INTRODUCTION

"Allelopathy", in a literal sense meaning mutual harm, refers to the gross biochemical interactions among all types of plants including microorganisms. The term coined by Molisch (1937) included both detrimental and beneficial reciprocal biochemical interactions. However, Rice (1974) defined allelopathy to be any direct or indirect harmful effect, that one plant exerts on another (microorganisms included) through the chemical mediation that escape into the environment. Khailov (1974) showed that a given compound will act as inhibitory or stimulatory depending upon the concentration of the compound present in the surrounding medium.

Competition involves the removal or reduction of some factor from the environment that is required by the other plants sharing the habitat while allelopathy involves addition of some compound to the environment which will have either promotory or inhibitory effect on the surrounding plants. Muller (1969) suggested the term interference, involving both competition and allelopathy which refers to the overall influence of one plant on another. He opined that allelopathy should be characterised as one of the environmental factors while analyzing the mechanisms of plant interactions.

Grummer (1955) suggested specific terms should be used for the organic compounds, considered to be the allelopathic agents depending on the agent producing and the other getting effected. He gave the name antibiotic, for a chemical produced by a microorganism and effective against microorganism. Waksman's term phytoncide pertains to an agent produced by a higher plant effective against a microorgamism. Gaumann's term marasmin is for compounds produced by a microorganisms and active against a higher plant and Kolines for chemicals produced by higher plants and effective against higher plants.

Allelopathy is of universal occurrence, ranging from Natural ecosystems to manmade ecosystems; from forest regeneration to agricultural fields; playing various roles in plant pathology as well as in Algal succession.

The significance of allelopathy lies in the ability of allelochemicals or toxic organic chemicals to affect species composition of vegetation, rate of succession and plant productivity. These events are accomplished through regulation of the metabolism of the species receiving through the donor species. The effect may be observed as a loss of plant productivity or a complete absence of the plant. The rate of succession may increase or decrease depending upon donor species and receiver species.

The allelochemics may interfere directly with the essential physiological processes of the receiver, or indirectly via an effect on soil microorganisms such as those that fix and mineralize soil nitrogen or form mycorrhizal relationships (Horsley, 1977).

Quantities of allelochemicals within plants vary with the plant tissue, phenology, and environmental conditions (Putnam and Duke, 1978; Rice, 1984). The magnitude of allelopathic interactions is dependent upon the concentration and chemical stability of the active compounds, plant tolerance to such compounds and their microbial metabolites (Phillips _et_ _al_., 1980).

Allelochemicals

Allelochemicals form a very heterogenous group comprising of members from almost all classes of compounds (Muller, 1966). They range from very simple aliphatic compounds to polycyclic aromatic compounds. Certain compounds produced are of little or apparently no metabolic, physiologic or structurally of any use to the producer and are believed to serve as biochemical defences (Whittaker and Feeny, 1971; Swain, 1977; Bell, 1981). The important groups of allelochemicals are the following :

Aliphatic Organic Acids

Aliphatic organic acids are common decomposition products of the carbohydrates and proteins found in plant residues in the soil. Di- and tricarboxylic acid intermediates of the kreb's cycle, monocarboxylic acids of the lower fatty acid series (formic, acetic, propionic and butyric acids) and oxalic, glycolic, lactic, and tartaric acids are the most common allelochemicals. Dihydroxystearic acid and alpha-crotonic acid are some other acids found inhibitory to plant growth (Stevenson, 1967).

Lactones

Patulin, a simple lactone of restricted occurrence in nature, has been implicated in inhibiting growth of higher plants. This compound is an antibiotic produced by several species of the fungus Penicillium (Norstadt and McCalla, 1968).

Alkaloids

Alkaloids form the largest class of secondary plant products occurring primarily in Angiosperms. Hordein and gramine are the two alkaloidal inhibitors exuded by the roots of Hordeum sativum (Overland, 1966) exhibiting allelopathic potential. Though there has been no recent work on the allelopathic effects of alkaloids (Rice, 1974), the potential for allelopathic inhibition by alkaloids in species that do not possess the enzyme systems to detoxify them was discussed by Winter (1961).

Amino acids and Polypeptides

Protein amino acids have rarely been associated with allelopathic inhibition of plant growth. Under aerobic soil conditions they are rapidly reabsorbed into normal metabolic pool by both higher plants and microorganisms (Whitehead, 1963; Campbell and Lees, 1967) although they may accumulate under anaerobic conditions caused by high soil moisture content (Patrick, 1971). But some of the non-protein amino acids such as azetidine-2-carboxylic acid and rhizobitoxin are implicated in allelopathy (Fowden, 1963; Owens, 1969).

Cyanogenic glycosides

Three aromatic cyanogenic glucosides which have been reported to cause allelopathic inhibition includes, Amygdalin and prunasin, constituents of peach root bark residues, are responsible for the peach replant problem (Patrick, 1971). Dhurrin, a constituent of Johnson-grass is responsible for delayed succession in old fields (Abdul-Wahab and Rice, 1967). During tissue decomposition the cyanogenic glycosides are hydrolyzed to the toxic volatile hydrogen cyanide, and either benzaldehyde (amygdalin, prunasin) or p-hydroxybenzaldehyde (dhurrin) and glucose. The aromatic aldehydes upon oxidation with air yields corresponding benzoic acids, which are toxic in nature (McIlroy, 1951).

Terpenoids

The terpenoids having allelopathic properties are primarily released by volatilization from aromatic plants and are responsible for bare ground zones around the donor plant. Of a large number of terpenoids, a few have been identified as allelopathic inhibitors of plant growth. All the allelopathic terpenoids i.e. the monoterpenes, sesquiterpenes and sesquiterpene lactones are constituents of the volatile oils.

Monoterpenes

The monoterpenes, which form the largest group of compounds in the essential oils, have been identified most frequently as inhibitors. Essential oils and pure monoterpenes inhibit seed germination and plant growth (Sigmund, 1924).

α-pinene, β-pinene, α-phellandrene and cineole from Eucalyptus leaves and the surrounding soil, were isolated of which cineole was the most toxic, though all the four at high concentration inhibit Bromus rigidus germination (Horsley, 1977).

Asplund (1968) tested the inhibitory properties of several structurally related monoterpenes and concluded that the presence of a functional ketone group was correlated with toxicity. He concluded that the toxicity of other compounds depended on the ease with which metabolite can be converted to a ketone.

Highest phytotoxic effects were observed for cyclic compounds, α — and β—unsaturated ketones, thujone, and carvone being the most active (Fischer, 1986).

Sesquiterpenes

Some of the sesquiterpenes exhibiting allelopathic influences include, an essential oil obtained from Cyperus serotinus which inhibited the germination and growth of lettuce and rice (Komai et. al., 1981). The active constituents farnesol, its acetate, methyl farnesate and β -selinene were responsible for exhibiting anti-auxin and anti-gibberellin activities.

Sesquiterpene lactones

It comprises of one of the largest groups of natural products (Fischer et. al., 1979; Seaman, 1982; Picman, 1986) and are predominantly present in Asteraceae. The most common sesquiterpene lactone is with α-methylene-γ-lactone moiety. Many lactones contain α , β -unsaturated aldehydes, ketones, and esters as well as epoxide functions. They exhibit a broad spectrum of biological activities including phytotoxic and plant growth regulatory properties (Picman, 1986).

Diterpenes

Very few diterpenes are found to be allelopathic in nature. Some of the examples are spenolobane from *Anastrophyllum minutum*, 17-Acetoxyacanthoanstrolide from *Melampodium longipilum* (Fischer and Quijano, 1985) and cis-dehydromatricaria ester from *Solidago altissima* (Saiki and Yoneda, 1982).

Triterpenes, Sterols and Saponins

Medicagenic acid glycoside derivatives obtained from alfalfa root saponins were the primary inhibitors of winter wheat seedling growth (Oleszek and Jurzysta, 1987). Pure alfalfa root saponins also had strong inhibitory effects on the growth and development of several weeds including cheat, barnyard grass, pigweed, dandelion, and coffeeweed (Waller, 1989). From the roots of *Amaranthus viridis* L. the sterol, amasterol inhibited the germination and growth of lettuce and also the growth of pathogenic fungus *Helminthosporium oryzi* (Roy *et*. *al*., 1982).

Phenolic Compounds

Phenolic substances have been identified as allelopathic inhibitors, more often than any other class of chemicals. They generally occur in plants either as glycosides or esters, thus rendering them water soluble and hence can be easily leached from plant tissue. The important classes of phenolic inhibitors are the benzoic and cinnamic acids and coumarins. Other phenolics of allelopathic nature are simple phenols, acetophenones, phenylacetic acids, phenyl propenes, flavonoids, quinones and tannins.

