microbial community in their vicinity, affect herbivores, encourage beneficial symbiosis, change the chemical and physical properties of the surrounding environment, and directly inhibit the growth of competing plant species (Pedrol *et al.,* 2006). Community composition and the co-existence of plant species may be strongly influenced by interaction between species (Inderjit and Callaway, 2003). Leachates from stemflow and litterfall are responsible for the cell division, mineral uptake and biosynthetic effect (Molina *et al*., 1991), and phytotoxic substances exuded by many trees species allelopathically retard the growth of associated crop species (Suresh and Rai, 1988). Negative interferences could include limitation of light and nutrients (Wagner and Radosevich, 1991; Jobidon *et al*., 2003). It has been suggested that, if the teak tree is planted at a wider spacing (e.g. 5-6 m. apart), there would be least chances of adverse shade effect of teak on food crops growth and yields under agroforestry systems in Mizoram. According to Singh *et al*., (1989), wider row subabul spacing (7.2m) provided better crop yields than narrow subabul spacing (3.6m). However, the reduction of maize yield at narrow spacing could also be due to shading effect of the crop itself (Lawson and Kang, 1990). Besides, adverse influences of trees on crops may also be due to competition for growth resources *viz.*, soil moisture, soil nutrients and light.

In allelopathy, plant-plant interferences in natural habitat occur through two possible mechanisms, direct competition for necessary growth factors or through addition of toxic factors to the environment (allelopathy). When rainfall passes through the intact green foliage or falls on decomposed litter, many organic compounds including allelopathic agents are released into the soil (May and Ash, 1990, Dormaar and Williams, 1992). The presence of these agents in the soil in sufficient quantities has both detrimental and beneficial ecological consequences (Whittaker, 1970). The presence of phytotoxins is also considered as a factor affecting competition (Rice, 1984) and a number of higher plants were observed to possess allelopathic potential (Hong *et al.,* 2003). The allelochemical substances secreted by aerial organs of pigweed are released through washing by rain or irrigation water to the soil (Karimi, 1995; Khan *et al*., 2005). Weeds may disrupt germination and growth of agricultural crops by chemicals production leading to lower yield production (Rezayi *et al*., 2008).

It was known that tree crops release some phytotoxins into soil, which adversely effect the germination and yield of crops. The most commonly found allelochemicals which alter the growth or physiological function of the receiving species includes cinnamic and benzoic acids, flavinoids and various terpenes (Singh *et al.,* 2003b), and these compounds are known to be phytotoxic (Einhelling, 2002). Kaul *et al*. (1989) found the allelopathic activity of commonly grown farm tree species viz. *Acacia nilotica, Dalbergia sissoo, Bauhinia variegata, Ficus bengalensis, Eucalyptus* spp.*, Morus alba, Populus deltoides, Salix babulonica* and *Leucaena leucocephala*, *Acacia nilotica* promoted seedling growth.

The paddy intercropping with neem enhances the growth and yield under field condition, which agreed with the study of various workers, these intercropping are not only superior in increasing production but also very effective in conservation of soil and water (Verma *et al*., 1994). Application of neem cake as fertilizer to forest tree species, like *Leucaena leucocephala* L. and *Tectona grandis* L. and *Pinus elliotti* L. has also been found to enhance their growth and dry matter production. Shyam Sunder (2006), reported yield data from large scale farm trials on paddy and sugarcane with neem cake coated urea, the increase in paddy yield was 22.8% over urea alone and in sugarcane it was 15.5% (Shyam Sunder, 2006).