Simple Phenols

Hydroquinone is the most widely distributed plant phenol. This and its glycoside arbutin have been identified as allelopathic inhibitors in *Arctostaphylos glandulosa* (Chou and Muller, 1972) arbutin was identified among the inhibitory decomposition products of the flavonoid, phlorizin, found in apple root residues (Börner, 1959).

Phenols like catechol, 4-methyl catechol, tyrosol and hydroxytyrosol were found to exhibit phytotoxic effects on *Lycopersicon esculentum* and *Cucurbita pepo* (Capasso *et al.*, 1992). They are liberated from vegetable wastes, oil mills etc.

Phenolic acids

The phenolic acids form a major group of allelochemics. This include both benzoic and cinnamic acids and their derivatives. The important benzoic acids are benzoic, *p* —hydroxybenzoic, vanillic, syringic, gentisic etc. The cinnamic acids commonly found are ferulic, sinapic, *p* —coumaric and caffeic etc.

Benzoic Acids and Aldehydes

Phenolic acids and aldehydes are common soil constituents and are known to accumulate in soils to a detrimental level for plant growth (Börner, 1959; Whitehead, 1964; Guenzi and McCalla, 1966; Patrick, 1971; Wang *et al.*, 1971 and Chandramohan *et al.*, 1973). *p* —hydroxybenzoic acid and vanillic acid are the most common benzoic acids found in soils; some other benzoic acids and aldehydes found in soil include benzoic, 3,5-dihydroxybenzoic, ellagic, gallic, 3-O-methylgallic and syringic acids; p-hydroxybenzaldehyde, syringaldehyde, vanillin, iso vanillin and 5-hydroxyvanillin. Eucalyptus globulus leaf leachates contain the following benzoic acids, gallic, ellagic, vanillic and gentisic acids (del Moral and Muller, 1969; 1970). p-Hydroxybenzaldehyde is seen in leaf and rhizome extracts of Johnsongrass (Abdul-Wahab and Rice, 1967) salicylic acid is present in leaf extracts of cherry bark oak (De Bell, 1971), p-hydroxybenzoic and vanillic acids in leaf leachates of Camelina alyosum (Grümmer, 1961) and sulfosalicylic acid in Digitaria sanguinalis (Parenti and Rice, 1969).

Acetophenones and Phenylacetic acids

The allelopathic phenomenon of Encelia farinosa, a desert shrub is because of an acetophenone (3-acetyl-6-methoxybenzaldehyde), which is responsible for the failure of annual plants to grow beneath the shrub (Gray and Bonner, 1948a, b) is the only known acetophenone to have allelopathic properties.

Cinnamic acids, derivatives and coumarins

The cinnamic acids of most frequent occurrence in soils are p-coumaric and ferulic acids. Other cinnamic acids in soil are sinapic, caffeic, chlorogenic, iso-chlorogenic, and 5-hydroxy ferulic acid. Cinnamic acids, like p-coumaric, caffeic, ferulic, and sinapic acid, occur combined with sugar or with other compounds. Caffeic acid for example occurs as the quinic acid ester, chlorogenic acid. Like the benzoic acids, the cinnamic acids are also easily leachable and hence identified as allelopathic inhibitors. Cinnamic acids are found frequently with benzoic acids as soil constituents, and accumulate to toxicity levels in the soil for plant growth (Morrison, 1963; Whitehead, 1964; Morita, 1965; Guenzi and McCalla, 1966; Henniquin and Juste, 1967; Wang et al., 1967a, 1967b; Wilson and Rice, 1968; Ly et al., 1970; Al-Naib and Rice, 1971; Patrick, 1971; Wang et al., 1971 and Chandramohan et al., 1973).

The coumarins are lactones of *O*—hydroxycinnamic acid, occurring as glycosides in plants, glycosylation render them leaching capacity and frequently been identified as the cause of allelopathic phenomenon. Several hydroxycoumarins like umbelliferone, aesculetin and scopoletin are known allelochemics (Harborne, 1973).

Phenylpropenes

Being lipid soluble, these compounds are isolated in the essential oil fraction along with the volatile terpenoids. Gant and Clebsch (1975) identified eugenol in the inhibitory foliage runoff and litter leachates of Sassafras along with several monoterpenes. Eugenol and safrole were also found in the soil along with monoterpene inhibitors.

Flavonoids

Flavonoids, form the largest class of plant phenolic compounds and are present in all parts of many plants. There is a tendency for particular classes of flavonoids to be located in particular plant parts (Geissman, 1962). They are present in glycosidic form and hence are water soluble. A few of these have been assigned allelopathic activity. Phlorizin, a dihydrochalcone is found in apple root residues and a few other plants. Phlorizin and its decomposition products phloretin (the aglycone), phloroglucinol, p-hydroxycinnamic and p —hydroxybenzoic acids were responsible for the poor growth of apple seedlings. Rice and Pancholy (1974) identified glycosides of the flavonols, kaempferol, quercetin and myricetin, and the flavones iso-orientin and 3,4,7-trihydroxyflavone as allelochemics.

Quinones

Juglone, 5-hydroxy naphthaquinone is the only allelopathic quinone produced by higher plants. Juglone was noted when it was found that many plant species do not grow or grew poorly in association with black walnut and particularly if contact occurs between the roots (Massey, 1925).

Anthraquinones

Root exudates from Polygonum sachalinense inhibited lettuce seedling, and affected the seedling growth of several tested plant species. The compounds responsible for the interference and potent allelopathic reactions were isolated and identified as emodin-1-O-β-D-glucoside and physcion-1-O-β-D-glucoside. The effective concentrations of emodin occurs in the soil during fall (Inoue et al., 1992).

In addition to the above mentioned compounds there are innumerable reports in which the compounds are not being identified by the investigator(s). Since they do not contribute to the knowledge of allelochemics they are not included here.

Release of Allelochemics

Virtually all plant parts contain inhibitors. The release of allelopathic inhibitors in sufficient quantities into the soil appears to be necessary for the development of an allelopathic conditions (Bonner, 1965; Guenzi et al., 1967). Bioassay studies show that species responded not only to the amount of debris but also to the change in debris location with respect to growing roots. Phytotoxicity was not only facilitated by soil incorporation of the legume debris but also increased organic nitrogen availability (Breman and Wright, 1984). Incorporation of the plant debris into the soil may promote chemical and microbial decomposition accompanied by the enhancement of the release of soluble organic constituents. Thus increasing the probability of weed or crop seeds and roots in close proximation to interact with allelochemicals. Conversely debris located on the soil surface may decompose at a slower rate and release allelochemicals in lower quantities, distant from expanding roots. Contact of these substances with germinating seeds and seedling roots would then be controlled primarily by the water solubility and soil adsorptive characteristics of the compounds and by other environmental factors influencing leaching (Randall et al., 1989).

The leaves and roots are the important sources of phytotoxic compounds. Leaves show largest quantity and greatest variety of inhibitors, followed by roots which are the second major contributor of inhibitory substances (Harborne, 1964; Harborne and Simmonds, 1964). Certain chemicals are localised within plants hence two different organs of the same plant can have different complement of inhibitory chemicals (Bonner, 1965; Ohman and Kommendahl, 1960). The release of water soluble and sparingly water soluble organic constituents or inhibitors takes place after loss of membrane integrity, thus phytotoxic release continues for some months after death (Guenzi et al., 1967). Compartmentation in the tissue at times prevents the plants from coming close of the toxic chemicals. With the death or the advent of decomposition of plant remains,these chemicals may react with one another, resulting in the formation of toxic products. Example of such kind is the cyanogenic glycosides such as dhurrin and amygdalin (Patrick, 1955; Abdul-Wahab and Rice, 1967).

Soils beneath donor plants frequently become toxic when the inhibitors are released from living tissue (Lodhi and Rice, 1971) or after litter leaching they become more toxic (Wilson and Rice, 1968; Al-Naib and Rice, 1971).

Modes of Release of Allelochemics

Release of allelochemics by the plant species to the environment occurs through many ways. Some of the important routes are, residue decomposition, root exudation, leaching and volatilization.

Residue decomposition

The residual matter of the plants i.e., fallen leaves, stems, bark, fruits, seeds etc., which remains on the soil surface along with the green plants added as green manure form the sources of allelochemics. These are subjected to the forces of nature, get dried up and break into smaller particles. The soil water extracts the water-soluble compounds which either diffuses into the surrounding environment or gets washed away. The microflora acts on these plant parts and their constituents and convert them into related compounds or break them into smaller units. During the decomposition of residue, a wide spectrum of organic compounds gets distributed into the soil. Most of the water soluble compounds gets dispersed into the lower layers of soil while the lipidic components remain in the surface layers. Prominent in agricultural fields, it also occurs in deciduous forests.

Root exudation

Roots being the site of synthesis of compounds like phenolics and alkaloids, root exudation contains mostly these compounds. Since the intact roots contain a number of antimicrobial compounds, the microbial activity will be much lesser in the close vicinity of the intact roots. In such cases the exudation is the active process. The residual matter of roots remaining in the soil will be acted upon by the microbes, this also will cause the liberation of chemical constituents into the soil. Almost all the compounds released by this process are water soluble.

At times the root exudation is the major form of release of all allelochemics, which continues throughout the year.

Leaching

Water soluble organic constituents from living plant tissue, particularly aerial parts, reach the soil dissolved in rain water or fog drip, constitute the process of leaching. Tukey (1970) found that all plants are leachable to some degree. The variety of chemicals that can be leached includes all the known classes of allelopathic inhibitors and non-allelopathic agents such as free sugars, pectic substances, sugar alcohols, amino acids, growth regulators, terpenoids, alkaloids, and phenolic substances (Mothes, 1955; Tukey and Meklenburg, 1964; Tukey, 1969, 1970; Gant and Clebsch, 1975).

Volatilization

Release of volatile toxins is volatilization. It is a phenomenon of plants of arid and semiarid climates (Whittaker, 1970). Inhibitory volatiles were identified as terpenoid essential oils, mainly simple monoterpenes (Muller and Muller, 1964; del Moral and Muller, 1970; Tyson _et al_., 1974; Halligan, 1975) and also sesquiterpenes (Mc. Cahon _et al_., 1973; Halligan, 1975). Glucosinolates (members of Brassicaceae) and methyl ketones (_Amaranthus_ sps.) are other compounds released by volatilization (Oleszek, 1987; Bradow and Connick, 1988).

Soil Adsorption and Incorporation into Humic Acids

Soils have great capacity for fixation of certain compounds of allelopathic importance, for eg., large amounts of added aliphatic organic acids, alkaloids, or phenolic acids were bound in the soil and were not recoverable by leaching (Winter, 1961; Wang *et al*., 1967; Blum and Rice, 1969; Wang *et al*., 1971). Organic acids of low molecular weight are known to be bound by soil minerals and colloids and are responsible for the downward movement of iron and manganese in some soils (Hurst and Burges, 1967; Elliott and Blaylock, 1975). This property of phenolic compounds binding with metals is often used for spectroscopic identification of these compounds (Ribereau-Gayon, 1972; Morita, 1975). Stratified layers of phenolic acids (Wang *et al*., 1967) or tannins (Rice and Pancholy, 1974) have been found in soils. Incorporation into humic acid appears to be another significant mode of fixation of phenolic acids in the soil.

If we knew the mode of binding of allelopathic chemicals in soils, we may be able to devise treatments to release chemicals from soil binding for the growth of desired plants. Organic compounds such as urea (Ogner, 1973) ammonium ion (Chandramohan, *et al*., 1973) and calcium ion (Morita, 1975) are suggested to be useful in releasing bound phenolic compounds from the soil.

Fate of Allelochemics and Microbial Metabolism of Allelochemicals

To study the physiological modes of action of allelopathic substances, we need to demonstrate the residence time, avenues of movement, the fate of allelopathic chemicals in the soil and the form in which they are presented to plant roots. Toxins produced by donor plant move through the soil and reach the receiver plant unchanged, is unreasonable to presume. The soil, being dynamic system, is characterized by change of its constituent substances. Organic chemicals released into the soil are adsorbed on soil colloids, fixed in soil humic substances, transformed and degraded by soil microorganisms. The changes taking place may be both qualitative and quantitative. Allelochemicals are diminished and qualitatively changed, under aerobic conditions but are increased or actually synthesized and undergo a minimum of change under anaerobic or partially anaerobic soil conditions (Horsley, 1977).

A wide variety of substances are released from roots into the soil, some favourable and others non-favourable for the growth of other plants, or of soil micro-organisms (Borner, 1960; Martin and Rademacher, 1960; Woods, 1960; Winter, 1961). Mostly the release of allelopathic materials is partly or primarily through death and decay of roots, rather by exudation from living roots. But because of the rapid turnover of root hairs and fine roots by death and replacement and sloughing of dead root bark, the relative significance of release through living surfaces and through death and decay is difficult to establish (Whittaker, 1970). Allelochemics released not only depends on allelopathic effect on bacterial action on decay products, to one dependent on a toxin released from the metabolism of a bacterium or fungus utilizing decay products. Some antibiotics are toxic to higher plants, other such as patulin, liberated from species of

Penicillium growing in decaying plant litter and straw also probably present some allelopathic effects (Wright, 1951; Brain, 1957; Behmer and McCalla, 1963).

The first change to occur in phenolic compounds is the enzymatic hydrolysis of these linkages either by microorganisms in the soil (Borner, 1959; Westlake et al., 1959; Winter, 1961) or enzymes freed by loss of membrane integrity in dying tissues (Harborne, 1964) releasing the free aglycone. Soil type, soil physical properties like moisture content, oxygen concentration and reaction, concentration of phenolics in the soil, resistance of the compound to microbial attack and species of micro organisms also play important roles here (Kononova, 1961; Henderson, 1963; Möje, 1966). Many of the organisms which degrade phenolic compounds are aerobic, so soil moisture content can have a considerable effect on the potential for development of allelopathic relationship. In general, phenolic compounds are oxidised to either protocatechuic acid or catechol after which aromatic structure disappears and aliphatic organic acid products are utilized in the kreb's cycle. During this process, hydroxyl groups are added, methoxyl groups are converted to hydroxyl groups and side chains are oxidised, resulting in transformations among phenolic compounds (Möje, 1966).

Winter (1961) found phenolic acids in the soil from the decay of plant parts, a few common ones are p—hydroxybenzoic, vanillic, ferulic and p—coumaric acids. The transformations in the soil are coumaric acid ---> hydroxybenzoic acid ---> benzoquinone and other materials and ferulic ---> vanillic acid (Wang et al., 1967). These transformations are not restricted to the phenolic acids. Wang and coworkers (1967) demonstrated that addition of volatile organic acids to the soil resulted in transformation of short chain aliphatic organic acids to longer chain acids, and although phenolic compounds were not added, still total phenols increased. The ability of many soil microorganisms to synthesize phenolics compounds is well versed. Thus one toxic chemical gets transformed into another during its residence into the soil.

Sometimes higher plants themselves do not produce toxins but may provide carbon source for producing inhibitors by soil microorganisms. However, the presence of certain physico-chemical conditions in the soil and the metabolic activities of soil microorganisms determine the metabolism and life span of the toxic chemicals in the soil. Hence, inhibitory chemicals are produced by both higher and lower plants and are released into the environment.

Uptake and translocation of allelopathic chemicals

Plant roots are presented with a wide variety of organic chemicals, the levels of some may go high in the soil. To cause a detrimental effect most allelopathic agents must be absorbed and translocated to a site of physiological action (Norman, 1955; 1960). The inhibitory activity, however, depends upon the amount being absorbed, than the amount being presented to the roots (Brain, 1957; Winter, 1961). The mode of uptake may be either passive or active. Glass and Bohm (1971) gave evidence for active uptake of arbutin in isolated barley roots while its aglycone hydroquinone was thought to enter by diffusion. pH dependence was shown for some substances but not for others. Rate of uptake may vary even for closely related compounds. For e.g., yeast cells and barley and lettuce seeds were all able to absorb ^{14}C-coumarin rapidly; but ^{14}C-cinnamic, caffeic and ferulic acids were not rapidly taken up. This is accounted as the reason for low toxicity of ferulic acid to these species (Van Sumere _et al_., 1972). It appears that plants do have some degree of control over the rate at which certain organic molecules are taken up.

Conjugation of allelochemicals

Allelochemicals occur as conjugates in plants. The functional groups such as aliphatic hydroxyl, phenolic hydroxyl and carboxyl groups as well as amino and mercapto groups are believed to be involved in conjugation by plants. They are the characteristic form in which phenols, aromatic acids, flavonoids, steroids, and many other secondary products exist in plants. The endocons involved in these conjugations may be derived from monosaccharides (glucose, galactose, mannose, and apiose) disaccharide (gentiobioside and glucosylxylose), oligosaccharides, aromatic acids (benzoic acid, gallic acid and caffeic acid), amines (putrescine and spermine), alkyl groups (methyl, acetyl, and dimethylallyl), amino acids and peptides (aspartic acid, glycine and glutathione), aliphatic acids (acetic, malic and malonic acids) cyclic hydroxy compounds (shikimic acid) and inorganic acids (sulfuric and phosphoric acids) (Barz and Koster, 1981). This great diversity of endocons makes it difficult to predict what particular exocon-endocon conjugate will be present in a particular plant (Harborne, 1980).