The present experiments dealt with the leaf leachates; however, there could be other plant parts which may release phytochemicals to the soil affecting growth and yield of intercrops. Most of the literatures support the leaf as the potential source of allelochemicals inhibiting plant growth and therefore, we selected leaves for the study. The relative efficacy of different plant parts, however, can add to better understanding of allelopathic tree-crop-weed interactions in agroforestry system and can provide some management interventions for better land and crop productivity. Experimental results evinces that the teak plants grown by the farmers are too dense to interfere with maize productivity. It is suggested that the tree spacing be increased so as to reduce allelopathic interference and besides, the shading effect of trees and shedding effect of leaves may be reduced to a considerable effect, probably further benefiting the intercrop. The chemical compounds that are present in various plant parts and are released into the environment by a given plant or microorganism need to be analysed. A single compound present in the plant part may not be that effective as compared to a mixture, so a detailed study on chemical composition would further add to the mechanism of allelochemicals in soil-plant environment. Besides, some manipulative field studies on spacing, cropping management etc. could also help advocating better agroforestry practices for the state of Mizoram and all future studies should be directed on these issues.

Chapter-8

SUMMARY

The present investigation entitled "Study on allelopathic effect of tree-crop-weed interactions in agroforestry systems in Mizoram" was conducted during the year 2009-2011. The investigation covered the allelopathic effects of aqueous leaf leachates of trees (*Melia azadirach* L. and *Tectona grandis* L.) and weeds (*Ageratum houstonianum* L. and *Mikania micrantha* L.) on test crops (*Oryza sativa* L. and *Zea mays* L.) under bioassay, the effects of different treatments of soil and leaf litter and leaf powder of the selected trees and weeds on crops under pot culture, and the effects of trees on crops under field condition. The investigation aimed to find out the difference in germination percentage and initial growth parameters and yields of the selected crops (*viz*; paddy and maize) as affected by concentrations of leachates and/or soil infected with allelochemicals under different set up. The main objectives of the study were:

a) To find out the allelopathic effects of trees (*Melia azadirach* L. and *Tectona grandis* L.) and weeds (*Ageratum houstonianum* L. and *Mikania micrantha* L.) on the seed germination, growth of crops and biomass of fresh and dry weight of roots and shoots of the selected crops (*Oryza sativa* L. and *Zea mays* L.) under laboratory bioassay condition.

b) To find out the allelopathic effects of soil beneath the neem and teak plantation, leaf litter and leaf powder of *Melia azadirach* L. and *Tectona grandis* L., *Ageratum houstonianum* L. and *Mikania micrantha* L. on the seed germination, growth and yield of crops under pot culture condition, and

c) To study the allelopathic effects of *Melia azadirach* L. and *Tectona grandis* L. on the seed germination, growth and yield of crops (*Oryza sativa* L. and *Zea mays* L.) under fields condition.

Based on the investigations carried out under different set up, the following results were obtained:

i) Under bioassay the seed germination of both *Oryza sativa* L. and *Zea mays* L. under aqueous leaf leachates of *Melia azadirach* L., *Tectona grandis* L., *Ageratum houstonianum* L. and *Mikania micrantha* L. under different concentrations at various treatments showed concentration dependent i.e. as the concentration of leaf leachate increased, the percentage of seed germination decreased.

ii) The gradual inhibition of root and shoot elongation of *Oryza sativa* L. and *Zea mays* L. had been observed as the concentration of the leaf leachate increased. However, the root and shoot elongation of *Oryza sativa* L. under lower concentration of the leaf leachates of *Mikania micrantha* L. and *Ageratum houstinianum* L. was found to be enhanced. In general, the root and shoot development was more sensitive and responded strongly to the increasing concentration of the aqueous leaf leachates in comparison to the control and also showed that the root growth was more affected than that of the shoot growth under various concentrations.

iii) Fresh weight of root of *Oryza sativa* L. under aqueous leaf leachates of *Mikania micrantha* L. and *Ageratum houstonianum* L. had been increased under lower concentration while other treatments showed inhibition effect on fresh weight of *Oryza sativa* L. and *Zea mays* L. irrespective of leachate concentrations.

iv) The dry weights of both root and shoot of paddy were inhibited by different concentrations of leaf leachate of *Melia azadirach* L., *Tectona grandis* L., *Ageratum houstonianum* L. and *Mikania micrantha* L. without any exception, while reverse was the case for dry weight of root and shoot of *Zea mays* L.

v) The inhibitory effect was found to be more pronounced at higher concentration for the selected test crops at various parameters. However, their effects were not considerable at low concentrations and the effects were also of different degree when compared between the crops. Moreover, between the test crops, maize seems to be more significantly inhibited by the different concentration of leaf leachates of the selected trees (*Melia azadirach* L. and *Tectona grandis* L.) and weeds (*Ageratum houstonianum* L. and *Mikania micrantha* L.).

vi) Under Pot culture, the difference in seed germination of both paddy and maize was not considerable when compared with control.

vii) The various parameters studied under pot culture showed significant increase in plant height, number of leaves and diameter of stem for both the crops under all the treatments, except that under DT the growth of *Oryza sativa* L. in terms of number of leaves and diameter of stem was significantly suppressed. Similarly, the plant height of *Zea mays* L. under DT was also suppressed. However, considering all the other initial growth parameters under different treatments, the degree of inhibition were low when compared with control.

viii) The grain yields of both *Oryza sativa* L. and *Zea mays* L. were found to be increased under *Melia azadirach* L. treatments while reduction in yields was recorded under all the other treatments.

ix) The biomass of fresh and dry weights of root and shoot had been found to be stimulated under various treatments when compared with control.

x) Although the crop performance under various treatments in pot culture exhibited promotion effect, the average plant height, yield and biomass production were low when compared with field experiments.

xi) Under field experiment, the seed germination of both the test crops *Oryza sativa* L. and *Zea mays* L. did not show much variation with respect to different treatments; however a promotion effect had been recorded for *Oryza sativa* L. seeds under *Tectona grandis* L. plantation.

xii) The initial growth parameters of *Oryza sativa* L. and *Zea mays* L. under *Tectona grandis* L. plantation had been found to be inhibited while the growth and development of *Oryza sativa* L. under *Melia azadirach* L. showed promotion effect when compared to the control.

xiii) In general, the grain yield of *Oryza sativa* L. under *Melia azadirach* L. showed a remarkable increase while it drastically decreased under *Tectona grandis* L. plantation.

xiv) The biomass of fresh and dry weights of root and shoot of both *Oryza sativa* L. and *Zea mays* L. were also recorded to be decreased on all the treatments in comparison with control.

xv) In general, though the average seed germination, growth and development of *Oryza sativa* L. and *Zea mays* L. might be inhibited by the treatments under pot and field condition, the overall yield of *Oryza sativa* L. grains under *Melia azadirach* L. was found to be enhanced in comparison with the control.

This increased in yield of *Oryza sativa* L. (paddy) under *Melia azadirach* L. (neem) in agroforestry system should be recommended and suggested to the farmers for improving their production especially in respect of *Oryza sativa* L. (paddy). This intercropping will not only increase the yield but will also help in maintaining the soil productivity, decreasing harmful effect of shifting cultivation, leaching loses of plant nutrients, supplying fodder for livestock and maintaining pollution free environment, etc.

It may be concluded that growing of maize and paddy (*Zea mays* L. and *Oryza sativa* L.) under teak (*Tectona grandis* L.) in agroforestry systems will not yield better result as the tree significantly depressed their germination, yield and dry matter production. However, neem (*Melia azadirach* L.) is good for the intercrops of maize and paddy (*Zea mays* L. and *Oryza sativa* L.) as it provides less shading effect and positive influence on growth of the crops owing to its allelopathic compatibility for crops. Looking into the negative influence of teak (*Tectona grandis* L.) on maize and paddy (*Zea mays* L. and *Oryza sativa* L.), it may be suggested to grow the species under spacing at a much wider spacing (6-7m apart) than the present practice (2 x 2m) spacing, so that the chance of allelopathic influence of its leaf leachates are reduced for the crops. Besides, the wider spacing may reduce shading effect for the crop as well. The experimental results further evidence that paddy (*Oryza sativa* L.) could grow successfully as an intercrop to boost its yield.

Although the present study provides some interesting findings on tree-crop-weed compatibility, greater depth of analysis by conducting more experiments are necessary for the state of Mizoram.

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