Such induced formation of glycosides is important with allelopathic compounds because the conjugate will most likely be less toxic to the plant than the aglycone (Miller, 1973) and conjugation of the toxins with sugar or other substances to render them less reactive and therefore less toxic, is considered as second line of defense against the inhibitory effects of absorbed toxic substances (Pridham, 1960; Stenlid, 1968). Also conjugation increases the water solubility and decreases the chemical reactivity of the parent compound.

Apart from glycosylation, esterification is another form in which compounds, such as quinic acid, occur in plant (Miller, 1938, 1939, 1940, 1943; Hutchinson et al., 1958; Pridham, 1960; Pridham and Saltmarsh, 1960; Harborne and Corner, 1961; Towers, 1964). However many glycosides and esters, when present in sufficient quantity, have toxic properties and produce inhibitory effects. The rate at which conjugation occurs influence toxicity to a large degree. Wheat plants converted the phenol glycoside, arbutin, from its aglycone hydroquinone in 5 minutes but to glycosylate the same quantity of hydroquinone, bean plants required 60 minutes. Some compounds are very difficult to conjugate, having unabated toxicity. Hydroxylation in the ortho position makes benzoic acids, such as salicylic acid difficult to conjugate because of steric hinderance and therefore the high toxicity of salicylic acid in plants is probably due in part to the inability of plants to detoxify this compound (Glass, 1974).

How quickly and to what extent an organism is able to reduce the concentration of an active chemical at the site of action is a major determinant of toxicity. Thus, differences in the capability of receiver to detoxify an active chemical is of major importance for selective action of allelochemicals. Selective toxicity will also be important if allelochemicals are to be put to practical use. For e.g., if allelochemicals are to be used as herbicides, the compound will have to be toxic to some plants (weeds) but non-toxic to others (the crops). Such selective toxicity could be accomplished if the crop, but not the weeds, had the ability to convert an administered allelochemical to non-toxic products (Balke et al., 1987).

Since most of the plants contain substantial amounts of potentially toxic materials, these allelochemics can take up any of the routes in any possible combination into the soil to cause its effects (Whittaker, 1970). Irrespective of their route of entry into the environment and in spite of their biodegradability the allelopathic agents have extended period of persistence in the soil (Mandava, 1985).

Mechanism of action of allelopathic agents

Effect on cell division, elongation and root tip ultra structure

Allelopathic agents inhibit cell division by preventing entry of cells into the stages of mitosis (Cornman, 1946; Rice, 1974; Horsley, 1977). They cause radial expansion by decreasing cell elongation (Jankay and Muller, 1976) and retard cellulose synthesis (Hogetsu *et al*., 1974). Accumulation of lipidic globules in cytoplasm of root tip cells, disruption of membranes surrounding nucleus, mitochondria, dictyosomes and also reduction in the number of intact organelles, suppresses the activity of mitochondria and also reduction in the rate of oxidative phosphorylation are the modes of action of allelochemics (Lorber and Muller, 1976, 1980).

Effect on hormone-induced growth

Many of the allelochemics nullify the effects of auxins. Coumarins, cinnamic acid and several phenolic compounds inhibit gibberellin-induced growth. However, this effect could be reversed by increasing the gibberellin content (Rice, 1984). Similarly tannins inhibited growth induced by GA in cucumber and dwarfpea seedlings, but growth induced by IAA was not inhibited (Geissman and Phinney, 1972; Corcoran *et al*., 1972; Green and Corcoran, 1975). Auxin-promoted elongation in *Glycine max* was inhibited by T-2 toxin produced by *Fusarium tricinctum* (Stahl *et al*., 1973).

Effect on membrane permeability

Phytotoxins produced by pathogens are found to alter the water and ion permeability of cytoplasmic membranes (Owens, 1969). The permeability of both the plasma membrane and tonoplast of root cells in *Avena sativa* was increased by victorin, a phytotoxin from *Helminthosporium victoriae* (Keck and Hodges, 1973).

Effect on mineral uptake

Allelopathic agents affect the rate of ion uptake by the cells. Balke (1977) surveyed various phenolic compounds for their effects on K^+ absorption by excised oat roots and found that at 10^{-4} M concentration flavonoids were generally more inhibitory than phenolic acids, juglone effected 79% inhibition of K^+ absorption and a 42% inhibition of ATPase activity. Balke (1977) and Balke and Hodges (1977) concluded that inhibition of K^+ absorption was primarily by decreased membrane-bound ATPase activity.

Effect on stomatal opening and photosynthesis

Affecting stomatal opening and photosynthesis is an indirect way of inhibiting the growth of the plants. Einhellig et al., (1970) showed that 10^{-3} M scopoletin-treated tobacco plants fixed only 51% as much Co_2 as the controls thus showing that the effect of scopoletin on net photosynthesis was the cause of growth reduction.

Kaempferol, a known allelopathic flavonol, inhibited coupled electron transport and both cyclic and noncyclic photophosphorylation in isolated pea (Pisum sativum) chloroplasts, thus suggesting kaempferol to be acting as an energy transfer inhibitor (Arntzen et al., 1974).

Effects on respiration

Adversely effecting respiratory mechanisms represents an important mode of action of many allelochemics. Lee (1966) found

4-hydroxybenzoic acid stimulated oxidation of NADH by enzymes from tobacco leaves, but a shift of the hydroxyl group from the 4- to the 3- position decreased the activity. Stenlid (1968) found that the flavonoids, naringenin and 2',4,4'-trihydroxychalcone, inhibited oxidative phosphorylation in higher plants and gave a distinct uncoupling effect whereas, Koeppe (1972) found that 500 μM concentrations of juglone after 1 hour of treatment inhibited oxygen uptake by excised corn roots by more than 90%.

Inhibition of protein synthesis and changes in lipid and organic acid metabolism

Inhibition of protein synthesis and changes in lipid and organic acid metabolisms are other modes of action of allelopathic agents. Danks et al., (1975) concluded that reduction in protein synthesis resulted in a reduction in growth. Cinnamic acid appeared to inhibit the mechanism of protein synthesis whereas ferulic acid caused a diversion of acetate into lipid synthesis rather than into Kreb's cycle and subsequent pathways leading to synthesis of amino acids and proteins.

Inhibition or stimulation of specific enzymes

Another important mechanism of action is by stimulation or inhibition of certain specific enzymes. The ability of pathogens to penetrate host cells depends on the effectiveness of the pectolytic enzymes produced by the pathogens and certain well known allelopathic agents are found to inhibit the activity of these enzymes. Tannins for example, strongly inhibited the action of cellulase and are very effective inactivators of invertase besides amylase, proteinase, dehydrogenases, decarboxylases, polyphenol oxidase, lipase, urease, etc. (Benoit and Starkey, 1968a, 1968b). Jankay and Müller (1976) found umbelliferone caused swelling response in cucumber roots coinciding with increased peroxidase levels and this higher peroxidase levels might be involved in the mediation of the radial expansion. Phosphorylase activity was inhibited by the activity of polyphenols, chlorogenic acid, caffeic acid, and catechol (Schwimmer, 1958).

Effects on corking and clogging of xylem elements, stem conductance of water and water relations

Some allelopathic agents have pronounced effects on water relations of neighbouring plants. Aqueous extracts of many allelopathic plant species caused browning, corking and clogging of xylem vessel. Histochemical evidences showed that the reduced ascorbic acid played a role in the formation of the brown substances which was a complex of pectins, lignin, suberin, melanins and many unidentified substances. These observations confirmed that redox processes in plant tissues subjected to allelopathic agents favours formation of mechanical barriers to toxin penetration (Grodzinsky and Bogdan, 1972, 1973; Bogdan and Grodzinsky, 1974; Bogdan, 1977).

Effects of allelopathy

Allelopathy may influence timing and sequence of succession in a number of ways. They are; (i) by speeding replacement of one species by a successor, by allelopathic self-toxicity of the first species. (ii) by allelopathic suppression of the first species by the second. (iii) by slowing of species replacement by direct allelopathic effects of the dominant species on potential invaders, (iv) by indirect effects through decay products or inhibition of soil organisms and (v) by influence on the sequence of species through allelopathic effects of one species which determines what other species can invade its community and replace it (Whittaker, 1970).

Scope of allelopathy

Allelochemicals are natural toxins and therefore they can be synthesised as they are or analogous compounds with better efficacy can be prepared and used as herbicides/weedicides (Dzyubenko and Petrenko, 1971; Tripathi 1977; Putnam and Duke, 1978). The herbicidal/weedicidal action is clear from the following examples. Some weed species of Commelinaceae control other weeds in coffee plantations (Anaya _et al_., 1982; Ramos _et al_., 1983). Corn pollen inhibits the growth of some weeds (Jimenez-Osornio _et al_., 1983). _Brassica_ sp. have been shown to inhibit the growth of weed seedlings in bioassays (Espinoza-Moreno, 1984; Jimenez-Osornio and Gliessman, 1987). Even bean and cowpea cover crops tested in raised field systems in Tabasco, Mexico suppressed weeds effectively (Boucher _et al_., 1983). Leaves of _Alnus firmifolia_, _Betula erecta_ and _Juncus_ spp. used as cover crops, not only reduced the total number of weeds significantly, but also increased the number of _Rhizobium_ phaseoli nodules and increased bean and squash production in corn/bean and corn/squash polycultures (Anaya et al., 1987).

Allelopathy plays an important role in soil management by the use of cover crops as green manure. Cover crops by reducing the number of viable weed propagules, improves the soil conditions. When weeds are used as cover crops they should be harvested prior to flowering to prevent further soil contamination with weeds seed flora. Cover crops during decomposition releases allelochemicals, affect weeds, through selective toxicity, provided crop species are insensitive to it (Rice, 1984; Anaya et al., 1988). Germinating seeds of plants are subjected to fungal, bacterial and viral infections in field conditions. Allelopathic activity of crop species results in delay of germination, reduction in radicle elongation of weed seedlings which complement the above mentioned stress factors for the establishment of seedling. Thus crop plants exhibit an indirect self-defence through interaction with other environmental stresses, and the combined effects of allelopathy and pathogenicity may help to eliminate some weed seedlings.

Allelopathy also play a direct role in self defence of crops Hydroxamic acids, found as secondary metabolites, reported from a number of cereals including, rye, wheat and maize play a major role in the defence of cereals against insects, fungi and bacteria, in the detoxification of herbicides and in allelopathic effects of crops (Barnes et al., 1986; Niemeyer, 1988; Perez, 1990). Allelopathic suppression of weeds is receiving increased attention as a possible weed management strategy (Altieri, 1989; Einhellig and Leather, 1988).

SOCIAL FORESTRY

Plantations of forest trees, shrubs, fruit trees, which are more accessible to the rural folk can be put under the subheading of social forestry. The necessity of social forestry programme being felt in India because the area under forest has drastically been reduced. Since 1980, fast-growing multipurpose trees, used either as shade bearing, ornamental, fuelwood, small timber or which increases the green cover, were introduced. These trees grown in field either as field bunds or to meet the requirements of farmers, form the basis of agroforestry systems. In social forestry programmes the plants are grown on vacant lands around the villages, alkaline, saline or barren lands which are not suitable for the cultivation of agricultural crops like cereal crops, fodder etc. Social forestry provides food, fuel, fodder, forage, fruits and fertilizers, the basic needs of the rurals, from the plants introduced. Prior to 1970, relatively little research was done on allelopathy with respect to forestry. However during the last two decades there has been a tremendous increase in research in this field and much research has been directed towards elucidating a few of the many roles of this phenomenon in agriculture and forestry (Gaba, 1987).

Suitable tree-crop combinations must be made by selecting the agrocrops which could overcome much of the intolerance due to the allelopathic potential of tree crops and also to identify the tree species with least allelopathic activity. Similar approaches in weed control may also be made possible by identifying phytotoxic metabolites and exploiting their use to inhibit seed germination and/or plant growth (Gaba, 1987).

A few of the exotic fast growing trees, introduced under various afforestation and reforestation programmes, in the country and studied for their allelopathic potential are given according to their importance.

Eucalyptus spp.

Eucalyptus forms one of the commonest trees planted in Agroforestry systems. The oil vapours containing monoterpenes like cineole and limonene from the Eucalytus trees in field are found to exert negative responses on the crops such as inhibition of germination of seeds and seedling growth, lesser rate of cell survival and reduced content of water and chlorophyll (Kohli et al., 1987). A strong reciprocal correlation that exists between the concentration and the seedling growth or the water content of the crops under study, supports the dose-linked allelopathic phenomenon. The poor performance of crops (Chickpea, Lentil Wheat, Cauliflower, Barseem and Toria) in a 12m wide strip, in the sheltered area of 8 ± 1 yr old Eucalyptus tereticornis is related to allelopathic effect (Singh and Kohli, 1992). Allelopathic exclusion of understorey species is proved in drier climates and not in areas of high rainfall. The leaf, stem, and root extracts of Eucalyptus showed severe effect on flowering of Abelomoschus esculentus (L) Moench and decreased yields of maize, cowpea, rice, wheat, barley and potato. The effects are reciprocally related to the distance of the plantations. The yields of chikpea (highly effected), lentil, toria, wheat, cauliflower, Egyptian clover were reduced by more than 50%. The deleterious effect of *Eucalyptus* on jute, groundnut and rice does not overcome even with the application of fertilizers. However, legumes were less affected than cereals. The leaf litter leachate had maximum inhibitory potential followed by soil leachate and drip water in a bioassay study. In pot trials, extracts of leaves at various concentrations decreased plant heights, leaf area and chlorophyll content. The phytotoxins responsible were phenolic acids like chlorogenic acid, *p*-coumaric, caffeic and gallic acids. The soil extract from different species inhibited the germination of cowpea, pigeonpea, horsegram and Indian bean. The impact of *E.citriodora* oil vapours compared to that of *E.globulus* oil or the pure terpenes was seen to be relatively greater in almost all the parameters. Among the various *Eucalyptus* sps., *E.camaldulensis* was found to have maximum harmful effect followed by *E.saligna* and *E.globulus* (Melkania, 1984; Sunil Puri and Amarjeet Khara, 1991). Soil phytotoxins were maximum in the litter free top soil surface. It also adversely affected above ground and root dry matter, number of nodules and their weights in *Glycine wightii* and *Panicum maximum* etc. (Paulino *et al*., 1987).

Acacia spp.

A.nilotica when growing near wheat field affected plant height, shoot number, ear length, grain number and grain yield.

The effect is reciprocally related to the distance of plantations (Sharma, 1992). Growth of cotton, pearlmillet and mustard was poor in the vicinity of trees. However, under rainfed conditions the effect was completely suppressed (Dalal et al., 1992). In another experiment the aqueous extracts of bark and leaves inhibited the germination, radicle and plumule length of sorghum, cotton, cowpea, egg plant, okra, chillies, tomatoes and sunflower. The bark extract was greater inhibitory than leaf extract (Swaminathan et al., 1989). The phytotoxin leached from the bark responsible for it, was tannins. The leaf leachate inhibited the germination, root and shoot length and vigor index of mustard, lentil, field pea and wheat (Sharma et al., 1967). Clusterbean, pearlmillet and sesame germination and seedling growth were found to be inhibited by Acacia tortilis leaves and stem leachates. The effect is reciprocally related to the concentration. Extracts were highly inhibitory in comparison to leachates proving some compounds were not leachable.

Phenolic acids like p-hydroxybenzoic, protocatechuic, vanillic, gentisic, p -coumaric, caffeic, ferulic and sinapic acids were the phytotoxins identified in the inhibitory extracts of Acacia dealbata, adversly affecting the germination, root and hypocotyl length of Trifolium pratense, T.repens, Phleum pratense and Lolium perenne (Casal et al., 1985).

Leaf leachates of A.auriculiformis A. Cunn decreased germination, growth and dry matter accumulation, plumule and radicle elongation of rice and cowpea. Rice radicle length and dry matter accumulation were severely affected (Jadhav and Gaynar, 1992).

Leucaena spp.

Leucaena leucocephala is a tropical fast growing and high production tree providing highly nutritious and palatable stock feed, firewood and timber (Kuo et al., 1982). The tree is known to cause allelopathic exclusion of understorey plantation, except its own seedlings (Chou and Kuo 1986). Leucaena yields mimosine, a non-protein amino acid from the seed and foliage. Mimosine is found to be present in higher percentage in sprouting leaves than the mature leaves, the content of which varied with the varieties of the plant.

Fresh leaf litter extracts affected the germination of wheat maize, pea and mustard adversely (Joshi and Prakash, 1992), but a marked increase in productivity of pigeonpea, sesame, castor and sorghum (Singh, 1983). Field study showed dry leaves mulched top soil and/or Leucaena aqueous extracts of leaves to depress sorghum, cowpea and sunflower germination, root length and dry matter production.

Prosopis spp.

Prosopis glandulosa exhibited concentration dependent inhibitory effect on the shoot and root length of various wheat cultivars of which, root growth was more effected than shoot growth. Its root exudates inhibited germination and radicle growth of sorghum, wheat, maize and safflower. Germination remained uneffected in chickpea and cowpea, however, a reduction in radicle growth was observed, whereas, in groundnut, germination was reduced but no effect was seen in radicle length elongation (Nimbal et al., 1990).

However, Prosopis cineraria did not affect the germination of crop and growth of normal plant population of chickpea even when the crop was in the close proximity of the tree (Dalal et al., 1992).

Populus spp.

Populus deltoides leaf extracts exhibited deleterious effects on the germination and growth of wheat, barley, lentil, chickpea, mustard, radish, brinjal, fenugreek and onion. Wheat, lentil and chickpea showed stimulation in germination rates initially, with accelaration of shoot growth in lentil and root branching in chickpea (Bisla et al., 1992; Nandal et al., 1992).

Populus balsamifera fresh leaf leachates, leaf litter and bud extracts inhibited seed germination and radicle growth (80% inhibition) of green alder. Inhibition of root hair development and meristematic necrosis of the radicle was also seen (Jobidon and Thibault, 1981). All the extracts inhibited the height root elongation and dry weight increment of nodulated and unnodulated green alder seedlings to some degree (Jobidon and Thibault, 1982).

Bamboo

Phenolic acids such as chlorogenic, ferulic, coumaric, protocatechuic, vanillic and caffeic acids from the fallen leaves of bamboo were considered responsible for the allelopathic effect of this plant. Groundnut seedlings showed inhibition in growth, leaf area, plant height, total chlorophyll and protein. The leaf extract concentration was inversely proportional to the growth decrement (Eyini *et al.*, 1989).

Delonix spp.

Delonix regia, one of the ornamental trees of South Taiwan, excludes weeds like *Isachne nipponensis* and *Centella asiatica* from under its canopy. The allelochemicals like phenolic acids, 4-hydroxybenzoic, chlorogenic, 3,4-dihydroxybenzoic, gallic, 3,4-dihydroxycinnamic, 3,5-dinitrobenzoic and L-azetidine-2-carboxylic acids and 3,4-dihydroxybenzaldehyde, from the foliage like twigs, leaves and flowers are reported. The latter showed a very high phytotoxicity (Chou and Leu, 1992).

Present work

In the present project, two social forestry trees, *Cassia siamea* Lam. and *Pongamia pinnata* L. which are not assessed for their allelopathic potential earlier were taken up for studying their effect on selected crops and weeds. The two crops chosen were wheat and rice while the two weeds selected were *Cassia tora* and *Cassia occidentalis*.

Cassia siamea Lam.

C. siamea is a robust vigourous tree reaching 13-15m in height. Bark is light to dark brown, hard. Leaves paripinate, bears 12-14 pairs of obovate-oblong leaflets. Flowers are yellow borne in large panicles. Pods flat, 20-30 cm long by 0.2 cm thick, compressed, pinkish purple to brown in colour, with alternate ridges and furrows bearing 25-32 seeds per pod. Seed 0.5 by 1.0 cm, brown to black, ovoid, bearing hilum at the tip. Centre of the seeds is light coloured translucent with dark coloured sides. The tree flowers in Sept. - Jan.

C. siamea leaves contain anhydrobarakol hydrochloride and related 5-acetonyl-7-hydroxy-2-methyl chromone besides siamine (3-methyl-6,8-dihydroxyisoquinol-1-one) (Ahn et al., 1978). Other constituents of the leaves are β-sitosterol, cassiamin A, physcion, chrysophanol, ρ-coumaric acid and apigenin-7-O-galactoside (thalictiin) (Wagner et al., 1978). Leaves possess in vitro dry matter digestibility ranging between 60-65% of which the crude protein constituents ranged between 13-28% (Akkasaeng et al., 1989). Besides these, sennosides and rhein also are reported from the leaves (Lohar et al., 1975).

Roots of C. siamea contain two anthraquinone galactosides which are 6,8-dimethoxy-2-methyl anthraquinone-3-O-β-D galactopyranoside and 1,5,8-trihydroxy-2-methylanthroquinone -3-o-β-D-galactopyranoside respectively (Tripathi et al., 1993). The root bark of C. siamea yield cassiamin, chrysophanol and lupeol (Dutta et al., 1964). Trunk bark contains sennosides, cassiamin A, B and

C (Patil et al., 1970). Cassiamin A, B and C are identical with cassianin, siameadin and siameanin (Chatterjee and Bhattacharjee, 1964, 1965).

Flowers of C. siamea yield β-sitosterol, lupeol and sucrose (Varshney and Rajpal, 1978). The petrol and chloroform extract of the flowers yielded cassiadinine, a chromone alkaloid, and (+)-6-hydroxymellein, a dihydro-isocoumarin isomer, 5-acetonyl-7-hydroxy-2-methyl-chromone along with three triterpenoids, cycloart-23-en-3B, 25-diol, friedelin and betulin (Biswas and Mallik, 1986).

Seeds of C. siamea possess a number of water soluble polysaccharides comprising of D-galactose, D-mannose and D-xylose in molar ratio of 3:6:2, a branched galactomannan consisting of a back bone of (1-->4) linked D-mannopyranose units and with branches of D-galactopyranose glycosidically attached at C-6 of every third D-mannopyranose (Khan et al., 1988). Lectins also are reported from the seeds (Lee et al., 1975). Seed oil consists of palmitic(19.0%), stearic(7.6%), oleic(11.6%), linoleic(42.7%), malvalic(2.0%), sterculic(3.1%) and vernolic(14.0%) acids (Daulatabad et al., 1988).

Uses : Crude hot water extracts of Cassia saimea has antimalarial effects tested in an in vitro test against Plasmodium falciparum, capable of 100% inhibition and constitute one of the eight medicinal plants of West Africa (Gbeassor et al., 1989).

C. siamea is probably the introduced species of Indonesia with good adaptability (Sidiyasa, 1986). The leaf production of the tree turned out to be highest in acid (pH 4.5) soil of Sumatra, Indonesia (Blair et al., 1988). It gave highest yield of edible material with accumulated dry matter production of over 2 kg. per tree besides woody stems which find use as firewood in the region (Akkasaeng et al., 1989). Mineral analyses of leaf indicated N, K, Ca and Mg to be adequate for animal production with P being below the critical level for animals (Blair et al., 1988). The tree has been found to possess better ability to tolerate stress due to pollution (Rao and Dubey, 1990) but is attacked by Catopsilia pomona which is an important defoliator of the tree (Gu, 1983). Seedlings of the tree show wilting when exposed to culture filtrates of Fusarium sps., fusaric acid was identified as causal factor (Shivappa et al., 1974). The dark-colored roots lack nodulation (Lim and Ng, 1977). An attempt to produce nodules failed, supporting the concept that the plant probably have some alternative source of N_2 (Athar and Mahmood, 1980). C. siamea leaves during decomposition initially showed N immobilisation which gradually changes to net mineralization (after about four weeks of incubation) however, N mineralization rate constants are correlated with initial N, polyphenol and lignin contents of leaves (Tian et al., 1992).

Though studies on the competitive effects of C. siamea and associated crops were conducted the result remained in conclusive (Rao et al., 1993).

Allelopathic effect of C. siamea along with other tree species was studied on understory vegetation. The soil from below the test tree did not inhibit the seed germination, however, leaf litter was inhibitory for the radicle growth of herbaceous species (Goel and Sareen, 1986). In another experiment allelopathic effect of C. siamea leaf material showed reduced germination (by 35%) of maize seeds and root number per seedling. Root weight per germinated seed was also significantly reduced (at the 7th day after innoculation (p=0.25) and (p=0.05) at the 13th day after innoculation, although the effect was found insignificant (Hauser, 1993).

In Gambia on a semi - arid site, Cassia siamea prunings applied as mulch were not effective to exert any effect on grain weight or quality of rice. The application of fertilizer along with prunings, also did not show much effect. Quantitatively, the effect was pronounced within 80 cm of hedgerows with lesser grain and straw than inner rows. In another experiment with Zea mays var Jeka the applications of pruning along with full recommended rate of fertilizers produced highest yield, both qualitatively and quantitatively (Danso and Morgan, 1993).

Pongamia glabra Vent.

P. glabra is a tree reaching 12-18 m in height; with spreading, glabrous branches and soft, greyish green bark. Leaves imparipinnate, 12-23 cm long and pale green. Leaflets are opposite, 5-9 (usually 5), 6-12 cm by 4-7.5 cms., ovate-oblong or elliptic, acute or (usually) shortly accuminate. Flowers are borne in short axillary racemes. Pods 4-5.0 cm by 3-3.5 cm, about 0.7 cm thick, oblong or slightly obovoid, compressed, narrowed at the base and with a short decurved mucro at the apex. The tree flowers in Apr. - Jun.

Leaves of *Pongamia glabra* contain flavonols like kaempferol and quercetin, furanoflavonoids like karanjin (3 methoxy furano (2":3"-7:8) flavone) pongapin, kanjone (6-methoxy furano (2":3"-7:8)flavone), pongamol, pongaglabrone, glabrachromene-I, glabrachromene-II, 2", 2"-dimethyl α-pyranochalkone, 3'-methoxy pongapin, 4'-methoxy furano (2":3"-7:8) flavone, 6-methoxy furano (2":3"-7:8) flavone, 6-methoxy furano (4":5"- 8:7) flavone, 7-methoxy furano (4":5"-6:5) flavone, 8-methoxy furano, (4":5"-6:7) flavone and -sitosterol (Limaye, 1936; Rangaswami and Seshadri, 1940; Murti and Seshadri, 1944; Rangaswami, 1946; Mittal and Seshadri, 1956; Pawanram and Row, 1956; Aneja *et al*., 1963; Khanna and Seshadri, 1963; Mukerjee *et al*., 1969a, 1969b; Sulekha *et al*., 1972; Sharma *et al*., 1973; Malik *et al*., 1976, 1977a, 1977b and Garg, 1979). From the leaf galls of *P. glabra*, pongapin, acrylamide and glabrin have been isolated. Besides these, leaf galls contain elevated levels of IAA concentration, this change in auxin level appears to be significant in host parasite relationships (Balasubramanian and Purshothaman, 1972).

Stem bark contains a furanodiketone, glabra I (5-piperonyl acetyl-4-methoxy coumarone) and a furano flavone, glabra II (5'-methoxy-3', 4'-methylene dioxyfurano (2":3"-7:8) flavone (Garg *et al*., 1978), the known flavones and furano flavones like pongapin pongachromene (2",2"-dimethyl- α -pyranoflavone) (Mukerjee *et* *al*., 1969b), karanjin, pongaflavone (2,2-dimethyl pyrano (5′,6′:8,7)-3-methoxyflavone) an analogue of karanjin (Lakshmi *et al*., 1974), pinnatin, gammatin (Pavanram and Row, 1956), 5-methoxy furano (2″,3″:7,8) flavone (Garg *et al*., 1978), besides the flavonols like kanugin, desmethoxykanugin (Mittal and Seshadri, 1956) and tetra-O-methyl fisetin (Mukerjee *et al*., 1969a).

Stem wood yielded pongachalkone-I (2′-hydroxy-6′ methoxy-6″,6″-dimethyl pyrano (3″:2″-3′:4′) chalcone) (Subrahmanyam *et al*., 1972/73). Other constituents are waxes, β-sitosterol, lonchocarpin (Jain *et al*., 1969), glabrachromene-II (Sharma *et al*., 1973), glabrachromene (Sulekha *et al*., 1972) pongachalkone-II, pongaglabrone (Khanna and Seshadri, 1963), pongachromene (Mukerjee *et al*., 1969), kanugin, demethoxykanugin (Mittal and Seshadri, 1956) besides karanjin, pongapin, pongamol and pongaflavone, an analogue of karanjin.

γ-Sitosterol and kaempferol were also isolated from the flowers (Sulekha *et al*., 1972). Talapatra *et al*., (1980) isolated from the petrol and chloroform extracts of the flowers, pongaglabol, a 5-hydroxyfurano (8,7-4″,5″) flavone, aurantiamide acetate (a rarely occurring modified phenylalanine dipeptide), furano-flavones, like lanceolatin, pinnatin, a simple flavone kanugin, a chromenoflavanone (-)isolonchocarpin, two furano-diketones (pongamol and ovalitenone) and β-sitosterol. Benzene extract of flowers gave karanjin, kanjone, pongaglabrone, gammatin (Pavanram and Row, 1956), kaempferol and quercetin, while the alcoholic extract contained phytosterol, kaempferol, quercetin, kaempferol-7-D-glucoside and quercetin-7-D-glucoside (Garg and Khanna, 1983). Kanungo et al., (1987) identified glabone (4′-methoxy-6,7-furanoflavone). Other compounds present are isopongaglabol (4′-hydroxyfurano (8,7-4",5") flavone and 6-methoxyisopongaglabol (4′-hydroxy-6-methoxyfurano (8,7-4",5") flavone), 2 furanoflavones (5-methoxyfurano(8,7-4",5") flavone and 5-methoxy-3′,4′-methylenedioxyfurano (8,7-4"5") flavone), two simple flavones (desmethoxy kanugin and fisetin) a chromeno-flavanone, ovalichromene B, two triterpenes (cycloart - 23-ene-3 β , 25-diol and friedelin) and β -sitosterol-β-D-glucoside (Talapatra et al., 1982).

The mature seeds contain karanjin (Limaye, 1936) and pongamol (Rangaswami and Seshadri, 1940), as the major component in contrast to immature seeds where kanjone (Aneja et al., 1963), and lanceolatin-β predominates (Roy et al., 1977). Other constituents of seeds are pongapin (Pavanram and Row, 1956), isopongaflavone (5′-methoxy-6′,6′-dimethylpyrano (2",3":7,8) flavone) (Roy et al., 1977; Roy and Khanna, 1979) and pongol (3′-hydroxyfurano (2",3":7,8) flavone) (Roy and Khanna, 1979), another furanoflavone is karanjachromene, a chromeno analogue of karanjin (Satam et al., 1973), 5-benzoyl acetyl-4-methoxy benzofuran (Narayanaswamy et al., 1954), pongaglabrone (3′,4′-methylene dioxyfurano (2":3"-7:8) flavone (Khanna and Seshadri, 1963), pongamol (Rangaswami and Seshadri, 1940) and isolonchocarpin (Naik Satam et al.,1972). Seeds contain a bitter reddish brown oil (30-35%), of which 1.8% constitute unsaponifiable matter, which yielded 57.3% sterol, giving β-sitosterol on crystallisation (Sinha, 1959).

The purified water soluble polysaccharide isolated from the gum of P.glabra contained L-arabinose, D-galactose and D-glucuronic acid in a molar ratio of 1.9:1.0:1.0. Autohydrolysis of the polysaccharide furnished a degraded product which on hydrolysis gave L-arabinose, D-galactose and D-glucuronic acid in a molar proportion of 2.8:3.5:1.0. The degraded polysaccharide on mild acid hydrolysis gave an aldobiouronic acid which was characterised as 3-O-D-glucopyranosyluronic acid -D-galactose (Guha et al., 1985).

P.pinnata in its root nodules contained quite a large amount of IAA. The IAA was metabolized in the nodules, was evidenced by the presence of the IAA oxidizing enzymes in the nodules (Sinha and Basu, 1981).

P.glabra healthy leaves contained Arthrobacter sp., Fusarium sp., and Aspergillus sp. Upon quantitative and qualitative examination, the healthy leaves were found to contain more number of microorganisms (Patel, 1977). Fusicladium pongamae infect leaves causing severe foliage blight, besides Haploravenelia hobsoni (cke) rust fungus) (Chavan and Patil, 1972) and Pseudocercospora pongamiae-pinnatae (Ram and Mallaiah, 1993) also are reported from this plant.

The oil obtained from seeds of Pongamia is used in Ayurveda, against skin diseases and rheumatism, and has antiseptic and healing properties. It is of value in the treatment of leucoderma and leprosy (Kirtikar and Basu, 1933; Nadkarni, 1954 and Chopra et al. 1982). The oil finds application in scabies, herpes and other cutaneous diseases. This oil is stomachic and cholagogue in cases of dyspepsia with sluggish liver. The powdered seeds are of value as a febrifuge and tonic in asthenic and debilitating conditions and find use for its expectorant properties in bronchitis and whooping cough (Chopra et al., 1982). Petroleum ether and ethanol extract of Karanj seeds is reported to have antimicrobial activity against human pathogenic fungi and bacteria and is used in ethnomedicinal preparations (Saxena and Vyas, 1986). It also has mild antiseptic action. Aqueous extracts from vegetative tissue have hypoglycemic activity upon oral administration, while aqueous extract of leaves have nematicidal activity in the intestine, due, to the presence of chromenochalkones (Chopra et al., 1982). A bath prepared from the aqueous extract of the leaves is used for relieving rheumatic pains and the root extract is used in the treatment of foul ulcers and sores (Chopra et al., 1982).

In a nutritive value evaluation of karanj seed cake, studies on isolation and evaluation of protein from Processed Karanj (Pongamia glabra) seed Meal (PKM) revealed that about 10-25% protein could be isolated from the 30% protein present in the PKM. This PKM protein isolates may be used as supplementary source of protein in animal feed (Mandal et al., 1986).

In another study of evaluation of nitrification retardation property of non edible oils and their influence on yield and nitrogen uptake by wheat in calcareous soil shows 64.2% inhibition of nitrification by Karanj oil at tillering stage. These oils retarded the conversion of NH_4^+ with the result the accumulation of NH_4^+ increased with time as a result highest accumulation of NH_4^+ and the lowest formation of nitrate at maturity stage (Prasad et al., 1986).

Components of the alcohol extracts of seeds can be usefully employed in increasing the efficiency of ammoniacal fertilizers. Alcoholic extracts of the seeds have maximum effect on the conservation of ammoniacal N, followed by the bark extract. The leaves, however, showed no inhibitory effect (Sahrawat et al., 1974). Seeds contains a potent (microbial nitrification inhibitor) karanjin, the major crystalline principle of Karanj. The study proves the furan ring to be essential for the inhibitory effect (Sahrawat and Mukherjee, 1977).

Insecticidal properties are associated to P.glabra seeds (Deshmukh and Borle, 1975), oil cakes is used to suppress the population of plant parasitic nematode (Alam et al., 1977). Also, pongam oil shows excellent cyclopicidal action (Bapna et al., 1988).

Besides this, other miscellaneous uses of Pongamia include its use as source of pulp, oil as an adulterant and as grain protectant of wheat during storage (Subramanyam, 1987; Mandal et al., 1988, Gupta et al., 1988).

Test plants

The two test crops wheat and rice are well-known to be discussed here. The two weeds selected i.e. Cassia tora and C. occidentalis are described below.

Cassia occidentalis Linn.

C. occidentalis is a diffuse, usually annual, under shrub of 0.6 m in height, with subglabrous, furrowed, often purplish branches. Leaves are paripinnately compound and are very foetid when bruised, with a single sessile gland near its base. Leaflets 3-5 pairs, membraneous, glaucous, ovate-lanceolate, gradually attenuated to a very acute apex. Flowers yellow, borne in short peduncled few flowered racemes. Pods, 10-12.5 cm by 0.5 cm thick, recurved, glabrous, compressed, transversely septate and distinctly torulose. Seeds number about 20-30, ovoid, compressed, acute at one end and rounded at the other, broad, hard, smooth, shining and dark olive - green. The plants flowers in Jul-Aug. C. occidentalis is a very common weed throughout India.

Seeds are found to cause apathy, ataxia, diarrhoea, vomitting, lateral recumbency and finally death in pigs, neuro-muscular dysfunction in growing pigs and cardiomyopathy in rabbits (Martins et al., 1986 and Colvin et al., 1986; and O'Hara and Pierce 1974; respectively).

The leaves exhibit antiinflammatory activity and capacity to stabilise the human erythrocyte membrane against hypotonicity induced lysis (Sadique et al., 1987) and activity against dermatophytes infection in man (Cacers *et al*., 1991). It is also used against Hepatitis virus A (Sama *et al*., 1976). The seeds are used as a substitute of coffee which is free of caffeine and tannin (Hassan *et al*., 1974). Roots and root extracts of *Cassia occidentalis* inhibited the growth of *Rhizobium* sps. in vitro (Rao *et al*., 1973).

C. occidentalis harbours Soybean mosaic virus (Galvez, 1974), Cowpea mosaic virus (Ladipo, 1988), antagonistic micro-organisms in the root zone resulting in the lack of nodulation (Ranga Rao and Subba Rao, 1974), mycorrhizae (Thomazini and Lilian, 1980), *Erisiphe polygoni*, (which causes powdery mildew in *Dolichos lablab*) (Chandra *et al*., 1981) and *Colletotrichun dematium* f *truncata* (a fungus valued for its mycoherbicidal activity) (Gudauskas *et al*., 1977). *Uredo cassiae-occidentalis* (Chavan and Kulkarni, 1974) and Negro coffee mosaic virus (Verma and Niazi, 1974) are the other pathogens reported from *Cassia occidentalis*.

In an allelopathic study on the effect of some weeds of vegetable crops on the germination and early seedling growth of *Pennisetum typhoideum* it was reported that aqueous extract of shoot and seeds of *C.occidentalis* caused much stronger inhibition on seed germination, leaf sheath elongation and root growth of *Pennisetum typhoideum* (Rao *et al*., 1979).

***Cassia tora*. Linn.**

This plant is an annual herb, emitting a foetid odour, reaching about 1 m in height. Leaves are pinnately compound 7.5

to 10 cms long, and the rachis is grooved, more or less pubescent, with a conical gland between each of the two lowest pairs of leaflets. Leaflets are in 3 pairs, opposite (the lowest pair the smallest), obovate-oblong, glaucous, membraneous more or less pubescent. Flowers are borne usually in subsessile pairs in the axils of the leaves. Pods 12.5 - 15 cms by 0.5 - 1.0 cm, subtetragonous, much curved when young, obliquely, septate, puberulous with broad sutures. Seeds 25 - 30 per pod, rhombohedral with the long axis in the direction of the pod. The plants flowers in July-Aug. This is a very common weed throughout India.

The immature seeds are found to elaborate brassinosteroids such as teasterone, castasterone and brassinolide (Park et al., 1993). Seed coats contain phenolic compounds which upon leaching cause inhibition of radicle and hypocotyl growth (Bhatia and Chawan, 1976).

Seeds are reported to contain phytoagglutinin also, which are toxic to rodents and birds (Gillon et al., 1983).

It is one amongst the other plants used in traditional phytotherapy among the tribals of Varanasi district, Uttar Pradesh (India). However their true therapeutic properties are yet to be ascertained (Singh and Maheshwari, 1983). It is also used by the traditional healers of Andhra Pradesh for treating jaundice (Reddy, 1988). It is a commonly used chinese medicine, capable of improving eyesight (Wu and Guo, 1988). Seeds shows antimicrobial activity against human pathogenic fungi and bacteria and their petroleum ether and ethanol extracts are used in ethnomedicinal preparations (Saxena and Vyas, 1986). Fatty oils extracted from seeds of C.tora has antibacterial efficacy against Bacillus subtilis, Salmonella typhosa and Salmonella paratyphi (Jain et al., 1987).

Natural gums and mucilages from the seeds is used to sustain the release of freely soluble drug propranolol hydrochloride from tablets. These natural gums have sustaining ability comparable to the widely used synthetic cellulose ethers (Baveja et al., 1989).

Nodulation studies carried out by innoculating Rhizobium strains in species of genus Cassia like Cassia tora and C. occidentalis showed lack of nodulation in both the tested species (Gaur, 1980). Root extracts and root exudate of Cassia tora inhibited the growth of Rhizobium sps. in vitro (Rao et al., 1973).

The effect of root exudates and extracts of C. tora on some dominant rhizosphere fungi isolated from plants were studied and found that root extracts induce a high degree of stimulation in rate of growth of a majority of the fungi tested (Sullia, Shankar Bhatt, 1973a). With the ageing of the plant a quantitative decrease in the rhizospheric fungal population which reached the maximum level at the senescent stage of the plants when the moisture content of the soil had fallen significantly along with the decrease in the amino acids and sugars contained in the root exudates (Sullia, Shankar Bhatt, 1973b). Fungal population associated with C.tora seeds were Chaetomium indicum, A.niger, A.flavus, Alternaria sp. and Fusarium sp. (Mishra and Srivastava, 1977). C.tora is very sensitive during seed germination and growth of the seedlings to low osmotic potential (Daiya et al., 1980).

It was found inhibited by parthenin, a sesquiterpene lactone from Parthenium hysterophorus, radicle was more severely inhibited in comparison to hypocotyl growth (Khosla and Sobti, 1981). The green young plants of C. tora, are found to improve yield and yield components namely panicles length, grains per panicle and test weight of transplanted rice and residual fertility in terms of available nitrogen, increased under the green manure treatments. Similar residual response is seen in the case of chickpea also (Rathore et al., 1993). Seeds and leaves form a minor component (upto 25%) of feeds of live stock, fish feeds and poultry (Makkar et al., 1990; Taparia et al., 1978; Manissery et al., 1988; Chan and Shukla, 1973, respectively).

Objectives of present investigation :

1. To study the allelopathic potential of C. siamea and P.glabra against wheat and rice by taking into account parameters like germination percentage, shoot length, root length and biomass accumulation.

2. To study the allelopathic action of these trees against weeds using the same parameters as criteria.

3. To find out the major source of allelochemics within the plants by analysing various plant parts.

4. To analyse various plant **parts** phytochemically to know the allelopathic constituents.
5. To study concentration effects of various treatments when applied to subject plants.
6. To assess the suitability **of these** trees in social forestry programmes.
7. To **find** out potential **sources** of herbicides/weedicides, if any.